GEMSS-E-08
Revision No. 05

Generator Unit Transformer (GUT)

VOLUME - 1

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Generation Projects Engineering Department
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### List of Abbreviations

- Minus
- per cent
± plus or minus
+ Plus
< less than
> more than
° Degree
°C degree Celsius
AABC Associated Air Balance Council
Ac alternating current
Ac/h air changes per hour
AFFF aqueous film forming foam
AHU air handling unit
ANSI American National Standard Institute
API American Petroleum Institute
ARI American Refrigeration Institute
ARU automatic run-up and loading
ASCE American Society of Civil Engineers
ASHRAE American Society of Heating, Refrigeration and Air-conditioning Engineers
AAASHTO American Association of State Highway and Transportation Officials
ASME American Society of Mechanical Engineers
ASTM American Society for Testing and Materials
AVR automatic voltage regulator
AWWA American Water Works Association
B&W black and white
BFP boiler feed pump
BMCR boiler maximum continuous rating
BOD biological oxygen demand
BOP balance of plant
BS British Standard
Btu British thermal unit
BWRO brackish water reverse osmosis
BIL Basic insulation Level
I&C instrumentation and control
CCB central control building
CCD charged couple device
CCR central control room
CCTV closed circuit television
CD ROM compact disk read only memory
CEMS continuous emissions monitoring system
CFC chloro-fluoro carbons
CFD computational fluid dynamics
CIF carriage, insurance and freight
CIP clean in place
CO carbon monoxide
CO₂ carbon dioxide
COD chemical oxygen demand
COI Critical Oxygen Index
Cr/SS chromium/stainless steel
Cos Cosine
CPP condensate polishing plant
cSt centistoke
CT current transformer
CV curriculum vitae
CW circulating water
CCCW closed circuit cooling water
dB(A) decibel (audio)
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<tr>
<td>Db</td>
<td>dry bulb</td>
</tr>
<tr>
<td>dc or DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DCS</td>
<td>distributed control system</td>
</tr>
<tr>
<td>DEH</td>
<td>digital electro hydraulic</td>
</tr>
<tr>
<td>DEHG</td>
<td>digital electro hydraulic governor</td>
</tr>
<tr>
<td>DFO</td>
<td>distillate fuel oil</td>
</tr>
<tr>
<td>DFR</td>
<td>design flow rating</td>
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<tr>
<td>DGP</td>
<td>data gathering panel</td>
</tr>
<tr>
<td>DIM</td>
<td>design intent memorandum</td>
</tr>
<tr>
<td>DIN</td>
<td>Deutsches Institut für Normung</td>
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<tr>
<td>DL</td>
<td>dead load</td>
</tr>
<tr>
<td>DLT</td>
<td>digital linear type</td>
</tr>
<tr>
<td>DM</td>
<td>dual media</td>
</tr>
<tr>
<td>DNB</td>
<td>departure from nucleate boiling</td>
</tr>
<tr>
<td>EEC</td>
<td>European Economic Community</td>
</tr>
<tr>
<td>EHV</td>
<td>extra high voltage</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EN</td>
<td>Euro Norm</td>
</tr>
<tr>
<td>EOTC</td>
<td>electric overhead travelling crane</td>
</tr>
<tr>
<td>EPC</td>
<td>engineer, procure and construct</td>
</tr>
<tr>
<td>EPR</td>
<td>ethylene propylene rubber</td>
</tr>
<tr>
<td>EPRI</td>
<td>Electrical Power Research Institute</td>
</tr>
<tr>
<td>EPRS</td>
<td>effective projected radiant heat absorbing surface</td>
</tr>
<tr>
<td>ESP</td>
<td>electrostatic precipitator</td>
</tr>
<tr>
<td>ESV</td>
<td>emergency stop valve</td>
</tr>
<tr>
<td>EVER</td>
<td>epoxy vinyl ester resin</td>
</tr>
<tr>
<td>EWS</td>
<td>engineer’s workstation</td>
</tr>
<tr>
<td>FAC</td>
<td>Final Acceptance Certificate</td>
</tr>
<tr>
<td>FAT</td>
<td>Factory Acceptance Test</td>
</tr>
<tr>
<td>FCB</td>
<td>fast cut back</td>
</tr>
<tr>
<td>FD</td>
<td>forced draft</td>
</tr>
<tr>
<td>FFFP</td>
<td>film forming fluoro-protein</td>
</tr>
<tr>
<td>FGD</td>
<td>flue gas desulphurization</td>
</tr>
<tr>
<td>FM</td>
<td>Factory Mutual</td>
</tr>
<tr>
<td>FOC</td>
<td>fibre optic cables</td>
</tr>
<tr>
<td>FOPH</td>
<td>fuel oil pump house</td>
</tr>
<tr>
<td>FTIR</td>
<td>Fourier Transform Infra Red</td>
</tr>
<tr>
<td>G</td>
<td>gauge (pressure)</td>
</tr>
<tr>
<td>G/Y</td>
<td>green/yellow</td>
</tr>
<tr>
<td>GCB</td>
<td>generator circuit breaker</td>
</tr>
<tr>
<td>GE</td>
<td>generator end</td>
</tr>
<tr>
<td>GGH</td>
<td>gas/gas heater</td>
</tr>
<tr>
<td>GIS</td>
<td>gas insulated switchgear</td>
</tr>
<tr>
<td>GR</td>
<td>gas recirculating</td>
</tr>
<tr>
<td>GRP</td>
<td>glass reinforced plastic</td>
</tr>
<tr>
<td>GT</td>
<td>gas turbine</td>
</tr>
<tr>
<td>GTMDO</td>
<td>gas transfer membrane de-oxygenation</td>
</tr>
<tr>
<td>H&amp;S</td>
<td>health and safety</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>Water</td>
</tr>
<tr>
<td>HAZAN</td>
<td>hazard analysis</td>
</tr>
<tr>
<td>HAZID</td>
<td>hazard identification</td>
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<tr>
<td>HAZOP</td>
<td>hazard and operability</td>
</tr>
<tr>
<td>HB</td>
<td>Brinell Hardness</td>
</tr>
<tr>
<td>HCFC</td>
<td>hydrochlorofluorocarbon</td>
</tr>
<tr>
<td>HCl</td>
<td>hydrochloric acid</td>
</tr>
<tr>
<td>HDPE</td>
<td>high density polyethylene</td>
</tr>
<tr>
<td>HEI</td>
<td>Heat Exchange Institute</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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</tr>
<tr>
<td>HFO</td>
<td>heavy fuel oil</td>
</tr>
<tr>
<td>HMI</td>
<td>human machine interface</td>
</tr>
<tr>
<td>H-OH</td>
<td>hydrogen-hydroxide cycle</td>
</tr>
<tr>
<td>HP</td>
<td>high pressure</td>
</tr>
<tr>
<td>HRC</td>
<td>high rupture current</td>
</tr>
<tr>
<td>HV</td>
<td>high voltage</td>
</tr>
<tr>
<td>HVAC</td>
<td>heating, ventilation and air conditioning</td>
</tr>
<tr>
<td>Hz</td>
<td>Hertz</td>
</tr>
<tr>
<td>I/O</td>
<td>input/output</td>
</tr>
<tr>
<td>ICEA</td>
<td>Insulated Cable Engineers Association</td>
</tr>
<tr>
<td>ID</td>
<td>induced draft</td>
</tr>
<tr>
<td>IBC</td>
<td>intermediate bulk container</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronic Engineers</td>
</tr>
<tr>
<td>IP</td>
<td>Ingress Protection</td>
</tr>
<tr>
<td>IPB</td>
<td>isolated phase busbar</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organization</td>
</tr>
<tr>
<td>ITP</td>
<td>Inspection and Test Plan</td>
</tr>
<tr>
<td>JIS</td>
<td>Japanese Industrial Standards</td>
</tr>
<tr>
<td>KCl</td>
<td>potassium chloride</td>
</tr>
<tr>
<td>Kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>kg/cm²</td>
<td>kilogram per square centimetre</td>
</tr>
<tr>
<td>kg/m³</td>
<td>kilogram per cubic metre</td>
</tr>
<tr>
<td>kJ/kg</td>
<td>kilojoule per kilogram</td>
</tr>
<tr>
<td>kJ/kWh</td>
<td>kilojoule per kilowatt hour</td>
</tr>
<tr>
<td>KKS</td>
<td>Kraftwerk Kennzeichen System</td>
</tr>
<tr>
<td>Km</td>
<td>Kilometre</td>
</tr>
<tr>
<td>KSA</td>
<td>Kingdom of Saudi Arabia</td>
</tr>
<tr>
<td>kV</td>
<td>Kilovolt</td>
</tr>
<tr>
<td>kVA</td>
<td>kilovolt amperes</td>
</tr>
<tr>
<td>kVar</td>
<td>Kilovar</td>
</tr>
<tr>
<td>kW</td>
<td>Kilowatt</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt-hour</td>
</tr>
<tr>
<td>Lb</td>
<td>pounds (Imperial weight)</td>
</tr>
<tr>
<td>l/s</td>
<td>litre per second</td>
</tr>
<tr>
<td>LAN</td>
<td>local area network</td>
</tr>
<tr>
<td>LCD</td>
<td>liquid crystal display</td>
</tr>
<tr>
<td>LED</td>
<td>light emitting diode</td>
</tr>
<tr>
<td>LHV</td>
<td>lower heating value</td>
</tr>
<tr>
<td>LL</td>
<td>live load</td>
</tr>
<tr>
<td>LP</td>
<td>low pressure</td>
</tr>
<tr>
<td>LSF</td>
<td>low smoke and fume</td>
</tr>
<tr>
<td>LTSA</td>
<td>long term service agreement</td>
</tr>
<tr>
<td>LV</td>
<td>low voltage</td>
</tr>
<tr>
<td>M</td>
<td>Metre</td>
</tr>
<tr>
<td>m/sec</td>
<td>metre per second</td>
</tr>
<tr>
<td>m³</td>
<td>metres cubed</td>
</tr>
<tr>
<td>m³/h</td>
<td>cubic metre per hour</td>
</tr>
<tr>
<td>mA</td>
<td>Milliampere</td>
</tr>
<tr>
<td>MCB</td>
<td>miniature circuit breaker</td>
</tr>
<tr>
<td>MCC</td>
<td>motor control centre</td>
</tr>
<tr>
<td>MCMS</td>
<td>Machine Condition Monitoring System</td>
</tr>
<tr>
<td>MCR</td>
<td>maximum continuous rating</td>
</tr>
<tr>
<td>MCWP</td>
<td>main cooling water pump</td>
</tr>
<tr>
<td>MDF</td>
<td>main distribution frame</td>
</tr>
<tr>
<td>MDI</td>
<td>methylene diphenyl disocyanate</td>
</tr>
<tr>
<td>MDPE</td>
<td>medium density polyethylene</td>
</tr>
<tr>
<td>MFT</td>
<td>master fuel trip</td>
</tr>
</tbody>
</table>
mg/m³  milligram per cubic metre
mg/Nm³  milligram per normal cubic metre
MICC  mineral insulated cables
MIG  metal inert gas
Min  Minute
MJ  Megajoule
Mm  Millimetre
mm²  millimetre squared
MOV  motor operated valve
MSL  minimum stable load
MV  medium voltage
MVA  megavolt-ampere
MVAr  megavolt ampere reactive
MW  megawatt
MWh  megawatt-hour
MWth  megawatt (thermal)
N₂  nitrogen
NACE  National Association of Corrosion Engineers
NaOH  sodium hydroxide
NB  nominal bore
NC  noise criteria
NCR  non-conformance report
NDT  non-destructive testing
NEC  National Electrical Code
NEMA  National Electrical Manufacturers Association
NER  neutral earth resistor
NFPA  National Fire Protection Association
ng/J  nanogram per joule
NH₄OH  ammonium hydroxide
Ni-Cd  nickel-cadmium
Nm  nanometre
NO₂  nitrogen dioxide
NOₓ  oxides of nitrogen
NPSH  net positive suction head
NTP  normal temperature and pressure
NWL  normal water level
O&M  operation and maintenance
O₂  Oxygen
ODAF  oil directed air forced
OFNR  optical fibre non-conductive riser
OFWF  oil forced water forced
ONAF  oil natural air forced
ONAN  oil natural air natural
OPC  OLE (object linking and embedding) for process control
OSHA  Occupational Safety and Health Administration
P&ID  piping and instrumentation diagram
Pa  Pascal
PABX  private automatic branch exchange
PAC  provisional acceptance certificate
PC  personal computer
PDF  portable document file
PED  Pressure Equipment Directive
PF  power factor
pH  potential hydrogen
PIMS  plant information management system
PLC  programmable logic controller
PME  Presidency of Meteorology and the Environment
Ppb  parts per billion
Ppm  parts per million
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<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPTB</td>
<td>pounds per thousand barrels</td>
</tr>
<tr>
<td>PSA</td>
<td>Pressure Swing Adsorption</td>
</tr>
<tr>
<td>PTFE</td>
<td>polytetrafluoroethylene</td>
</tr>
<tr>
<td>PTZ</td>
<td>pan/tilt/zoom</td>
</tr>
<tr>
<td>Pu</td>
<td>per unit</td>
</tr>
<tr>
<td>PVC</td>
<td>polyvinyl chloride</td>
</tr>
<tr>
<td>PWM</td>
<td>pulse width modulated</td>
</tr>
<tr>
<td>QCC</td>
<td>Quality Control Certificate</td>
</tr>
<tr>
<td>QCR</td>
<td>Quality Control Record</td>
</tr>
<tr>
<td>RAH</td>
<td>regenerative air heater</td>
</tr>
<tr>
<td>Rms</td>
<td>root-mean-square</td>
</tr>
<tr>
<td>RO</td>
<td>reverse osmosis</td>
</tr>
<tr>
<td>Rpm</td>
<td>revolution per minute</td>
</tr>
<tr>
<td>RSA</td>
<td>rolled steel angle</td>
</tr>
<tr>
<td>RTD</td>
<td>resistance temperature detector</td>
</tr>
<tr>
<td>RTR</td>
<td>reinforced thermosetting resin</td>
</tr>
<tr>
<td>RTU</td>
<td>remote terminal unit</td>
</tr>
<tr>
<td>SAC</td>
<td>strong acid cation</td>
</tr>
<tr>
<td>SAH</td>
<td>steam air heater</td>
</tr>
<tr>
<td>SASO</td>
<td>Saudi Arabia Standards Organization</td>
</tr>
<tr>
<td>SAT</td>
<td>site acceptance test (or saturation)</td>
</tr>
<tr>
<td>SBA</td>
<td>strong basic anion</td>
</tr>
<tr>
<td>SCADA</td>
<td>supervisory control and data acquisition</td>
</tr>
<tr>
<td>SCR</td>
<td>selective catalytic reduction or silicon controlled rectifier</td>
</tr>
<tr>
<td>SDI</td>
<td>silt density index</td>
</tr>
<tr>
<td>SDR</td>
<td>standard dimensional ratio</td>
</tr>
<tr>
<td>SE</td>
<td>steam end</td>
</tr>
<tr>
<td>SEC-WOA</td>
<td>Saudi Electricity Company – Western Operating Area</td>
</tr>
<tr>
<td>SF₆</td>
<td>sulphur hexafluoride (insulating gas)</td>
</tr>
<tr>
<td>SFC</td>
<td>static frequency converter</td>
</tr>
<tr>
<td>SI</td>
<td>International Systems of Units</td>
</tr>
<tr>
<td>SIL</td>
<td>Safety Integrity Level</td>
</tr>
<tr>
<td>SLD</td>
<td>single line diagram</td>
</tr>
<tr>
<td>SMACNA</td>
<td>Sheet Metal and Air-conditioning Contractors National Associated</td>
</tr>
<tr>
<td>SNCR</td>
<td>selective non catalytic reduction</td>
</tr>
<tr>
<td>SO₂</td>
<td>sulphur dioxide</td>
</tr>
<tr>
<td>SOE</td>
<td>sequence of events</td>
</tr>
<tr>
<td>SSD</td>
<td>Safety and Security Directive</td>
</tr>
<tr>
<td>STG</td>
<td>steam turbine generator</td>
</tr>
<tr>
<td>SUS</td>
<td>saybolt universal seconds</td>
</tr>
<tr>
<td>swg or SWG</td>
<td>standard wire gauge</td>
</tr>
<tr>
<td>SWRO</td>
<td>seawater reverse osmosis</td>
</tr>
<tr>
<td>T</td>
<td>Tonne</td>
</tr>
<tr>
<td>TDS</td>
<td>total dissolved solids</td>
</tr>
<tr>
<td>T/G</td>
<td>turbine generator</td>
</tr>
<tr>
<td>t/h</td>
<td>tonne per hour</td>
</tr>
<tr>
<td>TDH</td>
<td>total differential head</td>
</tr>
<tr>
<td>TDI</td>
<td>toluene disocyanate</td>
</tr>
<tr>
<td>TEMA</td>
<td>Tubular Exchanger Manufacturers Association</td>
</tr>
<tr>
<td>TFC</td>
<td>thin film composite</td>
</tr>
<tr>
<td>TI</td>
<td>temperature index</td>
</tr>
<tr>
<td>TIG</td>
<td>tungsten inert gas</td>
</tr>
<tr>
<td>TIMS</td>
<td>Tank Inventory Management System</td>
</tr>
<tr>
<td>TKN</td>
<td>total kjeldahl nitrogen</td>
</tr>
<tr>
<td>TL</td>
<td>thermal load</td>
</tr>
<tr>
<td>TMCR</td>
<td>turbine maximum continuous rating</td>
</tr>
<tr>
<td>TOC</td>
<td>total organic carbon</td>
</tr>
<tr>
<td>TP</td>
<td>terminal points</td>
</tr>
<tr>
<td>TSI</td>
<td>turbine supervisory instrumentation</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>TSS</td>
<td>total suspended solids</td>
</tr>
<tr>
<td>TSV</td>
<td>turbine stop valve</td>
</tr>
<tr>
<td>UBC</td>
<td>Uniform Building Code</td>
</tr>
<tr>
<td>UF</td>
<td>ultrafiltration/ultrafilter</td>
</tr>
<tr>
<td>UHF</td>
<td>ultra high frequency</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratories</td>
</tr>
<tr>
<td>UPS</td>
<td>uninterruptible power supply</td>
</tr>
<tr>
<td>UV</td>
<td>ultra violet</td>
</tr>
<tr>
<td>V</td>
<td>Volt</td>
</tr>
<tr>
<td>VA</td>
<td>volt-ampere</td>
</tr>
<tr>
<td>VDU</td>
<td>visual display unit</td>
</tr>
<tr>
<td>VGB</td>
<td>Technische Vereinigung der Graskraftswerks Beteriber (Technical Association of Large Power Plant Operators)</td>
</tr>
<tr>
<td>VOC</td>
<td>volatile organic compounds</td>
</tr>
<tr>
<td>VSD</td>
<td>variable speed drive</td>
</tr>
<tr>
<td>VT</td>
<td>voltage transformer</td>
</tr>
<tr>
<td>VPI</td>
<td>Vacuum pressure Impregnated</td>
</tr>
<tr>
<td>VWO</td>
<td>valves wide open</td>
</tr>
<tr>
<td>WAN</td>
<td>wide area network</td>
</tr>
<tr>
<td>Wb</td>
<td>wet bulb</td>
</tr>
<tr>
<td>Wc</td>
<td>water closet</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
</tr>
<tr>
<td>WL</td>
<td>wind load (or water level)</td>
</tr>
<tr>
<td>Wt</td>
<td>Weight</td>
</tr>
<tr>
<td>WTI</td>
<td>winding temperature indicator</td>
</tr>
<tr>
<td>WTP</td>
<td>water treatment plant</td>
</tr>
<tr>
<td>XLPE</td>
<td>cross-linked polyethylene</td>
</tr>
<tr>
<td>TEWAC</td>
<td>Totally Enclosed Water to Air Cooled</td>
</tr>
<tr>
<td>TIAC</td>
<td>Turbine Inlet Air Cooler</td>
</tr>
</tbody>
</table>
1 GENERAL DESCRIPTION

Definition: The primary function of GUT is to transforms all or a portion of the power output of the Generator, from the Generator terminal voltage to the transmission system voltage.

The generator transformer shall be an established design with a proven record of reliability for similar applications. Generators shall have rated output power and capability which shall exceed the capability of the respective generator for all the site ambient conditions and should not under any conditions limit the possible output of Generating unit.

The generator transformer operational capability over ranges of frequency and voltage shall be in accordance with Saudi Arabian Grid Code.

2 SCOPE

This specification covers Generator Unit Transformer (GUT) requirements. It shall be three phase core type, two winding or three winding 60 Hz outdoor type, adequately rated for duty imposed, oil immersed with ONAN, ONAN/ONAF, ONAN/ONAF/OFAF, OFAF or ODAF cooling, conservator type.

Transformers up to and including 30 MVA shall be with ONAN cooling.

Transformers above 30 MVA and up to 510 MVA shall be with ONAN/ONAF cooling, from 510MVA to 630MVA shall be ONAN/ONAF/OFAF cooling. Transformer above 630 MVA shall be with OFAF or ODAF cooling with unit coolers. Refer Layout A&B.

The specification defines minimum requirements for design, construction and performance. The manufacturer shall follow good updated engineering and manufacturing practices to produce a transformer, including accessories, which in conjunction with normal maintenance will provide safe and reliable service through the plant life under the rigors of service and ambient conditions in Saudi Arabia.

This specification is on continuous review cycle and is constantly being reviewed and updated. It is obligatory on the contractor or manufacturer to determine whether a given or quoted document is the correct edition.

Protection of transformer by installing dedicated "Metal enclosed SF6 insulated or porcelain enclosed M.O. surge arrestors" in accordance to COMPANY specification COMPANY-GP-004" both on high – voltage side and low voltage side forms essential part of transformer protection accessories and forms essential part of supply.


Performance and Guarantee Schedule – Layout A and Layout B form part of this specification. The manufacturer shall fill up and submit for COMPANY's perusal.
Where questions arise regarding the meaning of portions of specification as they relate to specific application it shall be brought to the attention of COMPANY. COMPANY will prepare appropriate response. Interpretation of COMPANY will be final and binding on the manufacturer/Contractor.

3 TERMINOLOGY

3.1 Multi-Winding Transformer

Transformer having more than two windings per phase, with simultaneous Power flow across two or more pairs of windings.

3.2 Split Winding Transformer

Multi-winding transformer which has at least two windings of identical voltage and power rating.

The type of split shall be radial as specified herein and as given in technical Layout A and B. Further, refer to CL 7.0.0 and Annex A.

4 RELEVANT STANDARDS AND REFERENCES

4.1 Relevant Standards

This specification shall be used in conjunction with the following publication:

The latest revisions of the following standards / publications shall apply as they are indispensable for the application of this Specification.

IEC 60068-3-9 Environmental testing. Guidance for solar radiation testing.

IEC 60076 Consists of the following parts, under the general title Power transformers:

Part 1: General.

Part 2: Temperature rise.

Part 3: Insulation levels, dielectric tests and external clearances in air.

Part 4: Guide to the lightning impulse and switching impulse testing – Power transformers and reactors.

Part 5: Ability to withstand short circuit.

Part 6: Reactors.

Part 7: Loading guide for oil-immersed power transformers.

Part 8: Application guide.

Part 10: Determination of sound levels.
Part 11: Dry-type transformers.


Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials.

IEC 60071 Insulation Coordination – Part I to Part V.

IEC 60270 Partial discharge Measurements.

IEC 60214 On-load tap-changers.

IEC 60296 Specification for unused mineral insulating oils for transformers and switchgear.

IEC 60542 Application guide for on-load tap-changers.

IEC 60567 Oil filled Electrical Equipment-sampling of gases and oil for analysis of free and dissolved gases- Guidance.

IEC 60616 Terminal and tapping markings for power transformers.

IEC 60651 Sound level meters.

IEC 60529 Classification of degrees of protection provided by enclosures.

IEC 60599 Interpretation of the analysis of gases in transformers and other oil-filled electrical equipment in service.

IEC 61181 Mineral oil filled electrical equipment – Application of dissolved gas Analysis (DGA) to factory test on electrical equipment

IEC 60909 Part 0 To 4 short circuit currents in three phase AC systems.

IEC 61160 Design Review.

IEC 62271-211 Direct connections between transformer and gas insulated metal enclosed switchgear for rated voltage above 52 KV.

IEC 62535/2008 Insulation Liquids – Test method for detection of potentially corrosive sulphur in used and unused insulating oil.

IEC 61198 Furfural Content.

IEEE C57.142/2010 Guide to Describe the Occurrence and Mitigation of Switching Transients Induced by Transformers, Switching Device, and System Interaction.

RAL 7032: Grey colour. (Deutsches Institute fur).

(Colour Code) Gutesicherung und Kennzeichnung e.V., D-5300 Bonn 1, Bernheimer Strasse 180, Germany.

4.2 Other Standards and Codes.

All components and materials used in construction of the transformer shall comply with the requirements of the relevant IEC and DIN standards unless otherwise specified.

Where other standards like ANSI/IEEE and DIN Standards are specified, the application is limited to that particular aspect of specification.

DIN standards specified shall be applicable to accessories.

The Saudi Arabian Grid Code

Other specification reference

SEC-GP-004 Metal enclosed SF6 insulated and porcelain enclosed M.O. Surge Arresters

4.3 Precedence of Codes and Standards

In case of conflict between this specification and any of the listed standards, this Specification shall take precedence.

5 DESIGN CRITERIA AND SYSTEM DETAILS

The Transformer shall be designed, constructed and installed such that every reasonable safeguard and provision for the safety of all personnel concerned with the construction, commissioning, operation and maintenance of the equipment and plant is incorporated.

The equipment shall be designed, constructed and installed to ensure satisfactory and safe operation under all operating conditions including load and voltage variation, frequency variation, transients from starts and stops, transients due to short circuits and other internal and external fault conditions.

The design, construction and installation of the plant shall be carried out under the consideration of maximizing the continuity of supply, availability of service and reliability.

The equipment shall be provided with suitable means for electrical disconnection, isolation and earthing of connections to facilitate maintenance.
All equipment shall be designed and integrated to facilitate rapid and economical maintenance.

All equipment shall be of proven concept and design under commercial operation and shall be manufactured by reputable and approved manufacturers to ensure high reliability.

Prototype or experimental equipment that has not been proven shall be excluded.

Ancillary equipment shall be factory assembled in modules for site erection and shall be complete with all piping and wiring for connection to other modules on site.

The Contractor/Manufacturer shall have facilities for power system engineering studies covering the following main topics as minimum, otherwise offer will not be considered:

- Load flow calculations.
- Short-circuit studies and calculations.
- Stability, both steady state and transient.
- Transient stability level and analysis.
- Harmonic frequency analysis.
- Reliability planning.
- Over-voltage studies consisting of:
  a. Over voltage generated by both, back flash over and shielding failure, taking in to account the application of metal-oxide arrestors.
  b. To find out possible sources of resonance in the network and their interactions with connected transformer and to recommend methods to limit the mode of such occurrences. See CL 22.2.2.
  d. Installation conditions where the energization of the transformer is from the remote end of a cable, SF6 bus duct or a long over-head line which can lead to severe exposure to over-voltages which can be frequent and repetitive.
  e. The direct connection between transformer and GIS switchgear by means of single cable or SF6-bus duct or single line forms propagation elements for carrying transients occurring due to operation of SF6 switchgear. When these oscillatory transients have frequency components near one or more of transformers natural frequency, large internal over-voltages may result due to resonance. The calculation of velocity of surge and frequency shall be submitted. It may be necessary to strongly consider transient mitigation means, this shall be studied and submitted to COMPANY for consideration.
  f. When vacuum circuit breaker is used as a generator breaker, high over-voltage may result due to switching off on unloaded transformer with a vacuum circuit breaker.

The magnitude and frequency of such over-voltage depends on the characteristic of the system and statistical behavior of breaker, this case shall be studied. Where the over-voltage exceeds the insulation level of LV winding of transformer, Surge Suppression shall be installed. A combination of R-C Suppressor and ZnO – Varister shall be used, as this combination has higher performance. This shall be treated as part of protection and part of contract.
Submittal of Technical details layout A & layout B along with technical offer. Without this, offer may not be evaluated.

Network study, including over-voltage analysis of 400 kV/220 kV/132 kV/110 kV SF6 Gas insulated switchgear and vacuum switchgear.

Switching transient induced by transformer, switching circuit breakers operation of disconnector and system interaction shall be evaluated.

Mitigation methods of reducing the peak interval voltage response of a transformer, when its terminals are subjected to an oscillatory transient voltage.

Design studies.

Analysis of transient potential oscillations in the transformer windings. Electric field distribution in the winding configuration.

The Contractor shall perform the detailed design studies of the complete transformers with control, protection and auxiliary system, and the power systems in which they are installed to establish the compatibility of Transformer.

The Contractor shall supply all the drawings, technical documents, calculations, as required by SEC necessary to demonstrate the correct design of the transformer, its installation to interface with other contractors and to allow efficient maintenance.

The delivery of documents necessary for erection, connection, site tests, operation and maintenance shall be written in English language and shall be submitted before dispatch of transformer.

Design Review meetings, immediately after placing of order and within one month and before finalization of design and manufacture.

Manufacturing and testing schedule.

Packing, conditioning equipment for transportation to site and storage facilities.

Quality control, inspection test in factory as described in this specification in the presence of the final customers and / or his agent.

Installation of surge arrestors on HV side of transformer together with protection & control cabling is obligatory and form part of this supply. The MO Surge arrestors shall be in accordance to COMPANY specification SEC- GP – 004.

Compliance with IEC standard and any of the cited standards or codes does not of itself conform immunity from legal obligations, where compliance with the specification is not met.
6 NETWORK CONDITIONS

6.1 380 kV System Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Frequency fr</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Configuration</td>
<td>3 phase, 3 wire</td>
</tr>
<tr>
<td>Neutral Arrangement</td>
<td>Solidly Earthed</td>
</tr>
<tr>
<td>Rated Voltage Ur</td>
<td>380 kV r.m.s.</td>
</tr>
<tr>
<td>Highest Voltage for Equipment --- Um</td>
<td>420 kV r.m.s.</td>
</tr>
<tr>
<td>Three Phase Symmetrical Short Circuit Current</td>
<td>63 kA r.m.s.</td>
</tr>
<tr>
<td>Duration</td>
<td>1 Sec</td>
</tr>
<tr>
<td>Three Phase Symmetrical Peak Withstand to earth</td>
<td>161 kA peak</td>
</tr>
<tr>
<td>Lightning Impulse withstand 1.2/50µs to earth</td>
<td>1425 kV peak</td>
</tr>
<tr>
<td>Switching Impulse withstand 250/2500µs to earth</td>
<td>1050/1175 kV peak</td>
</tr>
<tr>
<td>One min. power frequency withstand to earth</td>
<td>630 kV r.m.s.</td>
</tr>
<tr>
<td>Insulator Creepage distance</td>
<td>Refer to technical details layout A &amp; B</td>
</tr>
<tr>
<td>Clearance Rigid Cond. To Earth</td>
<td>3,700 mm</td>
</tr>
<tr>
<td>Clearance Rigid Cond. To Rigid Cond.</td>
<td>4,200 mm</td>
</tr>
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</table>

6.2 220 kV System Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Frequency fr</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Configuration</td>
<td>3 phase, 3 wire</td>
</tr>
<tr>
<td>Neutral Arrangement</td>
<td>Solidly Earthed</td>
</tr>
<tr>
<td>Rated Voltage Ur</td>
<td>220 kV r.m.s.</td>
</tr>
<tr>
<td>Highest Voltage for Equipment… Um</td>
<td>245 kV r.m.s.</td>
</tr>
<tr>
<td>Three Phase Symmetrical Short Circuit Current</td>
<td>50 kA r.m.s.</td>
</tr>
<tr>
<td>Duration</td>
<td>1 Sec</td>
</tr>
<tr>
<td>Three Phase Symmetrical Peak Withstand Current</td>
<td>125 kA peak</td>
</tr>
<tr>
<td>Lightning Impulse withstand 1.2/50µs to earth</td>
<td>1050 kV peak</td>
</tr>
<tr>
<td>Switching Impulse withstand 250/2500µs to earth</td>
<td>850 kV peak</td>
</tr>
</tbody>
</table>
6.3 132 kV System Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Frequency fr</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Configuration</td>
<td>3 phase, 3 wire</td>
</tr>
<tr>
<td>Neutral Arrangement</td>
<td>Solidly Earthed</td>
</tr>
<tr>
<td>Rated Voltage Ur</td>
<td>132 kV r.m.s.</td>
</tr>
<tr>
<td>Highest Voltage for Equipment… Um</td>
<td>145 kV r.m.s.</td>
</tr>
<tr>
<td>Three Phase Symmetrical Short Circuit Current</td>
<td>40 kA r.m.s.</td>
</tr>
<tr>
<td>Duration</td>
<td>1 Sec.</td>
</tr>
<tr>
<td>There phase symmetrical Peak withstand current</td>
<td>100 kA peak</td>
</tr>
<tr>
<td>Lightning impulse withstand 1.2/50µs</td>
<td>650 kV peak</td>
</tr>
<tr>
<td>Switching Impulse withstand 250/2500µs to earth</td>
<td>540 kV peak</td>
</tr>
<tr>
<td>One Min. power frequency withstand to earth</td>
<td>275 kV r.m.s.</td>
</tr>
<tr>
<td>Insulator creepage distance</td>
<td>Refer to technical details layout A &amp; B</td>
</tr>
<tr>
<td>Clearance Rigid cond. to earth</td>
<td>1,300 mm</td>
</tr>
<tr>
<td>Clearance Rigid cond. to rigid cond.</td>
<td>1,500 mm</td>
</tr>
</tbody>
</table>

6.4 110 kV System Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Frequency fr</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Configuration</td>
<td>3 phase, 3 wire</td>
</tr>
<tr>
<td>Neutral Arrangement</td>
<td>Solidly Earthed</td>
</tr>
<tr>
<td>Rated Voltage Ur</td>
<td>110 kV r.m.s.</td>
</tr>
<tr>
<td>Highest Voltage for Equipment ---- Um</td>
<td>123 kV r.m.s.</td>
</tr>
</tbody>
</table>
### 33 kV System Parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Frequency fr</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Configuration</td>
<td>3 phase, 3 wire</td>
</tr>
<tr>
<td>Neutral Arrangement</td>
<td>Solidly Earthed</td>
</tr>
<tr>
<td>Rated Voltage Ur</td>
<td>33 kV r.m.s.</td>
</tr>
<tr>
<td>Highest Voltage for Equipment ---- Um</td>
<td>36 kV r.m.s.</td>
</tr>
<tr>
<td>Three Phase Symmetrical Short Circuit Current</td>
<td>40 kA r.m.s.</td>
</tr>
<tr>
<td>Duration</td>
<td>1 Sec.</td>
</tr>
<tr>
<td>Three Phase Symmetrical Peak Withstand Current</td>
<td>100 kA peak</td>
</tr>
<tr>
<td>Lightning Impulse Withstand 1.2/50µs</td>
<td>200 kV peak</td>
</tr>
<tr>
<td>Switching Impulse withstand 250/2500µs to earth</td>
<td>165 kV peak</td>
</tr>
<tr>
<td>One Min. Power frequency withstand</td>
<td>70 kV r.m.s.</td>
</tr>
<tr>
<td>Insulator Creepage Distance</td>
<td>Refer to technical details layout A &amp; B</td>
</tr>
<tr>
<td>Clearance Rigid Cond. to Earth</td>
<td>550 mm</td>
</tr>
<tr>
<td>Clearance Rigid Cond. to Rigid Cond.</td>
<td>550 mm</td>
</tr>
</tbody>
</table>

All outdoor installations are subjected to high humidity and sand storms.

The effect of solar radiation is significant and cannot be neglected.

* For information only – not for design use.
7 **TYPE OF TRANSFORMER**

It shall be core type separate winding transformer. The transformer shall be two or three windings as indicated in technical detail layout A & B, double wound, three phase 60 Hz, oil immersed. The splitting of HV and LV windings in case of three winding shall be radial. Some of the schemes of splitting the windings are shown in Annex-A pages 1 to 10. The manufacturer may adopt any one of the schemes or follow his own scheme. **However, radial splitting of the winding is mandatory.** The voltage regulation of HV winding shall be by ON-LOAD TAP-CHANGER or with DE-ENERGIZED TAP-CHANGER. The requirement is set out in technical detail layout A & B.

The transformer shall be designed to operate in the climatic conditions extremes obtained in Saudi Arabia. The transformer will be subjected to maximum loading lasting for months during periods of maximum ambient temperature of 55°C.

**Ambient temperature for design of transformer shall be 50°C.**

8 **GUT RATED POWER (SR)**

The MVA rating shall allow for the full Generator utilization – both – lead and lag.

The required MVA rating shall be calculated using the following basis and in accordance with ANSI/IEEE C57.116: 1989 (R2005). The calculations shall be submitted with Tender. Where the rating specified in layout A & B is higher than that of calculated value, these values takes precedence over the calculated values. Where the calculated rating is higher than that specified in layout A & B, the calculated rating take precedence.

**Basis of calculations:**

- Load flow calculations.
- Turbine limit.
- Turbine generator apparent power capability curve.
  - Turbine output curve (with inlet air cooling).
  - Generator Reactive Capability limits for various system voltages.
  - Capability curve of GUT.
- Turbine performance data by the manufacturer.
- Excitation limiters (Curve to be submitted).
- Generator Reactive capability limits for various unit transformer impedance. Impedance range 12%, 13%, 14%, and 15%.
- Design ambient temperature – 10°C to 50°C.
- Altitude… Meter above sea level, ref layout A & B.
- Max. Relative humidity 35% to 100%.
- Calculations shall be based on peak load.
- The transformer rating shall never limit the generator MW output for any expected turbine output.
- The transformer rating shall allow for generator utilization (both lead and lag) assuming the maximum allowable negative impedance to tolerance. Further the required MVA rating has to be calculated using load flow program.

A Conservative MVA rating of transformer shall be determined by using the maximum generator MW output and corresponding generator MVAR output and assuming the maximum allowable negative tolerance on the impedance.

\[
MVA_T = \sqrt{MW_G^2 + MVAR_G^2}
= \sqrt{MWG^2 + [MVARG-0.925XT (MVAT)]^2}
\]

- Unit auxiliary transformer load shall not be subtracted from generator output.
- If different values of apparent rating are calculated under different condition of ambient, inlet temperature of turbine, RH, the highest of these values is the rated power.
- The required MVA rating may be calculated using a load - flow program.
- The calculations of MVA rating of GUT shall be submitted to COMPANY for approval.

The final rating of transformer shall be preferred number from IEC: 60076-1.

The transformer shall have a continuous rating as specified in relevant “performance and guarantee schedule - layout A and layout B” at all tap positions at design ambient of 50°C. Where the calculated value of MVA is less than that specified in layout A & B, the values in layout A & B shall take precedence over calculated values.

Where ONAN/ONAF, ONAN/ONAF/OFAF, cooling is specified in performance and guarantee schedule layout A and layout B, the ONAN cooling shall be ≥ 80% of ONAF or OFAF rating and shall be preferred number from CL 5.1.2 of IEC: 60076-1 as specified above.

The transformer shall be capable of supplying its rated power continuously with rated voltage on the secondary voltage winding under the stated design ambient temperature, at 100% cooling and service conditions. The maximum hot spot temperature shall not exceed 98°C at 100% of ONAN, ONAN/ONAF, ONAN/ONAF/OFAF, or OFAF or ODAF cooling at minimum ratio tap. The transformer shall be designed and manufactured for a design ambient temperature of 50°C.

The transformer shall be capable of delivering rated load at an applied voltage equal to 105% of the rated voltage of LV.

- Spare cooling shall be provided in accordance to CL 15.1.0 of this specification.
- Transformer out-put capability curve of ONAN, ONAN/ONAF, ONAN/ONAF/OFAF, OFAF or ODAF at various design ambient temperatures shall be submitted.

8.1 Loading Beyond Rated Power

The transformer shall be designed for overload criteria of 1.5pu for Trafo. ≤ 100 MVA and 1.3pu for > 100 MVA load as defined in IEC-60076-7 for a period of 4 hours with a continues pre-load of 100% at the minimum ratio tap with 100% of ONAN, ONAN/ONAF, ONAN/ONAF/OFAF, OFAF or ODAF cooling. At the end of overload, the following hot-spot temperatures shall not be exceeded, based on maximum ambient temperature of 50°C and 100% cooling, without spare cooling.
<table>
<thead>
<tr>
<th>No.</th>
<th>Parameter Description</th>
<th>&lt;100 MVA</th>
<th>&gt;100 MVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Power (p.u.)</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>2.</td>
<td>Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C).</td>
<td>≤ 140</td>
<td>≤ 140</td>
</tr>
<tr>
<td>3.</td>
<td>Other metallic hot-spot temperature (in contact with oil, aramid paper, glass-fiber materials) (°C)</td>
<td>≤ 160</td>
<td>≤ 160</td>
</tr>
<tr>
<td>4.</td>
<td>Top-oil temperature (°C)</td>
<td>≤ 115</td>
<td>≤ 115</td>
</tr>
</tbody>
</table>

During or directly after overload, the transformers shall comply with thermal and dynamic requirements of short circuit as specified in IEC 60076-5, ANSI C57.12.90 and this specification. The manufacturer shall submit calculation as per Clause 2.1 of IEC 60076-5 and ANSI/IEEE C57.12.90, ANSI/IEEE C57.12.00, and this specification regarding thermal and dynamic withstandability. Duration of symmetrical short-circuit current shall be 5 seconds. System impedance is to be ignored. The dynamic withstandability calculations shall be submitted for the perusal, & acceptance of COMPANY.

All current transformers shall be rated for over load of the transformer

The manufacturer shall submit over-loading curves verses time for LV or each LV1 and LV2 windings for a pre-load of 50%, 60%, 70%, 80% & 90% with 100% of specified cooling. Further, overloading curves verses time for LV, LV1 + LV2 winding for a pre-load of 40%, 50%, 60%, 70%, 80% & 90% with 100% ONAN, ONAN/ONAF, ONAN/ONAF/OFAF and OFAF or ODAF cooling.

8.1 Loading Of Multi-Winding Transformers (Including split low – voltage windings).

In multi-winding transformer, simultaneous power flow across two or more pairs of windings takes place.

Multi-winding transformers shall be capable of operation with any combination of winding loads and power flow directions.

1- The arithmetic sum of loading capability(ies) of output winding(s) shall not exceed the arithmetic sum of the loading capability(ies) of input winding(s) as specified in technical Layout A and B.

2- Possible power flow for three windings transformer. Refer Annex Z.

8.2 Loading Of Multi-Winding Transformers

For purpose of determining of transformer loading capabilities, all MVA loads shall be considered as in phase with one another.

8.3 Power Flow Direction

Multi-winding transformer shall be designed for power flow in the step down or step up direction with loading capabilities as defined in technical Layout A & B.

8.4 Energization and De-Energization

Transformers shall be capable of being energized or de-energized from any set of terminals as required by the system operation with or without load connected.
Transformers shall also be capable of withstanding transients which may occur when fault currents are interrupted and/or chopped by the switching device used for transformer protection.

9 **VOLTAGE RATIOS**

Separate tapping windings shall be used for voltage regulation. HV main winding shall not be tapped. The on-load tap-changer or de-energized tap changer shall be arranged to give variations of transformation ratio as set out in the relevant data sheet technical layout A&B.

All tapping shall be full power tapings.

Switching position (1) shall be maximum ratio tap.

Tap increments in the range of 1.25%, 1.333% and 2.5% are typical. Transformation has important to covering on reactive power (MVAR) generation and absorption and generator operation outside of its +5% voltage range, or both. The selection mode shall be checked by load flow program. The range and step specified in technical detail layout A & B shall be considered.

10 **OVER FLUXING**

Transformers shall be capable of continuous and short time operation at voltages above rated voltages and at frequencies above and below nominal 60 Hz frequency and the minimum acceptable V/Hz ratio's for un-loaded and fully loaded conditions. The transformer shall be designed and guaranteed to meet continuous 110% of rated voltage/Hertz, 1 minute for 125% of rated voltage/Hertz, and 10 seconds for 150% of rated voltage/Hertz. The over excitation curve for the transformer showing volts/Hz versus time shall be submitted with the tender.

At a current k times the transformer rated current (0 ≤ k ≤ 1), the over-fluxing shall be limited in accordance with the following formula:

\[
\frac{U}{U_r} \times \frac{f_r}{f} \times 100 \leq 110 - 5k \%
\]

10.1 **Operation At Higher Than rated Voltage / or at other than rated frequency**

The transformer shall comply with CL 5.4.3 of IEC: 60076-1/2011 regarding operation at higher rated voltage / or higher rated frequency.

11 **WINDING CONNECTIONS AND VECTOR GROUP**

The winding connections and phase relationship shall be as specified in technical details layout A & B.

12 **INSULATION LEVELS**

Transformer windings shall have insulation levels as per layout A and B as minimum. However, this is to be confirmed after over voltage study as already specified.
Non-linear resistors or metal oxide varistor shall not be connected across transformer high-voltage winding structures (such as HV-coarse or HV-fine winding) for dealing with high internal voltage caused by external oscillatory excitation including transformers natural frequencies.

Non-linear resistors or metal oxide varistor shall not be connected across transformer LV or MV windings for dealing with transferred over-voltages coming from HV winding. Further, resistors or capacitors shall not be connected across windings to keep the voltage within acceptable limits.

Transformers shall be designed and tested to the following minimum insulation levels. Where an insulation co-ordination study requires higher BIL, the manufacturer may adopt the same under intimation to COMPANY.

The rated insulation level shall be characterized as follows:

Um / SIL / LIL / LICL / ACL with the associated values for the line terminals of each winding.

For neutral terminals, the abbreviation shall be Um / LIL / ACL together with associated values.

The insulation levels given are valid up to an attitude of 1000m above sea level and standard service condition. For different altitude, service conditions correction factors shall be applied and these factors shall be given in test reports.

### 12.1 Insulation Test Voltage Levels For Transformer > 63 MVA

<table>
<thead>
<tr>
<th>Rated Voltage</th>
<th>Highest voltage for equipment winding</th>
<th>Full wave Lightning Impulse</th>
<th>Chopped wave Lightning Impulse</th>
<th>Switching Impulse</th>
<th>Applied voltage or line terminal AC withstand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ur =22 kV</td>
<td>24</td>
<td>145</td>
<td>160</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>Ur =33 kV</td>
<td>36</td>
<td>200</td>
<td>220</td>
<td>165</td>
<td>70</td>
</tr>
<tr>
<td>Ur =47.5 kV</td>
<td>52</td>
<td>250</td>
<td>275</td>
<td>210</td>
<td>95</td>
</tr>
<tr>
<td>Line Ur =110 kV</td>
<td>123</td>
<td>550</td>
<td>605</td>
<td>460</td>
<td>230</td>
</tr>
<tr>
<td>Neutral Ur =110 kV</td>
<td>123</td>
<td>550</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Line Ur =132 kV</td>
<td>145</td>
<td>650</td>
<td>715</td>
<td>540</td>
<td>275</td>
</tr>
<tr>
<td>Neutral Ur =132 kV</td>
<td>145</td>
<td>650</td>
<td>-</td>
<td>-</td>
<td>275</td>
</tr>
<tr>
<td>Line Ur =220 kV</td>
<td>245</td>
<td>1050</td>
<td>1155</td>
<td>850</td>
<td>460</td>
</tr>
<tr>
<td>Neutral Ur =110 kV</td>
<td>123</td>
<td>550</td>
<td>-</td>
<td>-</td>
<td>230</td>
</tr>
<tr>
<td>Line Ur =380 kV</td>
<td>420</td>
<td>1425</td>
<td>1570</td>
<td>1175</td>
<td>630</td>
</tr>
<tr>
<td>Neutral Ur =132 kV</td>
<td>145</td>
<td>650</td>
<td>-</td>
<td>-</td>
<td>275</td>
</tr>
</tbody>
</table>
12.2 Insulation Levels For 380 kV Transformers.

HV winding Line terminals

Um = 420 kV.
LIL = 1425 kV, LICL = 1570 kVp, SIL = 1175 kVp.
(AV) (LTAC) = 630 kV.

HV Neutral terminals

Um = 145 kV.
LIL = 650 kV.
(AV) (LTAC) = 275 kV.

LV winding (irrespective of rated voltage for example: 11 kV, 13.8 kV, ....25 kV).

Um = 52 kV.
LIL = 250 kV, LICL = 275 kVp, SIL = 210 kVp.
(AV) (LTAC) = 95 kV.

12.2.1 Insulation Levels For 220 kV Transformers.

HV winding Line terminals

Um = 245 kV.
LIL = 1050 kV, LICL = 1155 kVp, SIL = 850 kVp.
(AV) (LTAC) = 460 kV.

HV Neutral terminals

Um = 123 kV.
LIL = 550 kV.
(AV) (LTAC) = 230 kV.

LV winding (irrespective of rated voltage for example: 11 kV, 13.8 kV, ....25 kV).

Um = 36 kV.
LIL = 200 kV, LICL = 220 kVp, SIL = 165 kVp.
(AV) (LTAC) = 70 kV.

12.2.2 Insulation Levels For 132 kV Transformers.

HV winding Line terminals

Um = 145 kV.
LIL = 650 kV, LICL = 715 kVp, SIL = 540 kVp.
(AV) (LTAC) = 275 kV.

HV Neutral terminals

Um = 145 kV.
LIL = 650 kV.
(AV) (LTAC) = 275 kV.

LV winding (irrespective of rated voltage for example: 11 kV, 13.8 kV, ....25 kV).

Um = 36 kV.
LIL = 200 kV, LICL = 220 kVp, SIL = 165 kVp.
(AV) (LTAC) = 70 kV.

12.2.3 Insulation Levels For 110 kV Transformers.

HV winding Line terminals

Um = 123 kV.
LIL = 550 kV, LICL = 605 kVp, SIL = 460 kVp.
(AV) (LTAC) = 230 kV.

HV Neutral terminals
Um = 123 kV.
LIL = 550 kV.
(AV) (LTAC) = 230 kV.

LV winding (irrespective of rated voltage for example: 11 kV, 13.8 kV, ....25 kV).
Um = 36 kV.
LIL = 200 kV, LICL = 220 kVp, SIL = 165 kVp.
(AV) (LTAC) = 70 kV.

12.3 Insulation Levels For Transformer ≤ 63 MVA, High voltage of 33 kV and low voltage of level ≤ 15 kV.

HV winding Line terminals
Um = 52 kV.
LIL = 250 kV, LICL = 275 kVp, SIL = 210 kVp.
(AV) (LTAC) = 95 kV.

HV Neutral terminals
Um = 52 kV.
LIL = 250 kV.
(AV) (LTAC) = 95 kV.

LV winding (irrespective of rated voltage for example: 6.9 kV, 11 kV, 13.8 kV...).
Um = 36 kV.
LIL = 200 kV, LICL = 220 kVp, SIL = 165 kVp.
(AV) (LTAC) = 70 kV.

13 LEAKAGE MAGNETIC FIELD AND SHORT-CIRCUIT IMPEDANCE VOLTAGE

Leakage Magnetic field plotting & calculations with various combination of windings at principal tap, extreme plus tap and extreme minus tap with respect to placing of windings in relation to core and with respect to each other shall be submitted.

The drawing showing the positions of windings with reference to core shall be submitted.

Further, m.m.f diagram for principal tap, extreme plus tap and extreme minus tap with reference to position of windings shall be submitted.

The following combinations shall be considered.

For two windings:
1) HV - LV

For three windings:
1) HV-LV1, LV2 open
2) HV-LV2, LV1 open
3) HV-LV1 + LV2
4) LV1-LV2, HV open

Calculation of eddy current losses in the windings resulting from axial and radial component of flux field shall be submitted. Losses so generated locally shall be considered in hot – spot temperature rise calculation.
Additionally, temperature increment in the extreme core outer – packets of limbs and flitch plate and tank walls shall be calculated by the leakage flux analysis.

The calculation of impedance on the principal tap, extreme plus tap and extreme minus tap for the above combination of windings shall be submitted. Further, the variation of impedance across the tapping range shall be stated. The range shall be than be examined using generator reactive capability limits for various GUT impedance on the generator bus voltage operating range, in turn, the plant MVAR production and absorption.

The impedance values shall be submitted in ohms per phase or in percentage terms $z$ referred to the rated power and rated voltage of the transformer, referred to either of the windings along with the percentage values, corresponding to reference power and reference to voltage of windings.

Transformers of similar rating and voltage ratio shall have similar impedance characteristics so that they may operate in parallel or used for replacement.

**Negative tolerance at principal tap is not allowed.** The positive tolerance $\leq +7.5\%$.

One of the important parameter in maintaining unit stability with the transmission grid is the GUT impedance. Planning studies shall provide upper limits for GUT impedance. The GUT impedance shall meet transient, dynamic and steady state stability requirements along with limit on short circuit duties to within design values and provide acceptable voltage regulation.

**COMPANY requires evaluation of the impedance for system dynamic stability and short-circuit requirements.**

The maximum limit of impedance at principal tap shall be $= 14\%$ on ONAN or ONAN/ONAF or ONAN/ONAF/OFAF, or OFAF or ODAF rating i.e. that is on maximum MVA rating of Transformer.

14 **CONNECTION SYMBOL**

The connection and phase displacement symbols as given in technical layout A & B for GUT.

15 **OIL COOLING**

15.1 **General**

**Thermal Design**

The manufacturer shall present a through description of the thermal design including oil flow analysis showing oil velocity profile, oil flow and local turbulence in oil ducts. Information shall include the following at the maximum rating at the max. lost tap of the transformer. Loss calculation for the core, windings, and structural members. Hydraulic design and directional controls for the oil flow, and calculated velocities and heat transfer rates of the oil flow. Average and hot spot temp. calculations for the each of the above components. Calculated top average and bottom oil temp. rises, locations of hottest spots temp. within each winding. Location and magnitude of hottest oil temp. within each winding.
These calculation shall be substantiated by presetting of the magnetic field plots to reveal where and how losses are generated, particularly as affected by the stray flux.

Plots of load time capabilities shall be provided.

The hot spot temp. shall be on most onerous tap position with maximum load losses at a design ambient temp. of 50°C for 100% and spare cooling 110% ONAN, ON/ONAF, ONAN, ON/ONAF cooling and 1.15pu for spare cooling with OFAF (unit coolers).

All features, devices, control equipment and terminal connection shall be housed in whether proof marshalling box (protection class IP55). Wiring up to marshalling box shall be with XLPE cable 660/1100 volts grade cable.

Control shall be suitable for both manual and automatic operation of each group of fans.

There shall be duplicate auxiliary supplies, with automatic changeover facilities. Automatic transfer equipment shall include a 5 second time delay to prevent immediate transfer from the normal to standby sources. The manufacturer shall supply suitable control for time delay automatic transfer, mechanically inter-locked with under voltage and over current protection.

The control circuit shall be arranged both electrically and physically such that a single fault shall not cause the loss of more than half the cooling system.

Alarm indication shall be provided to indicate failure of main supply and switchover to standby supply.

Circuit breakers shall be installed for manual switching of each cooler group. Fuses shall not be provided.

The spare cooling group shall also to be connected in service.

All valves N25 and above shall be in accordance to DIN 3352-10-1979 Gate valves of stainless steel shall be used.

The cooling system should be ONAN or ONAN / ONAF or ONAN/ONAF/OFAF or OFAF or ODAF as specified in technical detail layout A & B. Forced directed oil circulation for any of the windings or core is not acceptable.

- MVA rating up to and including 30 MVA shall be provided with ONAN cooling.
- MVA rating above 30 MVA and up to and including 510 MVA shall be provided with ONAN/ONAF cooling. ONAN rating ≥80 % of total rating or. See layout A and B.
- MVA rating greater 510 MVA and less than 630MVA shall be ONAN/ONAF/OFAF cooling ONAN rating ≥60 %, ONAF rating ,80%, OFAF rating 100 % of the total rating
- MVA rating greater than 630 MVA shall be provided with OFAF or ODAF cooling with unit coolers see layout A and B.
Spare cooling for the transformers ≤ 510 MVA shall be provided such that at 1.1pu load and at minimum voltage ratio taps at ONAN and ONAF cooling such that Hot-spot temperature at each rating shall not exceed 98°C at an ambient of 50°C.

Spare cooling for the transformers ≤ 630 MVA with ONAN/ONAF/OFAF shall be provided such that at 1.1pu load and at minimum voltage ratio tap and at each rating corresponding to each type of cooling, the Hot-spot temperature shall not exceed 98°C at an ambient of 50°C.

Spare cooling for the transformers with OFAF or ODAF (unit coolers) cooling shall be provided such that at 1.15pu load at minimum voltage ratio tap, the Hot-spot temperature shall not exceed 98°C at an ambient of 50°C.

Provision of spare cooling in all the above cases shall be proved by temperature rise test & verified during temperature rise test.

15.2 Coolers

For type ONAN, ONAN/ONAF, ONAN/ONAF/OFAF cooling shall be by Radiators, isolating valves shall be provided at the inlet and outlet of each Radiator. Air release and oil drain plug shall be provided on each radiator.

Brass-encased and guarded thermometers screwed in thermometer pockets as per DIN42554 in each oil inlet manifold and each oil outlet manifold of each cooler group or Bank shall be provided.

Each cooler group or Bank shall have suitable valve in the outlet pipe of cooler group to draw oil sample for DGA. A label shall be fixed on such a valve.

The radiators shall be 520 mm wide, thickness of fin sheet ≥ 1.2 mm as per DIN 42559 shall be provided. Radiator shall be able to withstand 2 bar over-pressure under water for one hour and full vacuum. Throttle valve DN 80 as per DIN 42560, shall be welded to tank wall for mounting of radiators or for forming cooler bank.

The interior painting of the radiations shall be corrosion proof. The external surface of radiator shall be treated with cathodic dip coating (CDC).

Radiators from India shall not be used.
OFAF cooling shall be with unit coolers as per DIN 42551.

Axial Flow FANS

The fans shall be similar to DIN 42565.

The fans shall not be directly attached to the radiators and shall not protrude beyond the fins. Fans shall be mounted on suitable structural members using vibration mounts. They shall have sufficient capacity and shall be accessible for maintenance; they shall be individually removable without dismantling of the framework and without having to interfere with the operation of the other fans.
Mechanical protection against touching of the fan blades shall be provided by galvanized wire mesh guard. The fan motors shall be accessible without removing the guard.

Terminal covers and greasing clamps of fans motors removable without dismantling supporting framework.

Motor design: as per VDE 0530 or equivalent.

Insulation Class F to DIN, EN 60034 – 1.

Degree Class of Protection: IP55.

Voltage: as give in layout A & B, 60 Hz. 3 – Ph.

Balancing Quality G6.3 acc. to ISO 1940 part I Motor protection be equipped with over temperature protectors (Thermal contacts "TC") Balancing of quality G 6.3 ACC, to ISO 1940 part I.

Contact protection separate guard grille on the suction side according to the safety regulations (DIN EN 294-1). Motor shall be equipped with over temperature protectors (Thermal contact "TC").

Direction of air flow:
- Horizontal air flow.
- Vertical air flow.

Following to be submitted:
- Voltage
- Frequency
- Poles
- Fan Speed
- In put power Air flow (m³/s.)

Mounting components shall be made of stainless steel.

The control equipment for the fans and pumps (where used) including all auxiliary devices shall be accommodated in a weatherproof cabinet (protection class IP55) and mounted onto the transformers.

The radiators shall be assembled vertically in such a manner as to provide mechanical protection to themselves and to prevent vibrations. The radiator fins shall be welded with stiffening rods (horizontally and diagonally). In addition, suitable ironwork shall be fitted to the radiator groups to prevent vibration during operation of the transformers. Radiators shall be fully vacuum proof and pressure tested and shall be liquid tight. The radiators shall be fitted with suitable drain and vent plugs so that they can be completely drained and vented when fitted.

All parts of the equipment shall be accessible for inspection and cleaning.

The following standard accessories shall be provided:
- 1 (one) butterfly valve each for inlet and outlet for each radiator. Butterfly valves shall be DN 80 according to DIN 42560. Oil leak rate shall not exceed 0.61/minute at 1 kgf/cm² pressure in closed position.
- 1 (one) drain plug at the lowest point of each radiator.
- 1 (one) vent plug at the highest point of each radiator.
- Thermometer pockets as per DIN 42554 fitted with a captive screwed cap shall be fitted on the inlet and outlet manifold of each radiators bank at an approved location.
- One sampling valve DN15 shall be fitted with captive plug on the outlet side of each radiator bank at an approved location, to collect oil sample for DGA analysis.
- The following data about fans shall be provided:
  - No of poles.
  - Frequency.
  - Nominal voltage.
  - Operating current during normal flow.
  - Power consumption.
  - Speed (rpm).
  - Volume of air flow during normal operation.
  - Maximum static pressure drop.
  - Sound power level of single fan.
  - Insulation class of winding.
  - Corrosion protection.

15.2 Cooling Control System

For: ONAN/ONAF.

- A liberally sized auxiliary systems control kiosk weatherproof IP 55 for outdoor transformer, accessible from ground level, shall be provided to house the following:
  - Terminal blocks, for the termination of all control and auxiliary circuits plus fifteen percent for spares. Terminal blocks for incoming power cables shall be stud and nut type.
  - Thermostatically controlled anti-condensation heater for outdoor transformers, capable of maintaining a cabinet temperature of approximately 50°C above ambient.
  - Measuring and monitoring equipments.

A removable plate of adequate size shall be provided in the bottom of the cabinet, directly below the terminal blocks, which shall be field drilled for cable openings.

All wiring shall be brought to the auxiliary systems control cabinet by bottom entry in conduit or, alternatively, armored cable of a type approved by Engineer may be used.

The cabinet shall be provided with padlocking facilities.

The interior of the cabinet shall be treated with an anti condensation coating.

Protective covers shall be provided for power supply terminals and terminals of circuits having voltages more than 120 V.

- The fan motors or groups of motors shall be automatically controlled by a relay combination taking into consideration the winding and top oil temperature. The criterion for automatic “ON/OFF” switching operations shall be the winding
temperature (ON) and the top oil temperature (OFF), respectively. Control shall be such that frequent start/stop operation for small temperatures differences must be avoided. The fan motors shall be connected to the starting relays by minimum two individual groups. The switching ON of two groups shall be with a fixed time lag to avoid high starting currents.

The first group shall come into operation at lower temperature and the second group at higher temperature. The control shall be such that, if the first group fails to come into operation on winding temperature reaching the set value on the contacts of winding temperature indicator, the second group when it comes into operation, consequent to winding temperature reaching higher set value, shall bring the first group of fans also into operation. The fan groups shall not switch off on winding temperature falling to values set on winding temperature indicator for switching ON of the groups, but they shall switch off when the top oil temperature falls below set values to switch off the groups. That is, the starting impulse for both/all the groups shall be given by the winding temperature indicators and stopping impulse by the contacts on the top oil temperature indicator. The temperature differential between start and stop setting for each group shall not be less than 10K. The manufacturer of Contractor shall state in the test report the actual temperature setting based on temperature rise test results, recommended for each cooling group and winding temperature indicator.

All motor contactors and their associated apparatus shall be capable of holding in and operating satisfactorily and without overheating for a period of ten minutes if the supply voltage falls for that period to 85% of normal control voltage.

The contactors shall be protected by means of thermal and magnetizing tripping elements. However, motor protection switches are to be provided for each of the fan motors. A group alarm shall be initiated if any fan fails, however, switching off of any further motor of the same group must be avoided.

The cooling control circuit shall be suitable for 125 V DC while the fan motors shall be of 3 phases AC, 60 Hz, for voltage as given in layout A & B.

Electrical isolation of motor circuits shall be provided to facilitate replacement or repair of individual units during operation of the others.

Voltage relays shall be installed for supervision of the voltage supply circuits.

Changeover form automatic to manual control shall be possible.

The following alarm initiating devices having N.O. contacts shall be included as applicable for the cooling.

Auxiliary supply auto-changer over from power supply to stand by supply.

The following lamps initiating devices having N.O. contacts shall be included:

- Cooling fans start
- Cooling system on automatic control
- Cooling system on manual control
15.3 Measuring and Monitoring Equipment

The equipment of this item shall be wired up to terminal blocks inside the control kiosk. The complete wiring shall be of stranded copper and shall be furnished with approved slipover Ferrules at both ends. Thermometers and thermostats shall be provided with contact units of the snap action type. The contacts shall be adjustable to scale and shall be easily accessible when removing the lid/door. The thermometers shall be arranged inside or close to the control kiosk.

The thermometers shall be with micro-switches. Mercury switches are not acceptable.

Capillaries shall be properly protected throughout the total length. To avoid damages at the connection points of capillary tubes to temperature detectors all heads of these sensors must be completely covered.

The minimum cross-section of conductors of cables shall be 2.5 mm sq.

The following standard accessories shall be provided for each power transformer:

Thermometer pockets dispersed at various places on the lid for fixing thermometer sensors shall be type T DIN 42554 fixed on the top of transformer tank cover to measure top oil temperature. The recommended minimum number of pockets are as follows:

- Rated power ≥ 100 MVA: 3 pockets.
- Rated power from 20 MVA to < 100 MVA: 2 pockets.
- Rated power < 20 MVA: 1 pocket.

The position of the thermometer pockets and corresponding sensors should be chosen to present the top-oil temperature possibly in correspondence to the wound columns of the core.

Brass-encased and guarded thermometers screwed in thermometer pockets as per DIN42554 in each oil inlet manifold at top and each oil outlet manifold at bottom of each cooler group or Bank shall be provided.

- 1 (one) dial type thermometer for oil temperature with maximum position indicator, remote indicator and four adjustable contacts for oil temperature alarm and tripping and switching-off the fans. The range of temperature indicator shall be 0…160 degree C.
- 1 (one) thermal replica indicating winding with highest hot-pot temperature determined during temperature rise test by the "winding to oil temperature gradient" for the phase of HV winding to be connected to current transformer of that phase. The current transformer shall be class IFS <5 for radial split LV windings.
- Two thermal replicas in HV as shown in figure for axial split LV windings as show in Annex H. One thermal replica each for each axial split winding.
- 1 (one) thermal replica to be connected to the LV1 in phase with the highest Hot-spot temperature out of three phases through C.T.
- 1 (one) thermal replica to be connected to the LV2 in phase with the highest Hot-spot temperature and out of the three phases through C.T.
- 1 (one) dial thermometer for each thermal replica with local and remote indicator with four adjustable contacts. The range of temperature indication shall be 0… 160 degree C.

- 1 (one) temperature monitor (thermostat) with adjustable contact for top oil temperature alarm and top oil temperature tripping.

- Ammeters with selector switch of make before break contact type for checking the output of the current transformers of thermal replica.

- By disconnecting the secondary circuit of the instrument, it shall be possible to use it as an oil temperature indicator.

- In case of Axial split HV winding two CT, one for each half shall be provided for winding temperature indicators. Further, ammeters in circuit shall be provided to monitor the circulating current during unbalanced loading of LV1 and LV2.

- Two brass encased and guarded thermometers screwed in thermometer pockets of type T DIN42554 inlet manifolds of coolers.

- Two brass encased and guarded thermometers screwed in pockets of type T DIN42554 in the oil inlet and oil outlet manifold of each group or Bank of coolers.

Thermometers from the following manufacturers are preferable:
- MESSKO – Germany.
- AB Kihlstroms – Sweden.
- Qualitrol – Germany.

15.3 **Pump For ONAN/ONAF/OFAF and OFAF (with unit coolers) Cooling:**

The oil circulating pump shall be in-line axial flow mono-block (integrated motor) oil circulating pump with radial impeller and motor assembly shall be completely oil immersed type same as given in Cl. 15.4.2 of this specification. It shall permit oil circulation even when pump is idle.

The cooling control is same as given for OFAF cooling Cl. 15.4.2 of this specification.

15.3.1 **ONAN/ONAF/OFAF Cooling**

Cooling shall be by radiators and axial flow fans are of the same specification as for ONAN/ONAF cooling as described in Cl. 15.2.0 in addition to in-line axial flow pump for each bank of radiations to increase the velocity of oil flow.

The transformer shall be equipped with minimum two banks of radiators and axial flow fans mounted on radiators.

Suitable number of pumps for forced oil circulation shall be fixed in down stream side of the cooler bank.

Oil - inlet to the radiator battery shall be located at transformer tank cover (lid) for each radiator battery and it shall be from different place on the lid.
Pumps shall be fixed on down stream of oil. The oil outlet from the radiator battery shall be located at the bottom of the tank. The discharge of the oil in tank shall be in a closed channel having openings to discharge oil at the center of each phase winding on HV side for first battery and on LV side for second battery.

Oil inlet and oil outlet from transformer tank of each battery shall have suitable size throttle according to DIN 42560. Valves shall be with locking facility. Each battery of radiator shall be connected to transformer tank by means of stainless steel Bellows both at inlet and outlet.

The radiators shall be provided with throttle valve DN80 as per DIN 42560.

The interior painting of the radiator shall be corrosion proof. The external surface of radiators shall be treated with cathodic dip coating (CDC).

Axial flow fans: the type and specification of fans is same as in CL. 15.2.0.

Pump for OFAF cooling:

The type and specification of pump is same as in CL. 15.4.2

ONE SPARE PUMP FOR EACH Transformer shall be provided.

COOLING (OFAF):

ONAN/ONAF/OFAF cooling shall be applicable for transformers rating greater than 630 MVA and where space in the plant is available

OIL Flow METER.

Same specification as for OFAF cooling: CL. 15.4.2

The transformer shall be equipped with at least two independent batteries of coolers of equal heat dissipating capacity, to dissipate total losses of the transformer at 1.1p.u. full load at the lowest tap without exceeding a hottest spot temperature of 98°C at an ambient temperature of 50°C. Each battery of cooler group shall consist of one unit assembly of radiators cooler as per DIN 42551, one in line pump, and one group of axial flow fans. Each battery of cooler mounted on tank or separately mounted. Isolating valve shall be provided at the inlet and outlet of each battery of cooler. Air release plugs, oil drain cum filter valve at bottom and one filter valve at top of size DN25 as per DIN 42551 shall be provided for each battery.

Brass encased and guarded thermometers screwed in the thermometer pockets –type T DIN 42554 in the inlet and outlet manifold of each cooler battery shall be provided.

15.3.2 COOLING CONTROL SYSTEM

All features, devices, control equipments and terminal connection shall be housed in weatherproof marshalling box (protection class IP55). Wiring up to marshalling box shall be with XLPE cable 660/1100 volts grade cable.
Control shall be for both manual and automatic operation of each group of fans and pumps.

All the pumps shall come in to operations as soon as transformer is energized with a time delay of five seconds and switched off after transformer is de energized.

Starting impulse for fans shall be given by winding temperature detector at the preset temperature limits. The manufacturer shall set the controls to operate at the temperature he recommends for the transformer Design. Manufacturer’s calculations for setting of cooling shall be submitted for approval of COMPANY. He shall state in the test report the actual temperature setting which has been applied for each group. The OFF signal for each group of the fans shall be given by top oil temperature indicators.

The control shall be such that frequent start/stop operation for small temperature difference must be avoided. The fan motors shall be connected to the starting relay by minimum two individual groups.

Selector switches shall be provided for selection of fans to be in “service” or on standby.

There shall be duplicate supply feeder and it shall have all necessary equipment for automatic change over from normal to standby supply. Automatic transfer equipment shall be including a 5 second time delay to prevent immediate transfer from the normal to emergency sources.

Alarm indication shall be provided to indicate failure of main supply and switchover to standby supply.

Circuit breaker shall be installed for manual switching of each cooling groups, Fuses shall not be provided.

The spare cooling radiators and fans shall also be connected in service.

Controlled shall be suitable for both manual and automatic operation of each group of fans and oil pumps.

The fans shall be arranged in two groups for each battery.

For all the groups of fans the starting impulses shall be given by the winding temperature detectors (fitted on HV or LV winding) at pre-set temperature limits.

The temperature detector shall set the controls to operate at temperature recommended based on temperature rise tests. These shall be stated in test report.

The First group of fans shall come in to operation at lower temperature, signal initiated by the winding temperature indicator, recording the highest hottest spot temperature (HV or LV).

The Second group of fans shall comes in to operation at temperature, higher than the first group, signal initiated by that winding temperature indicator recording lower hottest spot temperature than that of first group (HV or LV).
The control shall be such, that if the first fan group fail to come into operation on winding temperature reaching the set value on the concerned winding temperature indicator, the second group of fans when it comes into operations consequent to winding temperature reaching higher set value, shall bring the first group of fans also into operation. The fans groups shall not switch OFF on winding temperatures falling to values set on respective winding temperature indicators for switching ON of the groups, but shall switch OFF when the top oil temperature fall bellow set value to switch OFF the group. That is, the starting impulse for both the groups shall be given by the sets of contacts on two winding temperature indicators and stopping impulse by the contacts on top oil temperature indicator.

The temperature differential between start and stop setting for each group shall not be less than 15 K.

A magnetic contactor with thermal over load relay and HRC link type fuses for short circuit protection shall be provided for each individual oil pump motor and maximum of two fans. Means shall be provided for isolating any fan or oil pump from the supply. Over-load relays shall be hand reset.

All motor contactors and the associated apparatus shall be capable of holding in and operating satisfactorily and without overheating for a period of ten minutes if the supply voltage falls for that period to 85% of normal control voltage.

The contactor shall be protected by means of thermal and magnetizing tripping elements. However, motor protection switches are to be provided for each of the fan motors. A group alarm shall be initiated if any fan fails, however switching off of any further motor of the same group must be avoid.

Electrical isolation of motor circuit shall be provided to facilitate replacement or repair of individual units during operation of others.

Voltage relay shall be installed for supervision of the voltage change –over from automatic to manual.

The following alarm initiating devoices having NO contact shall be applicable for the cooling:

- Auxiliary supply auto-changeover
- Cooling fan/fans failure for each unit cooler battery
- Oil pump failure for each pump
- Low oil flow for each pump

The following alarm initiated device having no contacts shall be included:

- Cooling fan start
- Cooling system on automatic control
- Cooling system on manual control

Unless stated otherwise auxiliary equipment shall be rated as follows:
a) Fan and pump motors – voltage as stated in layout B, 3-phase, 3-wires 60Hz

b) Control voltage as stated in Layout B, 60V DC

c) All contacts provided for alarm, tripping and indicating shall be suitable for 60 V DC underground systems.

15.3.3 **Control Kiosk**

The control kiosk shall be mounted on the side of the transformer tank using anti-vibration mounting.

15.3.4 **OFAF or ODAF Cooling With Unit Coolers**

Calculation of design velocity of oil flow in the coolers shall be submitted.

OFAF or ODAF cooling with unit coolers is applicable for transformers of rating greater than 630 MVA.

The transformer shall be equipped with forced oil, forced air type of cooling system (OFAF) provided by means of directly flanged-on or separately vertically mounted oil/air coolers. Forced directed oil circulation for any of the windings or core shall not be used. Where it is found to be used, transformer will be rejected.

The transformer shall be equipped with at least four independent unit cooling groups of equal heat dissipating capacity, to dissipate total losses of the transformer at 1.15p.u. full load at the lowest tap without exceeding a hottest spot temperature of 98°C at an ambient temperature of 50°C. Two spare unit cooling group shall be provided of the same unit capacity as above. Each unit cooler group shall consist of one unit cooler as per DIN 42551, one in-line pump, axial flow fans. Cooler group may be mounted on tank or separately mounted. Isolating valves shall be provided at the inlet and outlet of each cooler unit. Air release plugs, oil drain cum filter valve at bottom and one filter valve at top of size DN 25 as per DIN 42551 shall be provided.

Brass encased and guarded thermometers screwed in the thermometer pocket-type T DIN 42554 in the inlet manifold and outlet manifold of each unit cooler shall be provided. Fans are to be partitioned individually in the air manifold chamber in order to prevent recirculation of air flow.

The coolers shall be operated according to the cross current principle, i.e. the hot oil is being conducted in cross current to the cooling air.

The unit cooling elements shall comply with the requirement of DIN 42557 part I for oil/air coolers.

The oil headers of unit cooler shall have covers that can be removed for cleaning of the oil side.

The air inlet or outlet shall be at an adequate distance from wall or tank (at least three times the diameter of impeller) in order to allow a free flow of air.

**Preferable Equipment:**
RENZMANN GRUNEWALD GmbH (R&G): GEA GmbH

D-55569, Monzingen : Karl-Schiller - Strasse1-3.31157

Industriestrasse 6 : Sarstedt. Germany

Germany : E-mail info@gea-ecoflex.de.

Oil Circulating Propeller Pump:

In-line axial flow mono-block oil circulating propeller pump (integral pump & motor unit) with radial impeller and motor assembly shall be of the completely oil immersed glandless type. It shall permit oil circulation even when pump is idle. The flanges at the inlet and outlet shall be as per DIN 2501PN10. Design of the unit shall be as per VDE 0530 or equivalent.

Voltage as given in Layout B, 60 Hz, 3-phase

Insulation class B

Test voltage 2.5 kV

Degree of protection IP55

Cable gland Pg 16

Maximum temperature of oil 110°C

The velocity of oil shall not exceed 0.2 m/second.

Withstand test pressure > 5 bar at oil temperature of 120°C for 4 hours.

Arrows indicating the direction of oil flow shall be casted on the housing of the pump. Bleeding device shall be provided to ensure that air is not returned to the transformer when oil pump is put back into service. The pump shall incorporate a device, to prevent wrong direction of rotation of impeller.

Isolating lug type Butterfly valves in accordance to EN 593 of suitable size on either side of each pump shall be provided. This allows the pump to be isolated without removing main tank oil or the oil in the remainder of the cooler or radiator battery and piping connected to each pump.

Preferable Equipment:

RENZMANN GRUNEWALD GmbH (R&G)

D-55569, Monzingen

Industriestrasse 6

Germany
Performance Data:

The following data of the pump shall be submitted.

- Delivery Head v/s Discharge
  FLS \( m^3/h \)
- Input v/s Discharge
  Kw \( m^3/h \)
- Current v/s Discharge
  I amp \( m^3/h \)

Transformer Oil to Air Unit Coolers:

The cooling elements of the unit coolers shall comply with the requirements of DIN 42557 part I for oil/air coolers.

The oil header shall have covers that can be removed for cleaning of the oil side.

Withstand test pressure > 6 bar of transformer Oil of temperature 120°C for 6 hours.

Interior painting shall be corrosion proof. The external surfaces of the coolers shall be treated with cathodic dip coating (C D C).

Preferable Equipment GEA: Heat Exchangers

1)
RENZMANN GRUNEWALD GmbH (R&G)
D-55569, Monzingen
Industries Strasse 6
Ph. (06751) 9303-0
Fax. (06751) 9303-100
(06751) 9303-169

2)
GEA GmbH
Karl-Schiller - Strasse 1-3.31157
Sarstedt. Germany
E-mail info@gea-ecoflex.de.

Preferable Equipment: R&G or Qualitrol or GEA.

Oil Flow Meters:

Oil flow meters shall be of venturi – meter type indicating the rate of flow with two sets of NO contacts. The flow meters shall be fixed on down stream side of the cooler units.

Preferable Equipment: R&G or Qualitrol or GEA.
Axial Flow Fans or Air Blowlers:

Air blowlers or Fans shall not be over-hung from the coolers fins. They shall be mounted on suitable structural members using anti-vibration mounts or independently of the coolers. They shall be provided with a galvanized wire mesh guard with a protection IP20. Terminal covers and greasing clamps of fan motors shall be accessible without removing the guard. The fan or Air blowlers shall be removable without dismantling supporting frame work.

Motor design as per VDE 0530 or equivalent

Insulation class F according to DIN, EN 60034 – 4 (IEC 60034-1)

Degree class of protection: IP54

Voltage as given in Layout B, 60 Hz, 3-Phase

The control equipment for the fans including all auxiliary devices shall be accommodated in a weather-proof cabinet (protection class IP55) and mounted onto the transformers.

Starting from the hot condition (at 100% load), the transformer shall be capable of remaining in operation without exceeding hot spot temperature (windings) of 130°C after failure of forced cooling for not less than 60 minutes after outage of all forced cooling.

Preferable Equipment GEA: Heat Exchangers

1) RENZMANN GRUNEWALD GmbH (R&G) D-55569. Monzingen Industriestrasse 6 Germany
2) GEA GmbH :Karl-Schiller - Strasse 1-3.31157 Sarstedt. Germany :E-mail info@gea-ecoflex.de.

Cooling System Control:

All features, devices, control equipments and terminal connection shall be housed in whether proof marshalling box (protection class IP55). Wiring up to marshalling box shall be with XLPE cable 660/1100 volts grade cable.

Control shall be suitable for both manual and automatic operation of each group of fans and oil pumps.

All the pumps and first group of fans shall come into operation as soon as transformer is energized with a time delay of five seconds. i.e. ; interlocked with switching operation. The switching off of the pumps be by top oil temperature indicator and shall be last cooling equipment to be switched off. When the transformer remains in energized condition, where the transformer is switched off, the pumps are also to be switched off. For remaining fans group the starting impulses for fans shall be given by winding
temperature detectors at the preset temperature limits. The manufacturer shall set the controls to operate at the temperature he recommends for the Trafo. Manufacturer's design calculation for setting of cooling shall be submitted for approval of COMPANY. He shall state in the test report the actual temperature settings which have been applied for each group (group 2, group 3 etc.). The OFF signal for each group of the Fans shall be given by top oil temperature indicators.

The control shall be such that frequent start/stop operation for small temperature differences must be avoided. The fan motors shall be connected to the starting relay by minimum two individual groups.

Selector switches shall be provided for selection of fans to be in "service" or on standby.

There shall be duplicate supply feeder. It shall have all necessary equipment for automatic change over from Normal to standby supply. Automatic transfer equipment shall include a 5 second time delay to prevent immediate transfer from the normal to emergency sources.

Alarm indication shall be provided to indicate failure of main supply and switchover to standby supply.

Circuit breakers shall be installed for manual switching of each cooling group. Fuses shall not be provided.

The spare cooling group shall also be connected in service.

Control shall be suitable for both manual and automatic operation of each group of fans and oil pumps.

The fans shall be arranged in three groups.

For the remaining groups of fans, the starting impulses shall be given by the winding temperature detectors (fitted on HV or LV windings) at pre-set temperature limits. The manufacturer shall set the controls to operate at temperatures recommended based on temperature rise tests. This shall be stated in the test report. Fan group 2 shall come into operation at lower temperature, signal initiated by the winding temperature indicator, recording the highest hottest spot temperature (HV or LV). The third group of fans shall come into operation at temperature, higher than the second group, signal initiated by that winding temperature indicator recording lower hottest spot temperature than that of the 2nd group (HV or MV).

The control shall be such, that if the Fan group 2 fails to come into operation on winding temperature reaching the set value on the concerned winding temperature indicator, the third group of fans when it comes into operation consequent to winding temperature reaching higher set value, shall bring the second group of fans also into operation. The fan groups shall not switch OFF on winding temperatures fallings to values set on respective winding temperature indicators for switching ON of the groups, but shall switch OFF when the top oil temperature falls below set values to switch OFF the groups. That is, the starting impulse for both the groups shall be given by the sets of contacts on two winding temperature indicators and stopping impulse by the contacts on top oil temperature indicator. The temperature differential between start and stop setting for each group shall not be less than 15 K.
A magnetic contactor with thermal over-load relays and HRC link type fuses for short circuit protection shall be provided for each individual oil pump motor and maximum of two fans. Means shall be provided for isolating any fan or oil pump from the supply. Over-load relays shall be hand reset.

All motor contactors and their associated apparatus shall be capable of holding in and operating satisfactorily and without overheating for a period of ten minutes if the supply voltage falls for that period to 85% of normal control voltage.

The contactors shall be protected by means of thermal and magnetizing tripping elements. However, motor protection switches are to be provided for each of the fan motors. A group alarm shall be initiated if any fan fails, however, switching off of any further motor of the same group must be avoided.

Electrical isolation of motor circuits shall be provided to facilitate replacement or repair of individual units during operation of the others.

Voltage relays shall be installed for supervision of the voltage supply circuits.

Change-over from automatic to manual control shall be possible.

The following alarm initiating devices having NO contacts shall be included as applicable for the cooling:

- Auxiliary supply auto-changeover.
- Cooling fan/fans failure for each unit cooler.
- Oil pump failure for each pump.
- Low oil flow for each pump.

The following alarm initiating devices having NO contacts shall be included:

- Cooling pump start.
- Cooling fans start.
- Cooling system on automatic control.
- Cooling system on manual control.

Unless stated auxiliary equipment shall be rated as follows:

a) Fans and pump motors – voltage as stated in Layout B, 3-phase, 3-wire, 60 Hz.
b) Control voltage as stated in Layout B, V DC.

All contacts provided for alarm, tripping and indication shall be suitable for 60 V DC ungrounded system.

15.4 Control Kiosk

The control kiosk shall be mounted on the side of the transformer tank using anti-vibration mountings.

15.5 Preservation System

Ref. CL 21.5
16 REQUIREMENT WITH REGARD TO ABILITY TO WITHSTAND SHORT-CIRCUIT

Description given in CL 22.2.1 shall be considered as adjunct to this requirement.

The transformer shall be designed and constructed to withstand for 5 seconds a metallic short circuit on the terminals of HV or LV for two winding transformer & for multi winding transformer, between any pair of winding, the other windings open or between any windings and any other windings shorted and remaining windings open.

Leakage flux distribution analysis by computer for various combinations of windings shall be submitted.

For example,

For, two winding Transformer, for three winding Transformer, for four winding Transformer

<table>
<thead>
<tr>
<th>HV-----LV</th>
<th>HV-----LV1, LV2 Open</th>
<th>HV-----LV1, LV2 &amp;MV open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HV-----LV2, LV1 open</td>
<td>HV-----LV2, LV1&amp;MV open</td>
</tr>
<tr>
<td></td>
<td>HV-----LV1+LV2</td>
<td>HV-----LV1+LV2, MV open</td>
</tr>
<tr>
<td></td>
<td>LV1-----LV2, HV open</td>
<td>LV1-----LV2, MV &amp; HV open</td>
</tr>
<tr>
<td></td>
<td>MV-------LV1, HV &amp; LV2 open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MV-------LV2, HV &amp; LV1 open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MV-------LV1+LV2, HV open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HV- MV, LV1 &amp; LV2 open</td>
<td></td>
</tr>
</tbody>
</table>

The ability to withstand the dynamic affect of short circuit shall be demonstrated by calculation with reference to design and manufacturing consideration and if required by test.

The calculation of dynamic short-circuit withstandability shall be submitted for approval of COMPANY before finalizing design and production.

The manufacturer shall study system faults and their characteristics. Calculations for all possible systems configurations shall be considered. System impedance or Generator impedance shall not be considered for calculation of fault current, however, feeds from all sources shall be considered.

Abnormal operation of conditions such as the following shall be considered:

1- Out of phase synchronization. Out of phase angle of 180° to be considered. Generation Transformers susceptible to excessive over currents produced by connection of the generators to the system out of synchronism.

2- Where generator circuit breaker is not provided and SST is used for starting of unit Out of phase synchronizing of SST with UAT can produce high currents. Out of phase angle of 180° to be considered.

3- Operating voltage that is higher than rated maintained at the un-faulted terminals during a fault conditions.
4- Frequency mismatch between the generator and system voltages also can cause severe mechanical stresses.

5- Transformer terminals connected to rotating machines (such as motor or synchronous condensers) that can act as generators to feed current in to the transformer under system fault conditions.

6- Fast load transfer (by HST switches) from UAT to SST may under certain conditions results in high circulating currents flowing through the two transformers. It shall be assumed that phase angle difference between the two source voltage in 180°.

The method of calculation of high circulating currents flowing through transformers shall be calculated in accordance to CL 7.3 of IEEE C57.116-1989 (R 2005).

7- Unit auxiliary transformers and main generators step-up transformers directly connected to a generator bus may be subjected to a prolonged duration terminal faults as a result of the inability to remove the voltage source quickly.

8- In case of star/delta-connected GUT with earthed neutral, a single line to earth fault on the system connected to the star-connected winding may cause the most severe short-circuit conditions.

9- Faults initiated by circuit breakers that may under certain conditions, cause fault current in excess of those calculated in accordance with above clauses.

10- Operating voltage that is higher than rated maintained at the un-faulted terminal(s) during a fault condition.

11- Transformer terminals connected to rotating machines (such as motors or synchronous condensers) that can act as generators to feed current into the transformer under system fault conditions.

12- On units without generator breakers, faults on LV winding side of UAT, will be fed predominately by two sources, namely, through the UT from the system and from the generator.

13- Transformers accessories such as leads tapping leads, leads to bushing, OLTC and DETC, current transformers and bushings that carry current continuously shall comply with short circuit withstandability.

The calculation of short-circuit currents shall be based on VDE 0102 Part 1/11-71 and Part 2/11.75. The factor C shall be taken as 1.1. The impedance shall be taken with negative tolerance of – 10%. Where measured value of impedance is used, it shall be taken with negative tolerance—5%. The maximum symmetrical short-circuit current so calculated shall be increased by 10% as a safe margin to calculate the dynamic forces and thermal withstandability. Further consideration of short-circuit duty as specified in IEEE C57.116.

The amplitude of the first peak of the asymmetrical current that the transformer required to withstand shall be calculated by using factor of asymmetry in accordance to Clause 7.1.5.2 of ANSI/IEEE C-57.12.00 by considering the resistance & reactance of the transformer only.

The short-circuit current calculations, dynamic withstandability and thermal withstandability calculations shall be submitted to COMPANY for approval before proceeding with finalization of design.

Theoretical evaluation of the ability to withstand the dynamic affects of short circuit shall be in accordance to Annex A of IEC: 60076-5/2006 and additionally based on the principles established by the book "SHORT CIRCUIT STRENGTH OF POWER TRANSFORMERS " by M. WATERS published by Mc Donald London and the documentation needed for the purpose include all necessary technical data such as
electromagnetic design data sheets, Magnetic field plotting in windings, calculation of shot circuit current, electromagnetic forces and mechanical stresses, supplemented by drawings, material specifications, manufacturing practices and process instruction etc, produced for the purpose of the electro magnetic and mechanical design of the transformer. It is intent of Design Review to check the most critical mechanical force and stress values appearing in the design as a consequence of fault conditions specified.

The forces on the out-coming leads and tapping leads and cleats shall be calculated. The clamping arrangement of leads withstand ability shall be calculated for submission to COMPANY. along with dimensioned drawing of tapping leads manifold.

Design review, as the only component of quality assessment of power transformer is not acceptable to COMPANY. Short circuit testing is a vital part of the design and the crucial verification tool.

Company reserve the right to request to carry out short circuit test however contractor will be informed before submission of the commercial proposal . The cost of test shall not be remunerated in case of failure of the transformer during test .

In case of failure of transformer during short-circuit test, the entire lot will be rejected.

The manufacturer shall take into consideration factors which play a role in enhancing dynamic withstandability performance including the following:

1. Windings made of high-grade proof-stress copper instead of annealed copper.
2. Lower current densities in windings.
3. Use of epoxy-bonded continuously transposed conductors instead of individually insulated flat conductors.
4. Strictly controlled machine manufacturing processes of the windings.
   All winding machines shall have facilities for applying axial and radial force for compacting the windings at the winding stage itself.
   This makes the winding compact right from the beginning, which is one important requirement for short-circuit withstandability.
5. High-density pressboard in windings and end insulation components.
6. Elastic stabilization of windings and tight tolerances concerning winding lengths under specified clamping force and relative positioning of the winding.
7. Core & Coil clamping structure consisting of robust and stiff parts duly fastened.
8. Large sizing of all pressure rings, pressure and support blocks preferably made out of epoxy and their securing by means of pins, block washers and fastening devices.
9. Securing of all winding exit leads and connection to bushings and tap-changers shall be by pressboard. Wood or laminated wood shall not be used.
10. Final clamping of the winding blocks after impregnation with oil carried out to secure adequate, evenly distributed and long lasting axial force on them.
11. Windings, assembly of insulation, assembly of active parts shall be performed in dust proof, clean, constant humidity and temperature controlled shop.
17  REGULATION CONFIGURATION

Where ON-LOAD TAP-CHANGER is specified, it shall be furnished to provide ± 5 percent adjustment of low-voltage winding voltage so as to fully utilize the generator capabilities of both lead and lag power, fully utilized without producing stabilities stresses on the generator. The contractor / manufacturer shall perform system studies to establish this range.

The regulation of the transformer from no-load to continuous rated output at 1.0 power factor and at 0.8 lagging power factor shall be furnished. Refer to Layout A & B.

18  WINDINGS

Protective devices such as non-linear Metal Oxide elements that form an integral part of the transformer connected across whole or part portions of winding such as coarse and fine windings are not accepted. Such constructions are rejected.

Detail design of winding comprise of winding type, coils, design, dimensions and weights, conductor dimensions and conductor insulation definition.

All winding conductors and connection leads shall be paper insulated.

COMPANY reserves right to inspect and approve the following materials before production is taken up:

1. Insulated conductors.
2. Insulation papers.
3. Insulation materials both flat and molded.

The inspection will be in respect of the following:

1. Quality of materials.
3. Source of supply and procurement.

This inspection may be performed at any time during production or at the time of Final Acceptance Test, where inspection not performed before production.

Materials from India and China are not accepted, particularly:

1. Insulated conductors for windings.
2. Insulation materials both flat and molded.
3. Insulation paper etc.

Current density in the conductors of windings shall not exceed 2.5 A/mm² at maximum rating and at lowest tap. COMPANY reserves the right to inspect this. Aluminum conductor shall not be used for the
windings or leads. Electrolytic high conductivity copper of high tensile strength or copper alloy conductors (with the same electrical properties) shall be used for the windings.

Thermally upgraded insulation Kraft paper shall be used for conductor insulation and lead insulation. Thermally upgrading neutralize the production of acids caused by the hydrolysis (thermal degradation) of the material over the lifetime of the transformer these papers shall meet the requirement of retaining the bursting strength (>80%) when exposed to elevated temperatures in sealed tube accelerated ageing in mineral oil at 150°C. Further, the change of DP over time of thermally upgraded paper exposed to a temperature of 150°C. as given in Fig 1 of IEC: 60076-7 and the relatively ageing rate generally in compliance with Table 2 and normal insulation life generally in line with Table 3 of IEC: 60076-7. Insulation materials and structural design shall be such as to meet the short-circuit strength requirement. High-density pre-compressed press-board shall be used for partition cylinders and spacers. It is essential to maintain an overall and local ampere-turn balance between the windings along the entire length of the windings. Winding supports of high strength and impregnable material or preferably epoxy shall prevent vertical movement or distortion of any part of the winding and shall maintain axial symmetry. In any tap-changer position, the ampere-turn distribution shall be uniform along the winding and the mechanical stresses in the event of a short circuit shall be minimized.

There shall be separate voltage regulating and tapping windings. The HV main winding shall not be tapped. The regulation winding and tapping leads located at neutral end of HV winding shall be designed to withstand direct application of impulse to neutral at tap position of lowest voltage ratio.

Winndings shall be compact cylindrical round, including disk, helical and layer.

Molded insulation parts, such as shields, angle rings, spacers, drip – proof bellow etc shall be from M/s. Weidman Switzerland alternatively M/s OJI Japan can also be accepted subjected to Company review and approval.

The winding clamping shall ensure a tight coil assembly during the manufacture and throughout the service life of the transformer. Design of winding shall control and minimize the localized losses and heating by stray fluxes, so that high temperatures in the windings do not pose problem for transformer operation either during normal load or emergency over load. Details of winding arrangement, compaction and sizing shall be submitted to COMPANY for perusal acceptance and records. Drying and oil impregnation defining the following shall be submitted:

1. Winding drying and sizing process:
   o Drying phases….hrs.
   o Hot air circulating duration….hrs.
   o Vacuuming duration….hrs.
   o Drying temperature range…….°c.
   o Minimum pressure for sizing ……..kgf /cm².
   o Tolerance on axial heights…………± mm.

2. Ending parameters for each phase:
   o Hot air circulation duration….hrs.
   o Vacuum duration….hrs.
3. Vapor phase drying phase duration….hrs:
   o Ending parameter.

4. Moisture content measurement in the insulation by power factor measurement.

**Type of Windings:**

- **Low Voltage & Medium Voltage up to voltage Class 52 kV-for Currents requiring large conductor sections.**

  The conductor shall be semi-cured-resin-impregnated upgraded paper insulated continuously transposed conductors (CTCs). LV winding conductor, leads, bus bars shall be covered with Kraft paper. All windings shall have paper insulation.

  The windings may be:
  o Layer disc windings.
  o Two layer or four layer helical windings.
  o Multilayer windings.

- **High Voltage Main windings, Voltage class 72.5 kV and above**

  Single or multi rectangular conductor insulated with upgraded paper semi-cured resin – impregnated upgraded paper insulated continuously transposed conductors (CTC).
  o Fully interleaved high-series capacitance continuous disc winding.
  o Partially interleaved high-series capacitance continuous disc winding + continuous disc winding. The extent of interleaving to be submitted for the perusal and record of COMPANY.
  o Shielded windings including turn shielded continuous disc windings are not accepted. COMPANY reserve right to verify the type of winding used. Where non compliance to specification is detected, the transformer will be rejected.

  Drawing showing the interleaving shall be submitted to COMPANY.

- **Regulating / Tapped windings:**

  All tapping shall be full power tap. Single or multi rectangular conductor insulated with upgraded paper.

  The tapped part of the winding shall be arranged as a separate physical body and connected with main part of the winding, the winding may be:
  o Multi start loop layer Helical winding.
  o Interleaved disc winding.
  o Multi entry interleaved helical winding.
  o Helical looped windings.

  All tapping shall be full power tap.

- **Joints in Windings:**
Joints are permissible at locations external to the windings, specifically at crossovers between layers or discs. The jointing of conductors shall be by means of high-frequency (HF) Brazing or silver Brazing or Electrical welding. The procedure shall be based on the Swedish Standard SS065231. The joint shall be free from any notches and burr. The tensile strength of the joint shall be at least 80% of the parent materials strength. The strength calculation on the area of the contact surface, further the brazed joint, shall have at least 80% fault less surface.

Joints by crimping are not acceptable. Effective quality assurance procedure for verifying the conductors are free from defects in joints and that conductor burr, risks or indentation, dimensional tolerance and mechanical strength are within acceptable design of conductor joints and connections shall limit circulating currents and overheating such that abnormal ageing or deterioration do not occur when the apparatus is operated at load executed.

During manufacture, the core and winding structure shall be subjected to a treatment, which removes moisture from the insulation. Manufacture of insulation parts and assembly of winding and insulation shall be done in separate clean, humidity controlled, air pressurized areas. The moisture content in the insulation shall not exceed 0.3% by dry weight. The tan-delta of winding shall not exceed 0.5%. The drying of Transformer shall be by vapour-phase method. The processes of stabilizing and sizing the windings shall be submitted for perusal and record of COMPANY.

- **Leads and Support**

  Leads and lead support of pre compressed pressboard shall be designed for all dielectric, mechanical, and Thermal effects which could be encountered. The design shall not permit permanent deflection of supports and leads due to forces acting on the lead during short-circuit, transport or service.

  Tap leads and series or parallel cross-over leads and supports shall be designed to provide significant safety margins above the worst case dielectric stresses which would occur during specified impulse and power frequency tests, as though specified tests were performed at each tap position. Similarly, line leads shall be designed to provide reasonable safety margins during these conditions.

### 19 MAGNETIC CORE

The maximum flux density in any part of core limbs or yoke at normal voltage and frequency shall not exceed 1.6 tesla for Generator Transformer and 1.65 tesla for other transformers. The COMPANY reserves the right to verify this requirement. Core shall be manufactured from non-aging, cold rolled grain oriented silicon steel laminations of thickness 0.23 mm or 0.27 mm according to specification IEC 404-8-3/EN 10107 of any of the following type.

1. High-permeability super oriented/laser-etched or IEC: 60404-8-7/2008
2. High-permeability normal oriented steels. IEC: class C-22 of
3. Normal grain oriented steel. IEC: 6040-1
4. Japanese steel is preferred. Russian steel shall not be used.

Core lamination not inferior to lamination to IEC : 60 404-8-7 Class 22

or 60 404-8-8 Class 23

Thickness ≤ 0.27, loss ≤ 1.45w/kg at 1.7 Tesla and 60 Hz, when tested by Epstein test – Apparatus.
Specific total loss at frequency 60 Hz and peak magnetic flux density 1.7T (guaranteed max.) in non-annealed condition shall be stated in layout A and B.

The core shall be assembled from straight and smooth low magnetostriction laminations. Maximum allowable burrs on a sheet or cut edge of the lamination shall not exceed five microns (5 microns). The burr height shall be determined in accordance with IEC: 60404-9. The process of manufacturing the core shall be performed in such a way that mechanical stresses and deformation of the core sheets are minimized. Step–lap joints shall be adopted in assembly of core laminations.

The main limb and return limbs of core shall be wrapped with a second-band tape or semi-conducting tape with 50% overlap. Finally it shall be wrapped with crepe paper. Where required Yoke screen shall be provided.

The hot-spot temperature gradient of core above top oil shall not exceed 20 K and the core and its mechanical parts shall be designed to withstand forces produced during normal transportation, short-circuits and earthquakes. The core and winding assembly shall be fixed firmly both at tank bottom, sides and tank top at suitable number of points, to withstand severe impact during transport (Refer CL 21.21.1). The design shall avoid mechanical resonances at or near multiples of the frequency of the network (60 Hz).

Hot spot temperature calculation shall be submitted

Measures to minimize circulating current and stray losses in core and clamping system should be adopted by the following method:

The flitch plates of the clamping system shall be divided in its width dimension by slitting.

The first and second steps of magnetic core (outer most packets) shall also be divided in the width dimension.

Earthing of core shall be at one point. Size of earthing connection of core shall be of area > 80 mm². The connections inserted between laminations of different section of core shall have cross-section area > 20 mm². Magnetic core shall be directly grounded without any impedance or fuse like elements connected in service. Earthing lead from core and earthing lead from core clamps shall be brought through 3.6/250A bushings in accordance to DIN 42531 and enclosed in box. The two bushings shall be shorted and earthed on the top of tank cover or connected to station ground through cable.

A warning plate shall be provided stating, core ground must always be connected when transformers energized.

The insulation between the core and core clamps shall withstand DC voltage of 3.5 kV for one minute. The measured resistance shall be > 0.5M Ohms.
1) NIPOON or 2) JEF Shall be used

Steel from Pasco (Korea) can also be accepted subject to compliance of steel properties to COMPANY Specification. Where the manufacturer uses steel manufactured by others, permission of COMPANY after submitting the detail properties of steel shall be obtained.

20 ON-LOAD TAP-CHANGER (S) - OLTC / DE-ENERGIZED TAP – CHANGER - DETC

OLTC shall be fitted for all transformers of rating ≥ 5 MVA. Transformers of rating < 10 MVA, ≥ 5 MVA maybe fitted with OLTC or DETC as specified. Transformers of rating < 5 MVA maybe fitted with DETC as specified.

The tape changers shall be capable of carrying the same over currents due to short circuit as the windings.

Shall be suitable for Cover Mounting or Yoke-mounting

20.1 General

The OLTC shall be non-vacuum type equipped with diverter switch and tap selector of high speed spring operated with double resistor transition impedance, flag cycle sequence of operation based on Dr. Jensen principle. The diverter switch shall extinct arc at the first current zero. The mounting of OLTC and DETC shall be in the high-voltage regulating winding. Maximum effective number of turns shall be in switch position 1.

The diverter switch shall have its own compartment separate from the rest of the transformer and shall be provided with oil filter.

The tap selector mounted beneath the diverter switch

The ON-LOAD TAP-CHANGER operating to selector switch principle where the tap-selector and diverter switch function are combined together in one and housed in one compartment is not acceptable.

Type UBB and UZ of M/s ABB and type V, A and H of M/s MR shall not be used.

Reactance type of OLTCs and vacuum interrupter type OLTCs shall not be used.

The OLTC shall be mounted vertically inside the transformer suspended from transformer cover or mounted on yoke clamps.

The manufacturer/Contractor shall obtain approval of COMPANY for the type of on-load tap – changer/De-Energized tap changers, foreseen to be used.

Vacuum interrupter type shall not be used.
The diverter switch cylinder shall be of glass reinforced plastic.

The selector switch contacts temperature-rise over the surrounding oil shall not exceed 20K with current of 1.6 times the maximum rated through current at lowest tap.

De-Energized tap-changer and ON-Load tap-changers shall be of MR or ABB make.

The tap-changer shall be in accordance with IEC 60214: On-load tap-changers.

Details of special features associated with tap-changers required on transformers for use on networks with different nominal voltages are given in the relevant Technical details – layout A and B.

It is recommend, that selection and type of OLTC taking electrical stresses across regulating winding to be referred to OLTC manufacturer for approval. M/S, MR and M/S, ABB are equipped and providing free service for this.

**Tie-In Resistor**

Where the service voltages and the winding capacitances are such that the potential of the tapped winding requires limitation by means of a tie in resistor connected between the diverter switch and the mid tap of the tap selector, it shall be brought to the notice of COMPANY-Engineer and approval may be taken. The location of tie-in resistor shall be clearly marked on tap-changer drawing. Tap changer for cover mounting or yoke mounting to be clearly stated.

The OLTC selector and diverter switch shall be so designed that no form of surge control device such as non-linear resistors or spark-gap shall be used.

- Drilling template for top flange shall be supplied for first installation of transformer.
- Diverter lifting arrangement fixing pads shall be welded on top of cover.
- Diverter lifting arrangement shall be supplied with each ON-load tap changer.

**20.2 Performance**

The through current rating of OLTC and DETC shall be ≥1.6 times the rated capacity of transformer, at the lowest tap. The minimum current rating shall ≥ 200A

The tap changer shall be capable of carrying the same short circuit-current as the winding.

The contact temperature rise over the surrounding of oil shall not exceed 20K.

The tapping range, ratios, the number of steps, tap positions and nominal current rating shall be in accordance with technical data sheets layout A & B.

OLTC shall have over-current blocking device incorporated.

Transient voltage oscillations across the regulating winding at extreme minus tap, principal tap and extreme plus tap shall be calculated, simulated or measured. The highest voltage shall be one of the
important bases in deciding the insulation level of tap changer. Where the values specified by COMPANY are lower, the BIL of OLTC shall be increased to meet these over voltage under intimation to COMPANY.

Minimum BIL foreseen for terminal voltages and the corresponding OLTC and DETC:

For Line Terminal voltage BIL for OLTC and DETC
- Um = 420 kV LI 750 kVp, PF 325 kV
- Um = 245 kV LI 650 kVp, PF 275 kV
- Um = 145 kV LI 650 kVp, PF 275 kV
- Um = 123 kV LI 550 kVp, PF 230 kV
- Um = 52 kV LI 250 kVp, PF 95 kV
- Um ≤ 36 kV LI 200 kVp, PF 70 kV

The minimum voltage class and BIL for OLTC, Um= 72.5 kV, LI 325kVp, PF 140kV and rated through current (minimum) 400A.

The minimum voltage class and BIL for DETC, Um= 36 kV, LI 200kVp, PF 70kV and rated through current (minimum) 200A.

20.3 Tap-changer Enclosure

OLTC

The tap-changer diverter switch shall be housed in its own oil-tight and vacuum proof epoxy impregnated fiberglass cylindrical compartment, connected to a separate compartment of the conservator tank.

20.4 Rated Withstand Voltages of the Internal Insulation

The following power frequency and or impulse withstand voltage values should be stated and submitted to COMPANY, based on voltage class, connection of the relevant windings, the tapping range, the type of winding construction etc. A check shall be made to determine whether the highest stress on the tap selector does not exceed the related withstand voltages. See Annex F.

\[a_0 = \text{Between selected and preselected tapping on the diverter switch and tap selector. Lightning impulse withstand voltage stress on } a_0 \text{ in mid-position.}\]

\[a_1 = \text{Between tap selector contacts of the winding of one tap position (connected or not connected).}\]

\[a = \text{Between beginning and end of a tapped winding and also with coarse winding, between beginning and end of a coarse winding.}\]

Note for coarse tapping arrangement in (-) – position of the change-over selector:

When stressed with impulse voltage, the permissible withstand voltage "a" must be adhered to between the end of a coarse tap winding connected with the K tap selector contact and the tap selector contact at the end of the tapped winding of the same phase.

\[b = \text{Between the tap selector contacts of different phases and between change-over selector contacts of different phases, which are connected with the beginning/end of a tapped winding or with a tap selector contact.}\]
f = Between diverter switch terminal and ground.

Additional for coarse tapping arrangement in (+) – position of the changer-over selector:

c1 = From one (-) – change-over selector contact to terminal of the same phase.
c2 = Between (-) – change-over selector contacts of different phases.

20.5 Drive Mechanism

OLTC

The tap-changer shall be driven by a motor operated mechanism incorporating a stored energy device, which shall ensure that once a change of tap begins it is completed and so shall ensure that the mechanism does not fail in an intermediate position on loss of the supply voltage to the motor.

The motor drive control shall be such that on initiation of a tap-change operation by means of a control switch or push-button, the tap-changer shall complete its movement from one service position to an adjacent one irrespective of whether or not the control switch or push-button has been operated continuously during the running time of the motor drive.

Another operation shall only be possible when the control switch or push-button has been released and the control system is again in the rest position.

Three phase, 60 Hz motor shall be used. DC motor is not acceptable. The motor and control gear shall be supplied from the low-tension system as specified in technical details layout A & B and shall operate satisfactorily at any voltage between 85% and 110% of rated voltage.

Limit switches shall be provided to prevent over-running of the tap-change mechanism. These shall be directly connected in the motor circuit. In addition mechanical end stops shall be fitted to prevent over-running of the mechanism under any conditions.

The tap-changing arrangement shall be such that increasing the tap numbers shall result in increasing the L.V. voltage with constant voltage applied to the H.V. winding.

20.6 On Load Tap-Changer Control And Indication

20.6.1 General

Each power transformer shall be supplied with a tap-changer mechanism box containing all control equipment associated with the on-load tap-changer.

A control cabinet for each transformer shall be provided and located in the relay room. The following facilities shall be provided in each control cabinet:

(a) Manual or automatic raise/lower operation of tap-changer, independently or in parallel with other transformers in master-follower mode.

(b) Tap position indication.

(c) Automatic voltage regulation equipment.
(d) Cooler operation indication.

(e) Marshalling of alarm and trip signals from transformer.

The Transformer/Reactor Contractor shall liaise with the Switchgear/Civil Works Contractor to ensure co-ordination of design, programming and execution of work at this interface point.

20.6.2 Local Control and Indication

The tap-changer mechanism box installed at the transformer shall contain all the electrical and mechanical parts associated locally with control of the tap-changer.

A remote/local switch shall be provided at the mechanism box to select either remote or local operation. When this switch is turned to the “Remote” position, control shall be passed to the control cabinet in the Control room.

The control shall follow the step-by-step principle.

The following controls shall be provided in the mechanism box:

(1) Facilities for electrical ‘raise’ and ‘lower’ operation by control switch or push-buttons.

(2) Facilities for manual mechanical operation of the tap changer.

(3) An interlock, which will interrupt the electrical supply to the drive motor when the manual operation device is engaged.

Protection relays, located in the control cabinet, shall operate a contactor in the mechanism box to prevent a ‘raise’ operation if the transformer voltage exceeds a set value.

A mechanical tap position indicator shall be provided. This shall be visible through a window on the front of the mechanism box to a person standing at ground level.

Position transmitters shall be provided to:

(1) Signal tap position to the control cabinet in the control room.

(2) Signal tap position to a System Control Centre.

(3) Signal ‘out of step’ under parallel operating conditions to the control cabinet in the control room.

20.6.3 Tap-Changer Mechanism Box

The mechanism box shall have a hinged door and shall be mounted on the transformer tank using anti-vibration mountings the tap-changer mechanism box shall be sealed to IP55. The motor drive mechanism box shall contain all mechanical and electrical control devices.

Shall be mounted at 1.5m above base level of tank.

An internal lamp controlled by a door switch shall be provided.
The door shall be lockable by the Employer’s standard padlock.

About 10% spare terminals shall be provided in each mechanism box. Provision to be made for cables to enter mechanism box through bottom panel only.

A LV/AC 16A socket for local use shall be provided.

The mechanism box shall be protected by a sunshield.

20.6.4 **Test On On-Load Tap-Changer**

**Operation Test:**

a. Eight complete cycles of operation with Trafo. in un-energized condition. (A cycle of operation goes from one end of the tapping range to the other and back again).

b. One complete cycle of operation with the auxiliary voltage reduced to 85% of its rated value.

c. One complete cycle of operation with Trafo. energized at rated voltage and frequency.

d. Ten tap-changer operations across the range of two steps on each side from where a coarse or reversing change-over selector operates.

The operation to be carried out at tap current of 1.3 / 1.5pu load, depending upon the over-load specified for the Transformer.

This test may be carried out at the time of over-load temperature rise test on unit undergoing this test or during impedance measurement at 1.3/1.5pu load current.

20.6.5 **De-Energized Tap-Changer (DETC) and Drive Mechanism**

The tap changer shall be cylindrical type, designed in accordance with IEC: 60214-1. It shall be compact, robust, made of Rod and bar material exclusively from glass - fiber reinforced, Plastic (GFRP). Contact assembly of optimized field design by smooth surfaces and rounded edges. It shall be suitable for installation vertically below the cover in the tank.

DETC of horizontal mounted bar-type with sliding movement of contacts is not acceptable.

Type shall be:

1. Type: 3 Phase.

2. Rated through current ≥ 1.6 In, but minimum rated through current In≥ 200A.

3. Minimum High Voltage for equipment Um = 36 kV.

   Corresponding BIL = 200 kVp / 70 KV.

4. Buck and boost DETC tap-changer with separate regulating winding for transformers ≥ 1.2 MVA.
5. Safety devices: Electrical locking by cam – operated switch, lock-in shall occur after 1/12 actuating distance.

Contact: 1NO and 1NC Contact with common lock-in action switching of capacity AC: 250 V 8A.

Drive:

The drives sets the DETC tap-changer to the required operating position.

Types of drive:

1- Manual Drive with Mechanical locking for Transformers of rating ≥5.0 MVA.

2- Motor Drive with Mechanical locking for transformer rating ≥ 10 MVA.

Drive for item (1) & (2) shall be mounted at 1.5 m above base level of tank.

The driving assembly shall be the mechanical coupling between the drive and tap-changer. The Bevel gear shall be inside the weatherproof housing connecting the vertical shaft from the drive to the horizontal shaft, going to the driving unit of the tap-changer mounted on top of lid. All parts of driving arrangement shall be made of stainless steel.

It shall consist of:

- Bevel gear to connect horizontal shaft to the vertical driving shaft.
- Mechanical position indicator.
- Mechanical end stops.

Where required a mechanically operated micro switch to be connected to the release circuit of the circuit breaker of transformer. If the transformer is not switched off, the micro switch shall operate immediately after starting the rotation of the hand crank and release the circuit breaker.

The micro switch shall operate immediately after starting rotation of the hand crank and release the circuit breaker.

The drive mechanism housing shall be of degree of protection IP54 and mounted at 1.5m above base level of tank.

Operation test:

Eight complete cycles of operation with transformer in un-energized condition. (A cycle of operation goes one end of the tapping to the other and back again).
21.1 General

The tank shall be designed and manufactured to withstand minimum acceleration of at least (3g) in longitudinal i.e. in direction of movement of consignment, (2g) in lateral (side to side) direction and (2g) in vertical direction in addition to the acceleration due to gravity. The manufacturer shall demonstrate compliance by means of calculation.

Tank stress Analysis preferably with FEM method shall be submitted.

The transformer shall be skid mounted.

All fasteners shall be stainless steel.

Bell type of tank shall not be used.

HV, LV and MV Bushing shall be mounted on tank cover (lid) not on tank walls.

Hand holes and manholes shall be provided in suitable locations to afford access to tap changing mechanisms, terminal boards, current transformers and the lower ends of all bushing and connections.

Internal pockets, where gas can collect, shall have a collar extending down into the oil so that only that gas which is evolved vertically below the collar is trapped by the collar. All such pockets shall be piped to the gas detector relay which shall be provided with bleed devices for venting trapped air or gas. Gas collection points which cannot be piped to the gas detector relay, such as the pressure relief vent pipe, and the spaces between bushing draw leads and bushing central tubes, shall be provided with deflections to prevent gas from entering such points. Active part (Core and windings) shall not be fixed to lid. By removing lid it shall be possible to have full accesses to the active part and leads.

The thickness of bottom plate of tank shall be ≥ 12 mm for all transformer upto 50MVA and ≥ 20 mm for Trafo. above 50 MVA.

21.2 Tank Shielding:

Transformer having current in leads or bushing in excess of 2500A shall have to shield the tank from the magnetic flux due to the high current. Flux shunts, conducting screens, or special tank walls construction shall be made to mitigate tank over – heating. The solution implemented has to be informed to COMPANY. Flux density in shield shall not exceed 1.4 Tesla.

Transformers shall have the tank cover bolted and gasket or welded to the main tank.

Tank covers shall be provided with lifting lugs to facilitate removal.

Four jacking steps shall be provided off-set outwards from the skid centre lines and shall have a minimum height of 300 mm. Each jacking step shall have a capacity for lifting one-half the weight of the completely assembled transformer filled with oil.
Drain holes shall be provided in all box stiffeners.

Lifting facilities shall be provided for lifting the completely assembled transformer filled with oil.

21.3 Tank-Vacuum and Pressure Withstand

(a) The tank, conservator and coolers shall be designed to withstand full internal vacuum.
(b) The tank shall be designed for minimum Positive pressure of 1 kgf/cm² for 24 hours.

The Contractor shall state the maximum internal pressures which the main tank and tap-changer diverter switch enclosures are designed to withstand.

If the tap-changer diverter switch enclosure is inside the main tank, it shall be so designed that, in the event of full vacuum being applied in the main tank, no oil can leak from a full diverter switch enclosure.

21.4 Tests On Transformer Tank, Conservator & Accessories

VACUUM WITHSTAND AND DEFLECTION TEST:
Shall be generally in line with CL 11.9 of IEC: 60076 – 1 /2011

Completely assembled tank with its coolers, cable box, conservator and other accessories shall be subjected to full vacuum (< 1 milli bar) when empty for 8 hours and there shall be no leakage. The permanent deflection of flat plates after the vacuum has been released shall not exceed 1 mm.

PRESSURE AND PRESSURE DEFLECTION TEST:
Shall be generally in line with CL 11.10 of IEC: 60076 – 1 /2011

The transformer tank filled with oil including conservator, coolers, cable boxes and other accessories shall be subjected to a pressure of 1.0 kgf/cm² for 12 hours. All mechanical joints to be covered with talc – alcohol mixture. Pressure gauges installed on drain valve and vent pipe connected to dehydrating breathe. The permanent deflection of flat plates after the excess pressure has been released shall not exceed 1 mm. Deformation measured at marked point shall be submitted along with tank drawing.

LEAK TEST (with pressure):
Shall be generally in line with CL 11.8 of IEC: 60076 – 1 /2011

Completely assembled transformer with turrets and all other accessories and fittings as assembled for routine test by filling completely with oil at a pressure corresponding at least normal pressure plus + 50 kpa on top of transformer-Conservator The pressure to be maintained for 24 hours during which time no leakage, or sweating and no permanent deformation of the tank shall occur.

The entire transformer shall be visually inspected for leaks.

21.5 Surface Treatment

The transformer tank and accessories shall be adequately protected against corrosion. The whole of the tank and fittings shall be sand blasted inside and outside to remove all scale and rust before
painting. The surfaces shall be prepared according to DIN ENISO 12944 to a degree of Sa 2½ standard finish.

The inside of the tank shall under coat:

1) One-coat two components epoxy polyamide primer thickness to 70 µm.
2) Mano-component anti-condensate enamel color: white RAL 9010, thickness 120 µm.

The outside of the tank shall be painted gray color RAL 7032. Thickness = 240 µm. External surfaces of the radiator banks shall be hot-dip galvanized and painted grey RAL 7032 and, the procedure for painting shall be in accordance with the manufacturer practice. The inner surface of the radiators shall be coated with the special paint (CELERO4) to elcometer reading of 10 µm. The painting procedure shall be submitted for approval.

The tank top cover shall be painted with Non-Skid paint.

The final film thickness testing shall be performed and recorded by Elcometer Micron Testing.

21.6 Oil Preservation System

Cylindrical conservator with sump of 50 mm and drain valve shall be provided.

For Transformers ≥ 5.0 MVA.

A conservator tank consisting of two/three separate cylindrical compartments one for main tank, one for OLTC, one for cable boxes or bushing turrets where applicable shall be provided.

The size of Conservator for main tank shall be sufficient to accommodate the change in oil volume from the coldest ambient to the highest mean oil temperature experienced when the transformer is loaded to the highest allowed by the provision of over-load specified in CL 8.1 and shall be of sealed type with a separate flexible diaphragm of the air-bag type in compartment. Each compartment shall be provided with a magnetic oil level indicator. The level indication in the main conservator tank shall have two sets of alarm contacts, one for low level and another high level.

The bottom of conservator above lid shall be such as to keep the oil level in Bushing turrets and cable box at least 1 meter pressure of oil. Suitable size valves shall be provided at the conservator to cut off the oil supply from main tank or pipes for turrets or cable boxes.

The conservator shall be vacuum proof and withstand a pressure of 1 kgf/cm².

The oil level gauge contacts shall be wired into the control cabinet. In case diaphragm is broken, oil level gauge shall send an alarm signal.

The diaphragm shall be preferably from Fujikura or Pronal.

In case diaphragm breaks, oil level gauge shall send an alarm signal.
For Transformer ≤ 5.0 MVA:

A conservator tank shall consist of two separate cylindrical compartment, one for main tank, and one for cable boxes or bushing turrets. The conservator shall be free breathing type with prismatic type oil level guage, drain valve NW25, one filling hole R 11/2 with cap.

21.7 Breathers

In accordance to DIN 42562 type L. Each compartment of the conservator tank shall be fitted with an approved Silica-Gel breather for drying the air including air above the diaphragm. The breathers shall be located such that maintenance can be carried out at ground level. The breathers shall be designed to work satisfactorily with high levels of humidity. The connecting pipes from all compartments to breathers shall be provided with leak proof valves.

Dehydration breathes sizes: 0.5 – 1 kg DIN 42567

2 – 3 kg DIN 42562

21.8 Pressure Relief Device with Directional Shield

Pressure relief devices with trip contacts which are set to open on excess pressure and to reseal automatically shall be fitted to the main tank and the tap-changer diverter switch compartment(s). Two numbers shall be provided for main tank on top of tank cover for transformer ≥ 10 MVA, and one number for transformer < 10 MVA.

Qualitrol make pressure relief device with directional shield.

The contacts of these devices shall be wired to file terminals located in the control cabinet.

Operating pressure for main tank pressure relief device 0.85 ± 0.03 kgf/cm² and for diverter switch 0.5 ± 0.03 kgf/cm² or as advised by OLTC manufacturer.

21.9 Oil Sampling Devices

Oil sampling devices shall be fitted for taking oil samples from the top, middle and bottom of the main tank and from the tap-changer diverter oil compartment(s). Size of valve DN15-DIN42568-15.

Sampling points shall be accessible to a person standing at ground level.

One sampling device shall be fitted to bottom connecting pipe of radiator bank on either side of radiator bank, size of valve DN15 for taking oil sample.

Oil sampling valves with suitable adapter to draw oil from main oil stream from return oil circuit of each group of radiators or battery of coolers for DGA analysis.

21.10 Oil Conditioning and Vacuum Processing

The transformer shall be fitted with oil valves and suitable removable flange with adaptors for the connection of oil conditioning equipment.
For Transformer >50 MVA:

Two Stainless steel spherical valves as per EN:1984 with indicator of size DN80 mm, one filter valve for the top and the other diagonally opposite for the bottom oil. Both the valves shall be located at the bottom.

For Transformer <50 MVA:

Two Stainless steel spherical valves as per EN:1984 of size DN50 with indicator shall be fitted to the tank, one for the top and the other diagonally opposite for the bottom. Both the valves shall be located at the bottom.

21.11 Lifting Lugs

Lifting lugs shall be provided for lifting the weight of the transformer including core, windings, fittings and with the tank filled with oil.

21.12 Inspection Holes

Inspection holes of min. size 500 x 500 with covers shall be provided on lid. One inspection manhole of suitable size on the tank against selector switch of OLTC shall be provided. All inspection covers shall be fastened by captive nuts with gaskets.

No Inspection holes are required for transformers ≤ 4.0 MVA.

21.13 Jacking Pads

Four jacking pads shall be provided near the corners to the tank of each transformer and approximately 400 mm above the lowest part of the tank. These pads shall be designed to take the complete weight of the transformer filled with oil. Each pad shall be designed to take 50 % of the total weight.

21.14 Hauling Eyes

Hauling eyes shall be provided on all sides of the transformer.

21.15 Earthing Terminals

Two earthing terminals capable of carrying for 5 seconds the full lower voltage short-circuit current of the transformer shall be provided on the transformer close to each of the four corners of the tank to facilitate easy earthing of the transformer to station ground.

21.16 Oil Valves

All oil valves shall be as per EN:1984 standard and shall be provided with means of securing them in the open and closed positions. They shall clearly indicate whether they are in their open or closed positions.

21.17 Seals and Gaskets

The gasket shall be suitable for transform oil at 120°C. Viton, neoprene, nitrile rubber or Rubberized asbestos shall be used.
21.18 Buchholz And Gas Pressure/Oil Surge Relays

21.18.1 Buchholz Relay

The Buchholz relay shall be in compliance with DIN 425566/EN 50216 size, DN80 for transformer >10 MVA, DN 50 for transformer <10 MVA for main tank. One Buchholz relay BR25 for each and every HV line, HV neutral, LV cable boxes and or for Bushing turrets where applicable. Buchholz relays with hollow floats are not acceptable.

The Buchholz Relay shall be with double element dry reed magnetic operated reed switches. Mercury switches are not acceptable.

Withstand pressure shall be ≥ 2.5 kgf/cm² withstands & full vacuum withstand. Shock resistance class 4M6, impact withstand ≥ 50g for 11 ms, vibration resistance max 35 g (50 – 100 Hz) degree of protection: IP54, Contact setting of switching system shall be provided with two change-over contacts.

Double float Buchholz relay shall be provided in the pipe connection from the main tank, cable boxes, bushing turrets etc. to the oil conservator. The upper float shall operate a contact to give an alarm on accumulation of gases caused by a gradual fault. The lower float shall operate a contact to make a circuit to trip associated circuit breakers on occurrence of a sudden oil flow caused by an explosive development of gases. Buchholz relay manufactured by below mentioned companies shall be used.

EMB Buchholz relay with solid polymethacrylimd floats alone shall be used.

Address M/S Siemens M/s EMB
Bereich : Bachhofstrasse
Energieübertragung und-verteilung : Energietransformatoren
Geschäftsgebiet Leistungstransformatoren : 39179 Barleben/Germany
Katzwanger StraBe 150 Fax: + 49 39203 5330
D-90461 Nürnberg, Germany : E – mail: info@emb-online.de
http://www.ev.siemens.de

21.18.2 Gas Sampling Device

The gas release connection from the Buchholz relay shall be brought down to a gas sampling device which shall be accessible to a person standing at ground level.

Isolating valves shall be provided in both the gas sampling and test connections. These valves shall be accessible to a person standing at ground level.

The gas sampling device shall have the following facilities:

(a) Gas connection from the Buchholz relay through an isolating valve on the gas sampling device

(b) Coupling in the pipe connections to enable the device to be removed from the transformer.
21.18.3 OLTC Oil Surge Relay

A protective relay shall be mounted in the pipe leading from the tap-changer diverter switch oil compartment(s) to the oil conservator where applicable. The relay shall be actuated by an oil flow caused by a diverter switch fault and its contact shall make a circuit to trip associated circuit breakers.

21.18.4 Transformer Oil

The transformer oil shall be in accordance to IEC: 60296 inhibited type super grade. It shall be Naphthenic base oil. Paraffinic base oil is not acceptable.

Either the transformer oil manufactured by M/s. NYNAS NAPHTHENICS AB or transformer oil manufacturer by M/s SHELL type Shell-Diala S4 ZX-I, shall be used.

The oil shall be free from potentially corrosive sulphur and shall meet the requirements in the CCD test in accordance to IEC: 62535 "Test method for detection of potentially corrosive sulphur in used and unused insulating oil". Further it shall have high oxidation stability.

The transformer manufacturer shall submit to COMPANY for approval the test certificate from the transformer oil manufacturer attesting that the oil meet the requirement of CCD test. The test certificate shall be included in maintenance manuals of the transformer.

Further transformer oil manufacturer shall declare that their oils does not contain any undeclared additives

As far as practicable the transformers shall be supplied and shipped with their initial oil filling.

If this is not practicable the transformers shall be supplied and shipped with a filling of dry air/nitrogen. Drained oil shall be delivered in drums in a sufficient quantity to refill the transformers and to replenish losses during subsequent processing at site. Extra 1% of total oil shall be supplied along the transformer.

The physico-chemical analysis of oil shall be performed before first filling. The complete first filling shall be new oil and shall be provided by the manufacturer / Contractor.

### Quality of Transformer Oil before filling in transformer and before testing transformer:

The following tests shall be performed on the processed oil before filling in the transformer and before commencing the transformer testing.

The same tests are to be repeated after all the tests, before energizing during commissioning and six months after loading the transformer.

<table>
<thead>
<tr>
<th>Test</th>
<th>Unit</th>
<th>Test method</th>
<th>Values required</th>
</tr>
</thead>
</table>

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• Break down voltage \(kV\) IEC: 60156 \(> 70\)
• Water content \(mg/ kg\) IEC: 60814 \(< 5\) ppm
• IFT \(mN/m\) ISO 6295 \(> 40\)
• Acidity \(mg \text{kOH/g}\) IEC: 62021 \(< 0.01\)
• Dielectric dissipation factor (DDF) at 90\(^\circ\) C IEC: 60247 \(< 0.001\)
• DGA in accordance to IEC: 61181/2007 Refer CL 23.12.15
• Particulate content, the oil shall filtered to comply with the limitation regarding number and size of particles as defined in CL 23.12.16.

21.19 **Terminations**

The Transformer manufacturer or Contractor shall liaise with the Switchgear/Civil Works Contractor to ensure co-ordination of design, programming and execution of work at this interface point.

The final design of all transformer terminations shall be submitted to the COMPANY Engineer for approval before taking up production.

21.19.1 **General**

Bushing for terminal voltage \(Um = 36\) kV, \(Um = 52\) kV and above shall be Epoxy Resin impregnated, fiber glass or paper or polymeric fabric (Class E) Capacitance graded Bushing, and shall have test tap for measurement of Capacitance and tan delta values of the Bushing. Each and every conductor bushing shall be supplied with test tap-adapter.

The temp. class shall be E (120\(\circ\)C) explosion proof..

However, Bushings for voltage \(Um = 36\) kV, \(Um = 52\) kV up to current rating \(Ir = 8\) kA, may be porcelain insulator, generally in line with DIN 42541 may be used.

The hot temp. limits of metal parts and terminal rod / pipe under 1.6 pu load at lowest tap operating condition shall not exceed 105\(\circ\)C. The temp. connecting joints at the connection of terminal board and out coming leads from winding (under oil) shall not exceed 105\(\circ\)C.

Where condenser Bushings are enclosed in Bus duct or cable boxes, a terminal box corresponding to each Bushing shall be fixed outside Bus duct or cable box to facilitate measurement of capacitance and tan delta of the Bushing. A permanent connection of the test tap on the condenser bushing and terminal box fixed outside bus duct or cable box shall be with test tap adaptor and connection between two shall be by XLPE insulated flexible conductor of 10 kV class

All HV, HV-N, MV, and LV Bushings shall be mounted on the top of tank cover (lid) not on the sidewalls of tanks.

Where bushing are mounted on turrets each, individual terminal terminals for each phase shall have individual turret. Common turret for all phase shall not be used. Each turret shall have individual NW25 buchholz relay piped to the conservator. No pipe connection the radiator bank or unit coolers shall be taken from turrets.
Details of the termination are specified in “performance and guarantee schedule – layout A and B” and Annex A.

Condenser Bushings with tan δ at 30°C higher than 0.4% shall be rejected.

Each and every condenser Bushing shall be supplied with Test tap adapter

The type of HV line terminal entry to HV main winding such as “winding top entry” or “winding mid point entry” shall be stated and shall be shown on connection diagram plate and shall be shown on rating plate.

Mid winding feed-through and winding top entry shall be in accordance to M/s Weidmann’s recommendation

Where connection by SF6 bus duct or cables is specified, the transformer contractor shall liaise with switchgear/civil work’s contractor to ensure co-ordination of design, programming and execution of work at this point.

Material for carrying HV – Leads, tapping leads, LV leads, LV bus bar etc inside the transformer shall be press-board with fiber glass / Nylon bolts and nuts. *Laminated wood shall not be used.* Porcelain insulators of bushings and post – Insulators mounted on the lid shall be coated with minimum 0.5 mm thick coat of RTV silicon liquefied rubber, after installation at site.

The final design of all transformer terminations shall be submitted to COMPANY Engineer for approval before start of production.

### 21.19.2 Bushings For Over Head Line Terminations

Oil to Air bushing terminations shall be epoxy resin, vacuum impregnated paper condenser core with housing of cylindrical porcelain body, color of glaze Brown

Condenser Bushing with tan delta at 30°C higher than 0.4% shall be rejected.

The lower end shields of condenser bushings shall be insulated with wet moulded cellulose material. Shields insulated with only an epoxy coating shall not be accepted.

RAL 8015 to 8017. Porcelain shell shall be in one piece, the test tap for capacitance and power factor measurement with screwed cap for earthing and moisture protection shall be provided. Test tap shall withstand 2 kV, 50 Hz one minute.

The bushing shall be suitable for hot line pressure washing. The porcelain shall be coated with minimum 0.5 mm thick coat of RTV silicon liquefied rubber after installation at site.

A test tap connector in bushing tap adopter suitable for test tap of bushing for measurement of capacitance and tan delta values of bushings shall be provided for each capacitor bushing.

Test certificates with dimensional drawing shall be submitted for approval of COMPANY.
21.19.3 (a) H.V. Cable Terminations (≥ 123 kV Class)

The details of cable as specified in Annex C. The transformer manufacturer shall liaise with cable contractor/cable manufacturer.

The terminations shall conform to the following conditions.

- Separate oil filled housing shall be provided for bottom entry of single core copper conductor cable of type specified in Layout B, for voltage class specified.

- Windings shall be terminated in oil-to-oil transformer bushings of Epoxy resin, vacuum impregnated paper condenser core type, mounted on top cover of transformer tank – lid.

- The lower end shields of condenser bushings shall be insulated with wet moulded cellulose material. Shields insulated with only an epoxy coating shall not be accepted.

- The turret of bushing shall project minimum of 10 mm beyond lid inside tank and shielded to prevent fault gases in the main tank lodging inside turret.

- Condenser Bushing with tan delta at 30°C higher than 0.4% shall be rejected.

- The measuring tap of condenser bushing shall be fixed out side cable box in terminal box to facilitate measurement of capacitance $C_1$ and tan delta $\delta_1$ from the out side. The connection between measuring tap on the bushing and measurement terminal out side cable box shall be with suitable adopter and shielded cable to withstand ≥ 10 kV.

- Oil filled housing and the boxes shall be designed to withstand full vacuum. The cable compartments shall not be in communication with the transformer main tank oil. Oil system shall be maintained by the oil conservator and shall be monitored by Buchholz relays of size DR25 in the pipe line between each cable box and conservator.

- Cable box of each phase shall have individual Buchholz Relay of size DR25.

- The top panel of the cable box housing shall be designed to mount the test bushing for testing. Suitable disconnecting points shall be arranged within the housing to allow separate tests on the winding and on the cables.

- Earthing point for connecting transformer bushing to ground during cable testing at the site shall be provided.

- The exact type and size of cable and number of cables per phase and number of core per cable will be specified in Layout B.

- The dimensions of the connection enclosure shall comply with IEC: 60859.

- The cable box shall be suitable for installation of cable sealing terminations.

- The cable box shall include provision in enclosure for connection of surge arrester.

- Provision to mount SF6 enclosed MO surge arrester, either vertically top or vertically bottom shall be provided.

- Corona free connections between surge arresters and HV bushings or HV lead shall be provided by interface oil to SF6 condenser Bushing.
For detail specification, Refer to Metal enclosed SF6 Insulated MO. Surge arrestors and Porcelain MO. Surge arrestors No. SEC- GP - 004 

Dimensional drawing shall be submitted for perusal and approval of COMPANY.

21.19.4 **(b) HV/LV Cable Terminations (≤ 52 kV Class)**

- Air insulated cable box suitable for Bottom entry of XLPE cables, with moisture & dust proof cable glands shall be provided.
- The cable shall be connected to bus-bars connected to bushings. The bus bar shall be supported by Post – Insulators conforming to DIN 43632 type FSR 10 …… 30.
- The cables shall be connected to bus bars that are connected to bushings. The bus bars shall be connected to Bushing by copper flexible connection pieces. The current density in bus bars ≤ 1 amp/mm².
- The measuring tap of condenser bushing shall be fixed out side cable box in terminal box to facilitate measurement of capacitance C1 and tan delta δ1 from the out side of cable boxes.
- The connection between measuring tap on the bushing and measurement tap in terminal box of cable box shall be with suitable adopter and shielded cable to withstand ≥ 10 kV.

Dimensional drawing for cable boxes shall be submitted for approval of COMPANY.

21.19.5 **Gas Insulated Bus Duct Connection**

**Terminations:**

The connection between the transformer and the switchgear shall be phase isolated SF6 insulated bus duct. The termination shall conform to IEC: 60517 & IEC: 62271-211 and shall be as follows:

- The windings shall be terminated in oil to SF6, Epoxy resin, vacuum impregnated paper condenser core type bushings mounted on top cover of transformer tank (lid) with a short length of GIS ducting per phase. The GIS ducting shall have a flange for connection to switchgear and shall be sealed for transport.
- The connection between bushing flange and bus-duct flange shall be by means of stainless steel bellow.
- The measuring tap of condenser bushing shall be fixed out side bus duct in terminal box to facilitate measurement of capacitance C1 and tan delta δ1 from the out side of bus-duct. The connection between measuring tap on the bushing and measurement tap in terminal box cable box shall be with suitable adopter and shielded cable of 10 kV class.
- The lower end shields of condenser bushings shall be insulated with wet moulded cellulose material. Shields insulated with only an epoxy coating shall not be accepted.
- Condenser Bushing with tan delta at 30°C higher than 4.0% shall be rejected.
- Oil to SF6 Bushing of type GOEK of M/s. ABB shall not be used.
Where oil to SF6 Bushings are mounted on Bushing turrets, the connection between the turret and conservator shall be through individual Buchholz Relays of size DR 25 through pipe of size NW 25.

Provision shall be made in the GIS ducts for installation of test bushing for testing the transformer windings.

The flange drilling and the position of each bus duct shall be agreed with the GIS supplier.

The bus duct shall include provision in enclosure for connection of GIS enclosed surge arrester either vertically top or vertically bottom mounting.

For detail specification. Refer to metal enclosed SF6 insulated M.O. surge arresters and porcelain M.O. surge arresters No. SEC-GP-004.

Corona free connection between surge arrester and HV bushing shall be provided with an interface RIP bushing SF6 to SF6 type.

The transformer bushing enclosure and bus bar enclosure and surge arrest enclosures shall be of cast or welded aluminum alloy, designed to comply with European pressure vessel codes (CENELEC).

A compensation joint such as stain less steel bellow shall be mounted over lid or bushing turret required to guarantee the necessary flexibility required for assembling at site.

A removable link shall be provided to isolated GIS from transformer for GIS dielectric test.

To isolate the circulating currents in the SF6 bus duct, from the ones circulating in the transformer tank, an isolating ring shall be provided by the transformer manufacturer on the busing flange on the compensation joint.

Test certificate giving all the parameter shall be supplied.

Dimensional drawing shall be submitted for perusal and approval of COMPANY.

21.19.6 HV Neutral Termination (≤ 145 kV Class)

The HV, neutral bushing shall be of insulation levels specified in CL 12.0 and layout A & B.

The bushing shall be oil to oil epoxy resin impregnated paper insulated condenser bushing mounted on top of tank cover enclosed in oil filled cable box. The BIL and current rating as given in layout A & B.

- Condenser Bushing with tan delta at 30°C higher than 4.0% shall be rejected.
- The current rating of neutral bushing shall be same as line terminals
- The lower end shields of condenser bushings shall be insulated with wet moulded cellulose material. Shields insulated with only an epoxy coating shall not be accepted.

The measuring tap of condenser bushing shall be fixed out side cable box in terminal box to facilitate measurement of capacitance C1 and tan delta δ1 from the out side of the cable box. The connection between measuring tap on the bushing and measurement terminal in terminal box shall be with suitable adopter and shielded cable to withstand ≥ 10 kV.

Dimensioning of neutral connection:
The neutral conductor and terminal of transformer shall be rated for the current same as line terminal and voltage class and BIL as specified in CL 12.0 and Layout A&B.

Separate entry of single core copper conductor cable with its cable-sealing end. The cable shall be connected to station ground. Oil filled housing and cable box shall be designed to withstand full vacuum.

Pipe connection between neutral cable box and conservator apartment for bushings shall be provided with Buchholz relay size DN25 as per DIN 42566.

A two core CT for restricted earth fault protection with parameter specified in protection and metering drawing shall be provided. The CT shall be epoxy molded with internal diameter suitable for passing through above-mentioned neutral cable.

The CT shall be housed in detachable box to be fixed to transformer tank. The CT box shall have terminal box for terminating secondary terminals of CT through 1.1 kV Bushings. The terminal box shall be weather proof with protection class IP55.

The terminal box of CT shall be provided with double compression dust and moisture proof cable gland for bottom entry of control cables to secondary terminals of CT from terminal Blocks in OLTC motor drive or control cubical. The terminal box shall have provisions for earthing one terminal of CT secondaries.

21.19.7 LV Winding Termination (LV, LV1, & LV2) ≤ 52 KV

The bushings shall be outdoor type as specified in layout A & B. The current rating shall be as stated in layout A & B. For current rating up to 8 KA, it may be condenser type or of porcelain insulator, generally in line with DIN 42541 standard. For current rating above 8 kA it shall be R I P capacitor bushings. The current rating of bushings enclosed in bus duct shall be calculated taking bus duct temperature of 80°C and top oil temperature of 100°C at an overload of 1.5p.u. The temperature rise shall not exceed 20k above top-oil at an overload current. The current rating calculation with current carrying capacities curves as supplied by bushing manufacturer shall be submitted for approval of COMPANY.

The minimum rated through current shall be more than 1.6 In rated current of transformer but not less than 630A. All bushing HV & LV shall be arranged on the top of the cover.

The bushing shall be with porcelain insulator on air side.

- Cree page distance ≥ 31 mm /kV
- Tap terminal in copper (silver Deleted)
- Bottom terminal in copper (Silver plated)
- Flange in Aluminum alloy
- Shall have air vent screw
- Test Tap
Strong magnetic fields caused by high circulating currents in isolated phase bus ducts, in transformer tanks and in covers and leads result in excessive temperature. Corrective measures such as use of anti magnetic steel shall be used in the design. The lid (tank cover) where the LV bushings are fixed shall be of anti-magnetic steel to avoid heating due to circulating eddy currents.

The capacitor bushings shall be of epoxy resin impregnated paper bushing conforming to IEC: 60137. The measuring tap of condenser bushing shall be fixed out side cable box in terminal box to facilitate measurement of capacitance CI and tan delta δ1 from the out side of cable box. The connection between measuring tap on the bushing and measuring terminal in terminal box shall be with suitable adopter and shielded cable to withstand ≥ 10 kV.

The current density in the flexible connection between winding lead and bushing terminal rod, shall not exceed 1A/mm² in air and 2A/mm² in oil on transformer side. The bushings of each LV1 and LV2 shall be enclosed in detachable terminal boxes suitable for bus duct or for bottom entry of suitable size single core XLPE cables and connected bus bars fixed to post insulators and connected through flexible connection to bushing terminals. The current density in bus-bars ≤ 1 amp/mm². For flanged connections to bus duct, a drain line shall be provided at the lowest point of each flange to remove any water accumulation. The drain line shall have a spring-loaded shut-off valve location near the base of the transformer.

The lead to be connected to line terminal or neutral terminal is to be brought and connected to bushing terminals Through flexible connections’ at the oil end by bolted joints, locked with spring washers or any other method. The bolt and nuts shall be stainless steel of grade 8.8.

Condenser bushings with tan delta at 30°C higher than 0.4 % shall be rejected.

Dimensional LV connection drawing shall be submitted for perusal and approval of COMPANY.

21.19.8 Delta Connection Of The LV Windings (< 52 kV)

Delta connection shall be formed internally. The top lead and bottom lead of windings are to be brought to the oil end of Bushing terminals and are connected in series to form a closed circuit of Delta. The joint shall be by stainless steel bolts and nuts, locked with spring washers or center punching or any other method.

The contact surfaces between flexible connections and bushing terminal shall be silver plated.

The lid (tank cover) where the LV bushings are fixed shall be of anti magnetic steel to avoid heating due to circulating eddy currents.

Dimensional LV connection drawing shall be submitted for approval of COMPANY.

21.19.9 Bushings Turrets

Each bushing turret, where used shall have individual Buchholz Relay of size DN 25 connected to conservator through DN 25 size pipe to cable box conservator apartment. The Buchholz relay for bushings turrets shall be of size DN 25 as per DIN 42566.
The turrets of bushing shall project minimum 10 mm beyond surface of lid inside tank to prevent collection of gases evolved in the tank due to fault, collection in turret.

Where CT are mounted in the bushing turrets, the terminals of CTs shall be brought-out through Turrets to terminal boxes fixed on Turrets. Running of control wiring inside the tank or under lid is not acceptable.

21.19.10 Terminal Markings

The terminal markings shall be clearly and permanently shown. Painted markings are not acceptable. The terminals shall be labeled in accordance with IEC: 60616.

Bushing clearances shall be in accordance to IEC:60076-3 table as given below:

<table>
<thead>
<tr>
<th>Highest Voltage for Equipment Um KV</th>
<th>Full wave Lightning Impulse (LI) KV</th>
<th>Minimum air clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>125</td>
<td>265</td>
</tr>
<tr>
<td>36</td>
<td>200</td>
<td>460</td>
</tr>
<tr>
<td>52</td>
<td>250</td>
<td>580</td>
</tr>
<tr>
<td>123</td>
<td>550</td>
<td>1325</td>
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<tr>
<td>145</td>
<td>650</td>
<td>1570</td>
</tr>
<tr>
<td>245</td>
<td>1050</td>
<td>2290</td>
</tr>
<tr>
<td>420</td>
<td>1425</td>
<td>3735</td>
</tr>
</tbody>
</table>

21.20 Labels, Rating Plates & Connection Diagram Plates

The rating plate and connection diagram plate shall be stainless steel material located and fixed at a height of 1.5m from platform level. The entries on the plates shall be indelibly engraved and marked.

21.20.1 Labels

All labels shall comply with the requirements of the relevant clause in the Section: GENERAL REQUIREMENTS and shall be in Arabic and in English.

21.20.2 (a) Rating Plate(s)

The rating plate(s) shall be stainless steel and shall have, in addition to those items specified in IEC: 60076-1 /2011 clause 8.2, the following shall be include.

- Transformer oil: Manufacturer/type designation/inhibited/non inhibited.
- Identification of: ON-LOAD TAP-CHANGER/DE-ENERGIZED TAP-CHANGER
- Technical details of tap changers and designation.
- Name of Tap changer manufacturer
- Design ambient temperature.
• Top oil temperature rise measured value.
• Winding temperature rise measured values.
• Hot spot temperature of each winding measured values.
• Nominal rated voltage.
• Highest voltage for equipment (Um) for each winding – line end and neutral end.
• Insulation level of each line terminal and neutrals.
• The rating plate should read:
  ▪ HV → Um/SIL/LIL/LICL/ACL.
  ▪ HVN → Um/LIL/ACL.
  ▪ MV → Um/ SIL/LIL/LICL/ACL.
  ▪ LV → Um/ SIL/LIL/LICL/ACL.
• Over-loading: 1.3/1.5p.u. for 4 hours with preceding continuous load of 1.0p.u.
• Short-circuit withstandability in KA of each winding and time as stated in layout A & B.
• Type of core 3+0 or 3+2.

21.20.3 Connection Diagram Plate

• Shall show Location and disposition of windings with respect to core.
• It shall show the internal connection and voltage vector relationship of the several windings in accordance to IEC: 60076, in addition, a plan view of the transformer giving the correct physical disposition of the terminals.
• A table stating tapping voltage for all tappings, Current, short-circuit impedance values for the principal tapping and the extreme tapings (preferably in ohms per phase referred to a specific winding) shall be given.
• Location and technical details of all current transformers shall be given.

21.20.4 (a) Locations of Valves and Air Release Cocks

A plate showing the locations and normal positions of all valves and air release cocks or plugs shall be provided. This plate shall incorporate a warning to operators to refer to the Maintenance Instructions before applying vacuum treatment to the tank.

A separate plate showing the application and position of valves at the conservator during vacuuming to be included.

(b) Circuit Diagram Plate

Plate showing the control, Measuring and monitoring circuits and terminal blocks. These plates shall be located in control cubical or motor drive cubical.

21.20.5 Direction of Rotation

The direction of rotation of operating handles and motors shall be clearly marked
21.20.6 **Roller**

Track wheels with roller bearing in accordance to DIN 42561.

21.21 **Control and Auxiliary Equipment**

All control and auxiliary equipment in the control kiosk and in the tap-changer mechanism box shall be clearly labeled.

The control cable shall be of XLPE copper cable suitable for voltage class 1.1 kV. The mini size for equipment connection > 2.5 mm²

The mini size for CTS connection > 2x4 mm²

- Fans ≥ 4x2.5 mm²
- Pressure relief Device 7x2.5 mm²
- Oil level indicator 7x2.5 mm²
- Buchholz Relay 7x2.5 mm²

21.21.1 **Auxiliary Supplies**

The low voltage AC 3-phase 60 Hz supply voltage will be as given in layout A&B.

This system shall be used for all pumps motors, fan motors, tap-change motors, anti-condensation heaters and lighting.

The DC supply voltage will be 125 Volts for all trip circuits and associated relays.

21.22 **Installation**

The installation shall be done by the manufacturer generally in line with guidance of IEC: 61936-1 (2002-10).

Installation by sub-contractor without approval of COMPANY is not acceptable.

Where sub-contractor for installation is proposed by the manufacturer/contractor the subcontractor shall undergo Technical evaluation by COMPANY Generation dept for qualification to carry out installation

21.22.1 **Transportation and Erection**

Dew point measurement to control surface moisture re-absorption during transport shall be provided. The values shall be recorded with concurrence of COMPANY and action taken recorded. The manufacturers’ instructions for the dew point measurement shall be followed.

**Transport Acceleration:**

The transformer shall be designed and manufactured to withstand the following acceleration:
Lateral (x) side to side……2 G.

Longitudinal (y)……………… 3 G.

Vertical (z) up and down…2 G. (in addition to the acceleration due to gravity).

The manufacture shall demonstrate compliance by means of calculations.

If value higher than above is recorded, it requires discussion between the manufacturer / contractor and COMPANY. It may require through investigation.

Three way impact recorders with weatherproof container, one mechanical type and one electronic type shall be fixed on top of transformer before dispatch. Recorders shall measure and permanently record in terms of G for period of journey and till the time of installation on foundation, the magnitude, time of impact and vibration on three axis: vertical, lateral, longitudinal. Record shall be directly in terms of G and shall indicate not only from which axis the force occurred but also from which direction on the axis, left side or right side, front or back, and top and bottom (acceleration and deceleration). The electric chart drive mechanism shall record magnitude, time of occurrence of all in transit impacts and vibration as well as the total running and down time of each trip within an accuracy of 0.5 second per day.

The Contract includes transport to site, and commissioning.

The transport to site and erection shall be carried out by the Contractor's skilled staff approved by COMPANY Engineer. Where sub-contractors are hired, Technical evaluation will be done by COMPANY before it is approved by Engineer.

The requirement of DIN VDE 0100, 0101 and 0108 must be observed for the installation and connection of transformer.

The Contractor shall fully inform himself of all the requirements and available facilities in regard to transportation, route planning, loading/unloading, etc.

All transport accessories, e.g. riding lugs, jacking pads, blanking off plates, etc. shall become the property of the COMPANY.

Any specialized erection equipment such as oil conditioning plant, including power supplies, shall be provided by the Transformer/Reactor Contractor.

At the time of receiving the transformer at site, the following to be inspected:

- The way in which the transformer has been secured on the trailer.
- That the delivery is complete according to order confirmation.
- Compare the packing list with the goods received.
- The transformer nameplate.
- External damage e.g. cracks in bushings.
- Impact recorders indications and records.
21.22.2 **Foundations**

The transformer shall be installed on concrete foundation surrounded by oil containment basin.

The Following is recommended brief of the containment.

Each containment basin shall be a concrete, liquid tight, open topped basin like structure which completely surrounds the transformer for which containment is provided. The structure shall be below grade with only a 200 mm high concrete curb projecting above the surrounding finished grade. The space within the basin shall be filled to the level of the adjacent finished grade with a free draining crushed or washed stone having 50 mm maximum and 30 mm minimum size aggregate, and at least 40% voids for the in-place installation.

Each basin shall be sized to provide containment volume within the 40% void spaces of the stone fill equal to at least 150% of the entire volume of oil required for the transformer (including allowance for fire protection water flows) with the surface of the oil rising no higher than 150 mm below the surface of the stones. The basin shall be sloped to sump (or sumps) provided with a capped, vertical, perforated pipe stubbed to 1.0 m above finished grade to allow installation of portable sump pumps when complete drainage of the basin is required.

It shall be the responsibility of the Transformer/Reactor Contractor to submit the foundation drawing, duly stamped to show his approval of the design, to the Engineer for approval.

21.22.3 **Bushings and Post-Insulators**

Bushings shall confirm to IEC: 60137. The condenser bushings shall be Epoxy resin impregnated paper insulted condenser core. The bushings for 52 kV and up to 8 kA class and less may be porcelain bushings generally in accordance to DIN 42541. Outdoor post insulators as per DIN 43632 type FSR 10…..30.

The condenser bushings shall be epoxy resin impregnated paper type. OIP bushings are not acceptable.

The minimum current rating shall not be less than 1.6xIn at temperature 80ºC and 90 ºC top oil temperature, the hot spot temp. of terminal bolt shall not be exceed 105ºC. The BIL as indicated in layout A & B.

Calculation of current rating with reference to Bushing manufacturers rating curves shall be submitted.

The current densities in leads, connected to lower oil end shall not exceed 2A/mm² at lowest tap. The top terminal and leads current density shall not exceed 1A/mm². The test tap of condenser bushings type oil to oil and oil to SF6 shall be brought out side the enclosed box and terminal enclosed in suitable terminal box to IP55. Test adopter for each type of condenser bushing shall be supplied for the purpose of testing.
Bushings from India and China are not acceptable.

Bushings from M/s PASSONI VILLA shall not be used. Oil to SF6 condenser bushing of type GOEK of M/s ABB shall not be used. Capacitor bushings from any of the following manufacturer shall be used HSP, ABB MICAFL (Switzerland), NGK, HAEFLY, MICAFL and TRENCH (France)

The following curves for bushings shall be submitted.

- Percent of rated operating voltage V/S power factor – percent.
- Temperature – degree centigrade V/S power factor – percent.
- Capacitance V/S voltage (CP) ---- C1 and C2
- Tan Delta V/S voltage ---- Tan δ1 and tan δ2
- Current rating at hot-spot temperature of ≤ 105°C.

The porcelain insulators of bushings (HV, MV and LV) and epoxy post insulators shall be coated with minimum 0.5 mm thick coat of RTV silicon liquefied rubber after installation at site.

Condenser bushings with power factor tan δ1 higher than 0.4% measured at 30° C shall not be used and shall be rejected.

21.22.4 Anti-Vibration Pads

In cases where transformer foundations form part of, and are close to buildings, the transformers shall rest on approved anti-vibration supports to avoid transmission of vibration. The design of these supports shall be subject to approval by Engineer.

22 DESIGN, MANUFACTURING, PROCESSES, QUALITY CONTROL, TESTING AND PERFORMANCE REVIEW

22.1 General

A design review (DR) is required to ensure there is a common understanding of the standards and COMPANY specification requirements and to provide an opportunity to scrutinize the design to ensure the requirements will be meet.

It is an in depth review and examination of an existing design for the purpose of compliance with system requirements, COMPANY specification, detection and remedy of deficiencies in the requirements and the design which could affect reliability, performance, maintain- ability performance, maintenance, support performance requirements, fitness for the purpose and identification of potential improvements.

The manufacturer shall also define the actual performance characteristics of the transformer to demonstrate that it meets or exceed these requirements.

DR may normally be held at the manufacturer's plant which allows for direct access to the manufacturer's design, testing, production, quality control personnel.
The information accompanied by calculation with formulas and simulations shall be submitted before and after DR meeting, but before finalizing design and proceeding with the manufacture for the perusal of COMPANY.

The discussions and information's exchanged during design Review process will be kept confidential.

22.2 **Design Review (DR)**

The selected supplier shall be required to undergo Design Review before finalizing the design of transformer and within one month after award of Contract.

The object of conducting design review on each type of transformer of each order is to ensure that the transformer satisfy specified dependability, safety, performance requirements, at a minimum cost in addition to in depth review of order.

- To ensure there is a clear and mutual understanding of the technical requirements.
- To define the system and project requirements and to indicate areas where special attention may be required.
- To verify the design complies with technical requirements of COMPANY.

The general principle followed is based on IEC: 61160 and CIGRE Report 204 of August 2002. The evaluation will be with respect to current status and state-of-art of transformer technology.

A structured check list is enclosed to ensure that COMPANY and the manufacturer have a mutual understanding of the requirements.

Further, the primary intent of the DR is to allow COMPANY to gain an understanding of the design, production, and quality assurance (QA) practices being applied to transformers manufactured for COMPANY, in addition, to have information about the technical capability, quality culture of organization and infrastructure of the organization.

It is essential that transformer shall be compatible and worthy of service in Saudi Electricity co. system layout and shall comply with COMPANY specification.

It is obligatory that the contractor / the transformer manufacturer to have as a minimum facilities for power systems Engineering studies covering the following main topics that are foreseen to be covered in Design Review (DR):

- Load flow studies and calculations.
- Leakage flux distribution field plot for various combination of windings. Calculation of Impedances. Stray flux control.
- Short-circuit studies and dynamic withstand calculations.
- Investigation of system stability both steady state and transient.
- Harmonic frequency analysis.
- Electric field analysis and dielectric withstand calculation of insulation.
• Insulation co-ordination to check the insulation levels of transformer windings. Study of over-voltage and identifying the most critical types of over-voltage generated to which transformer is exposed. Such as:
  o Temporary over-voltages (TOV).
  o Slow-front over-voltages (SFO).
  o Fast-front over-voltages (FFO).
  o Very-fast-front over-voltages (VFFO).
• Representation of network components, numerical consideration and analysis shall be in accordance to IEC: TR 60071-4/2004.
• Transformer insulation integrity under high frequency voltage stresses.
• The performance of transformer in the presence of oscillatory transients that are typically produced by the interaction of the switching device, transformer load, type of connection and system shall be evaluated.
• Voltage oscillation analysis of winding.
• Slow and fast change-over switching.
• Calculation / simulation of transferred over-voltages-transient surges or over-voltages from the high-voltage winding to a low-voltage winding. Loading of low-voltage winding open circuited. Calculations in line with Annex B of IEC: 60076-3.

The following design, production, process and testing review will be covered in DR:

• Magnetic circuits.
• Type, design and manufacturing of windings.
• Selection of OLTC and DETC.
• Winding and leads.
• Insulation processing.
• Thermal design, loading, cooling and cooling control.
• Accessories.
• Reliability planning.
• Testing.

Design review data is given in Annex M, Annex K, Annex R, Annex L and these form part of specification.

If it is discovered that transformer is not designed and manufactured to comply with all the specified requirements in the specification and contract, the manufacturer shall make those changes necessary to comply with all contracts specification. Where the manufacturer fails to comply, COMPANY reserves the right to reject the transformer. COMPANY shall be notified by the representative of the manufacturer at least 4 weeks in advance the date of DR meeting after award of contract.

22.2.1 Ability To Withstand Short-Circuits

The procedure for short-circuit withstand test as described in CL 23.14.6 shall be considered.

CL 16.0.0 is to be considered along with these requirements.

Design Review (DR) procedures described in the following has been specifically targeted to address the ability of a transformer to withstand the dynamic forces that are generated due to through fault
currents in the windings. It specifies the type, duration and the magnitudes of the fault currents that should be considered. It shall also cover the calculations required to demonstrate the thermal ability and Dynamic ability to withstand the short-circuits. Further, to consider appropriate design validation procedures taking into account specified service conditions.

Cumulative effect of multiple short-circuits strength is the most important factor for transformer.

The following shall be considered to sustain without damage the effects of over-currents originated by:

a. External short-circuits shall include three phase, line to line, double earth and line to earth faults. Calculations with formulas shall be submitted.

b. High-over-currents produced by connection of generator unit transformer to system out of synchronism. An angle of 180° out of phase shall be considered.

c. In case of star/delta-connected GUT with earthed neutral, a single line to earth fault on the system connected to the star-connected winding may cause the most severe short-circuit conditions.

d. Out of phase paralleling of UAT with the SST can produce high over-currents. Out of phase angle to be assumed 180°. (where generator circuit breaker is not provided and SST is used for starting of unit)

e. Load rejection by generator results in high generator bus voltages that also causes over excitation of the transformers connected to the generator buses. Should a fault occur during this period of excitation, it results in over-currents. This aspect shall be considered.

f. Transformers directly connected to rotating machines such as motors or synchronous condensers that can act as generators to feed current into the transformer under system fault conditions.

g. Frequency mismatch between the generator and system voltage also cause severe over currents.

h. Fast load transfer (by HST switches) from UAT to SST may under certain conditions result in circulating currents flowing through two transformers. It shall be assumed that phase angle difference between two source voltages shall be assumed to be 180°.

i. Calculation shall be performed according to CL 7.3 of IEEE C 57.116 – 1989 (R2005). It shall be submitted for COMPANY record.

j. Transformers used on circuit having reclosing features shall be capable of withstanding of the resulting of successive short circuits without cooling to normal operating temperature between successive occurrences of short circuits.

The transformers will experience numerous over-currents during plant life. The manufacturer shall study system faults and their characteristics along with all above mentioned items shall be considered. Over-current calculations and simulations shall be submitted for COMPANY perusal and approval.

System impedance or generator impedance shall not be considered for calculation of short-circuit currents.
The calculations of short-circuit currents shall be based on IEC: 60909 part 0, part 1, part 2, part 3 and part 5 and VDE 0102 part 1/11-71 and part 2/11-75. The factor C shall be taken as 1.1. The minimum calculated or measured value of impedance shall be taken with negative tolerance of -10%. The maximum short-circuit current calculated or simulated shall be increased by 10% as a safe margin to calculate the dynamic forces and thermal withstandability. The amplitude of the first peak of the asymmetrical current that the transformer required to withstand shall be calculated by using factor of asymmetry in accordance to Clause 7.1.5.2 of ANSI/IEEE C-57.12.00 by considering the resistance and reactance of the transformer only.

The transformer shall be capable of withstanding for 5 seconds a metallic short-circuit on the terminals of either the HV, LV, MV, LV1 or LV2 with rated voltage on the other windings and tap-changers in any position.

Theoretical evaluation of the ability to withstand the dynamic effects of short circuit should be in line with Annex A of IEC 60076-5 together with calculations.

The short-circuit calculation shall generally be based on the principles established by the book, “Short Circuit Strength of power transformers” by M. Waters published by Mc Donald London, along with the guidance given in Annex A of IEC: 60076-5, Ed.3.0. Calculations shall be submitted for perusal & approval of COMPANY.

Leakage flux distribution Analysis by a computer program for principal and extreme Tap position for various combinations of loading of the windings shall be considered for calculation and submitted.

Following combination shall be considered for short-circuit withstandability:

Further refer to CL 23.14.6.

For two windings:

HV → LV

For three winding:

1. HV → LV1, LV2, open
2. HV → LV2, LV1, open
3. HV → LV1+LV2
4. LV1→LV2, HV, open

For four winding:

1. HV → LV1, LV2+MV, open
2. HV → LV2, LV1+MV, open
3. HV → LV1+LV2+MV, open
4. LV1→LV2, MV+HV, open
5. MV→LV1, LV2+HV, open
6. MV→LV2, LV1+HV, open
7. MV→LV1+LV2+HV, open
8. HV→MV, LV1+LV2, open

The way of presenting the calculated data shall preferably in SI Units.

The manufacturer shall submit the following calculations with formulas before design review meeting and to be discussed during design review. It shall be demonstrated that the design strength of the winding and the clamping structure including all the external leads and accessories with regard to the
material and type of construction used, exceeds the calculated forces that will exist when the transformer is subjected to short circuit test as specified.

Winding sequence and mmf diagram of split winding shall be submitted

The calculation of forces shall be made for the maximum fault current for each winding determined from calculation of fault types specified in CL 22.2.1 of COMPANY specification using various fault types, fault locations and tap connection that calculation predicts will produce the most severe Mechanical stresses.

Axial short – circuit forces with core –type transformers are very sensitive to the relative positions of the winding holding m. m. fs of opposite sign. The manufacturer should specify which are the amounts of displacement due to workshop tolerance he has considered as well as the winding configurations (planes of symmetry and boundary conditions) he has assumed for the purpose of short – circuit force calculations. The computing procedure shall cover all possible cases of misalignment and m.m.f imbalance caused either by inevitable workshop tolerance or the effect of the winding pitch. The plane of symmetry of each LV-half to be considered with the corresponding HV- half for evaluating displacement.

For each physical winding, the most sever force condition resulting from the fault cases and tapping positions considered in design has to be identified. As regards the whole structure of transformer, one has to consider the forces resulting from the fault case involving the highest amount of reactive power drawn from the system(s).

Calculation of basic mechanical stresses on winding conductors and adjacent mechanically coupled structures originated by the short – circuit force. The following mechanical stresses should be considered. For each physical winding and structural component, the most severe stress condition originated by the short- circuit forces should be considered for the middle phase distortion taking factor for window.

The following electromagnetic forces and stresses should be calculated. The safety margin for dynamic withstandability ability stress shall not be less than 1.5 with core type transformers.

**Radial forces and stresses**

- Radial inward or outward force on each physical winding,
- Mean hoop tensile stress on outer windings (σ t).
- Mean hop compressive stress on disc, helical, single - layer – type inner windings (σ c).
- Equivalent mean hoop compressive stress on layer – type inner windings (σc eq).
- Stress due to radial bending on conductors in the span between axial sticks and between spacers used to build any axial cooling ducts within the winding radial width (σ br).
- Resistance against buckling of failure

**Axial Forces and Stresses**

The computing procedure shall cover all possible cases of misalignment and m-m-f imbalance caused either by inevitable workshop tolerance or the effect of the winding pitch.

- Maximum axial compression force on each physical winding (Fc)
- Displacement forces Fd. Maximum displacement assumed for Calculation shall be stated.
- Axial forces due to tapping of windings shall be considered.
- Maximum end thrust force (up/down) on each physical winding
- Maximum axial force –per limb on common press ring or individual ring (or plate) if used and core clamps.
- Axial collapse, axial instability mode of failure by tilting of conductors.
- Thrust force acting on the lead exits of each HV main, HV regulating, Medium and low voltage windings (T f).
- Stress due to axial bending on conductors in the span between radial spacers with disc and– helical – type windings (σ ba).
- Compressive stress on radial spacers with disc – and –helical –type windings (σ sp).
- Compressive stress on conductor paper insulation with layer – type windings (σ pi).
- Compressive stresses on end stack insulation structures (σ es). And end rings (σ er).
- Compressive stress on common press rings or individual press rings (or plates) if used (σ pr).
- Tensile stress on tie rods (flitch plates) of the clamping structure (σ rod).
- Calculation of natural frequency / Resonalces effect.
- Resistance to collapse of disc winding
- Forces in the end turn

The calculation shall be submitted along with the following data.

- The basic critical strength values for various materials and conductors arrangement by the material manufacturer shall be submitted along with the calculations.
- Disposition of windings with respect to core.
- Leakage field plot for various combinations of windings connections.
- Number of wound limbs of core.
- Number of unwound limbs of core.
- All assumptions and estimated parameters used to calculate/compute these forces shall be included in the report.
- Young’s modules of materials or composed materials such as copper, etc. epoxy-Bonded CTC conductor.
- Conductor material with grade of cooper according to EN1977 with yield point (MPa) at Rp0.2 shall be submitted

The forces shall be calculated for the middle phase, taking distortion factor for window for worst and maximum over currents.

**Over currents withstandability design**

The manufacturer shall describe the over-current withstandability design at the DR as described below.

- Maximum over current considered.
- Generated Forces. A summary of calculated forces generated during all possible over currents on each winding at any switch position. For each type of fault, the total force acting in each direction and on each winding shall be given. Local maximum pressures shall also be given. All assumptions and estimated parameters used to compute these forces shall be included in the summary.
- Failure Mode Analysis. A summary of the worst case mechanical stress in each winding, and a description of the design and construction used to withstand this stress, for each of...
the following mechanical failure modes: hoop buckling, axial compression, clamping failure, hoop tension, beam bending and mechanical resonance. A sketch shall be provided which shows the various regions of the windings and the type of fault which dictates the winding strength in that region.

- **Structural Support.** A description of the axial and radial loading of the windings and support structure.

- **Winding Preparation.** The manufacturer shall provide detailed description of all preliminary coil sizing and stabilization procedures, including preload clamping pressure applied to windings and the clamping system used. This description shall include pressures, temperatures and drying process, time, dimensional tolerances allowed, and the purpose for each step in the winding preparation.

- **Transformer components.** Transformer components such as leads, bushing, OLTC, or DETC tap changer, and current transformers that carry current continuously shall withstand the maximum short – circuit.

- **Leads and Supports.** A summary of worst case forces acting on all leads and crossovers. The ability of these leads and their supporting structures to withstand these forces shall be described.

- **Thermal withstand temperature.** The worst case temperatures which occur in each winding, and the condition which causes these temperatures, and the mechanical properties of the conductor materials at these temperatures, shall be described.

**Special consideration for Multi-Winding Transformer**

- The maximum Asymmetrical fault current for each winding shall be determined from calculation for the types of faults specified in CL 22.2.1 of COMPANY specification by various faults types, faults location at tap position on the windings and applicable system data.

- Testing of axial split winding include case of short-circuit on LV1 and LV2 windings with the other windings open plus the case of simultaneous short circuit on secondary windings at terminals of LV1 winding and LV2 windings together and short –circuit between LV1  and LV2 with HV winding open. Detail of short circuit test as given in CL 23.14.6 of specification.

- The short-circuits test may be for pre-established or post established short-circuit.

- When a transformer of Axial split of the type shown in Annex A or B Pages 1 to 10 suffers a short-circuit at the terminals of one of its LV windings, the fault current mainly involves the short-circuited LV winding and the HV winding across from it, but to a certain extent, the other HV winding is also involved by the fault current due to the electromagnetic cross-coupling between the two levels. The distribution of the electromagnetic forces along the height of the column is therefore not uniform and is not locally compensated, this gives rise to significant electromagnetic force components in the axial direction. This aspect must be carefully considered when studying the short-circuit withstand of the transformer.

- Axial split winding has main disadvantage in that this type of transformer is sensitive to axially directed forces caused by displacement of electromagnetic centers consequent to misalignment of windings. Traction forces at winding ends can never be avoided.

- The plane of symmetry of each LV- half to be considered with the corresponding of HV-half for evaluating displacement for axial split winding.
- In both cases, of Radial split and Axial split winding the manufacturer shall state the maximum displacement allowed in the final assembly and the method of checking the displacement for compliance.

- In axial split winding, substantial insulation results in consequent increased flexibility and causes increased sensibility for dynamic forces.

- Radial split winding design is better suited to withstand short circuits consequent to better control of electromagnetic center of windings. Hence this design is recognized and acceptable to COMPANY.

- In both cases the manufactures shall state the maximum displacement allowed in the finally assembly and the method of checking compliance.

The manufacturer shall take into consideration, factors which play a role in enhancing dynamic withstands performance during short-circuit currents including the following:

- Windings made of high-grade proof-stress copper instead of annealed copper.
- Lower current densities in windings.
- Use of epoxy-bonded continuously transposed conductors instead of individually insulated flat conductors.
- Part played by manufacturing techniques, processes, choice of materials and by quality control during manufacturing is important and these shall be stated.
- Use of proper winding machine with facilities to apply axial and radial pressure to consolidate the windings
- Strictly controlled machine manufacturing processes of the windings. Wind the windings under a controlled condition with enough tension in the conductors to ensure that there are no unwanted gaps between the individual conductors. Properly processes the minor and major insulation so that it is fully shrunk and oil impregnated and to demonstrate the ability to manage this process and control the quality of the insulation winding supporting structure.
- High-density pressboard (i.e. transformer board) in windings and end insulation components.
- Predict final winding dimensions and relative positions within the limited tolerance used in the force calculation, and specify how these dimensions are checked at the final stage of manufacture.
- The manufacturing process bear utmost importance in achieving the required mechanical strength.
- Elastic stabilization of windings and tight tolerances concerning winding lengths under specified clamping force and relative positioning of the windings. Properly size the windings to consolidate the radial & axial insulation to ensure that the winding turns are located as predicted by the design within the design tolerances.
- COMPANY highly prefers Individual winding clamping construction, where in, each winding assembly (i.e. one complete phase) shall have its own winding clamping construction. The pressure on each winding phase could be set independently and could be checked and readjusted even after service. Combination of common core and winding clamping construction is least preferred.

The manufacturer shall inform COMPANY the method of clamping used for the transformer.
• Core & coil clamping structure consisting of robust and stiff parts duly fastened.
• Large sizing of all pressure rings, pressure pieces and support blocks and their securing by means of pins, block washers and fastening devices.
• Securing of all winding exit leads and connection to bushings and tap-changers.
• Secure any accessories, leads, crossovers and lead exits to ensure that they will not be displaced during any fault current condition or transport.
• Final clamping of the winding blocks after impregnation with oil carried out to secure adequate, evenly distributed and long lasting axial force on them.
• Ensure that the winding supporting structure and winding conductor will withstand without permanent deflection the various types of stresses and forces that will be present such as radial bending, axial bending, radial buckling, hoop stress, tilting, axial and radial compression on the insulation and tangential twisting.
• Demonstrate the philosophy of the supporting structure, i.e. tie-rods or plate clamps, the type of support back to the core for inner windings, any pre-load used and any form of transport bracing.
• Ensure that the strength of the materials used is adequate to support the predicted forces.
• Adequate bracing of HV winding and LV windings and leads from regulating windings to tap-changer shall be on frame of high-density pressboard.

The transformers shall be designed and manufactured to withstand the highest value of over currents, considering all the factors mentioned above.

22.2.2 Ability To Withstand Over Voltages And Insulation Design Evaluation

Insulation co-ordination shall be in line with IEC: TR 60071-2/1996.


It is essential for the contractor / manufacture of transformer to establish the compatibility of the transformer insulation with respect to withstand the over-voltage, transient surges and the presence of oscillatory switching transients typically produced by the interaction of the switching devices, transformer, load and system. Further, the study is intended to check the surge arrestors installed on the HV terminals and LV terminals are adequately selected and that the dielectric insulation levels for the transformer windings are appropriate.

The manufacturer shall be equipped with computer software for analyzing transient potential oscillations in transformer windings and electric fields of the winding configurations and electric field distribution in the winding configuration. Insulation design shall be performed precisely from such calculations. Calculation of stressed oil gaps between windings, and between winding ends and grounded electrode and the gaps that are subdivided finely by press boards.

Refer to specification for metal enclosed SF6 insulated MO Surge Arrestors and porcelain enclosed M.O. surge arresters No. SEC-GP-004 for GUT

The Contractor / manufacturer shall have network study facilities as required by CL 5.0 and CL 22.2 of specification.
Characteristic data required for an over-voltage and system study is given in CL 25.0.

The transformer may in service exposed to more sever over-voltages than those applied in acceptance test. With reference to the network, location of transformer, type of connection, type of connection with the type of switchgear etc. transformer in service is exposed to voltages in excesses of normal operating voltages.

The following are the over-voltages foreseen in COMPANY System and as defined in CL 22.2.0.

**Lightning Impulse**
Transient over-voltage due to lightning strokes to earth near transmission lines, sometime direct strike to lines or transformer, are to be considered. The distance between the transformer and the spot of lightning stroke to be considered, shall be equal or less than limiting distance 2 km.

**Surges Generated within the Power System**
Sudden changes in the service condition, such as:

- Switching operation.
- Switching of reactive loaded transformers due to multiple transient current interruption in circuit breaker with front times up to fraction of a microsecond.
- Load rejection.
- Low frequency resonance phenomena.
- External insulation flashes over.
- There could be multiple re-ignitions with LV side and Generator switchgear which could cause internal over voltages. Resonance phenomena because of Network configuration.

**Computation of very fast Transient Over-voltages (VFTO's) and Internal Over-voltage Caused by High Frequency Oscillations.**

Analysis in accordance to CL 11 of IEC: 60071-4/2004

Surge propagation analysis for connection between GUT and SF6 GIS switchgear located at remote end of connection.

Switching operations, and fault conditions particularly in gas insulated sub-stations (GIS) and lighting impulses are known to produce very fast transient voltages (VFTO's) containing high frequency oscillations in the kHz and MHz range, which are dangerous for the transformer, generator and motor insulation.

Further, in medium voltage systems where vacuum circuit breakers are used, re-ignition causes high frequency oscillations, which can be dangerous because of their short-rise time.

Under special circumstances, the terminal over-voltages can arise close to or higher than the transformer BIL.
VFTO's might typically be expected to have rise time of 20ns and amplitude of 1.5p.u. In the worst case, a rise time of 10ns and an amplitude of 2.5p.u. should be expected and the fronted section of the wave is after followed by an oscillatory (or traveling wave) component whose frequency which is usually in the range of 1 Hz to 10 MHz, depending upon the traveling wave characteristics and type and length of connection, such as GIS bus bar system or cable system. It is also due to multiple reflections, the amplitude will increase approximately 30%.

The following kind of stresses in the transformer winding as the resulting consequences shall be looked into

- Generation of severe intersection voltages developed by the highly nonlinear distribution of the VFTO's within the windings.
- Part winding resonance produced by the oscillatory wave tail of VFTO.
- High frequency performance of the end windings, the inter turn and inter coil voltages together with insulation integrity of winding.

Aspects of the propagation of VFTO's in transformer winding shall be calculated /simulated

Transient voltage analysis shall comprise of verification of transient voltage distribution with LV1 tester and electric field analyses

Most of the time, resonant over-voltages can cause a flash over from the windings to the core or between the turns. The inter-turn insulation is particularly vulnerable to high-frequency oscillations and therefore, the study of the distribution of inter-turn over voltage is of essential interest

Response of the windings particularly, the regulating winding, to the above disturbances that can excite the resonance frequencies shall be checked for the voltages occurring across the regulating winding and tappings. Further, part winding resonance shall be checked.

Measurement by the low voltage impulse (LV1) application using a surge Generator to apply voltage to one or more terminal of transformer, while recording response at the tapings of regulating winding on fully assembled transformer is required by COMPANY.

The manufacturer shall perform the measurement at nominal, maximum plus and minus min. taps before tanking the active part and submit the record for perusal and record of COMPANY.

During internal resonance the voltage occurring across the tapings and voltage withstand of the selector switch taps shall be checked

It is essential to check the ability of a winding to withstand a full wave impulse voltage to that of its ability to withstand internal voltages produced by a terminal voltage of oscillating wave form.

The windings, of the connected ON-Load Tap Changer/DE-ENERGIZED Tap Changer shall be self protected type. The over-voltage withstandability and BIL shall be compatible with over-voltages experienced by the regulating winding. Further it shall be suitable for impulse testing of the neutral terminal by direct application of lightning impulse at the lowest tap. Proper evaluation of transient response of
transformer winding shall be done. Calculation / simulations shall be submitted for the approval of COMPANY-Engineer.

**Compatibility of Transformer in the presence of Oscillatory switching transients shall be evaluated in line with IEEE Std. C57.142/2010**

System configuration in COMPANY.

System with switching device on H.V. SIDE (SF6 GIS) through a cable, SF6 Bus duct or short transmission line

System with switching device (vacuum or SF6 – CB) on LV side (Phase isolated bus duct) and switching device (SF6 –GIS) on H V side through , a cable , bus duct or short transmission line .

System has both long and short cable. The length and details of cable for each trafo. shall be obtained from the concerned Project Manager for both case (a) or case (b) as applicable.

In a Power system, transformers and circuit breakers form a dynamic system during switching operations. Interaction action creates transient voltages containing components of high frequencies. When these transients voltage waves reaches the receiving end of cable, the voltage can reflect, or refract, or simply be absorbed depending on the relative impedance of the cable receiving and load – the Transformer. The performance of Transformer in the presence of Oscillatory transients that are typically produced by interaction of the switching devices, transformers, load connection elements (such as cables- bus duct, transmission line) shall be evaluated.

**SEC System Configuration (in Power Plant)**

![SEC System Configuration Diagram](image-url)
These transient voltages can be damped, oscillatory, triangular or exponential and can occur as a combination of these oscillatory switching voltages and may contain several high frequency components. If any of the frequency components near one of the natural frequencies of the transformer and if it is of sufficient magnitude and duration, it trigger resonance in the transformer winding and may cause permanent damage to the transformer internal insulation. Even in case of the voltage magnitude is below the surge arrester’s protection level or transformer terminal insulation level.

Such conditions are to be brought to the notice of COMPANY in writing with supporting evidence in the form of calculations and simulation. COMPANY will discuss with the Contractor / Manufacturer. the methods of mitigation to protect the transformer. Mitigation aspect does not form part of main contract and separate cost consideration will be accorded.

**COMPANY System Configuration to be evaluated**

The following systems to be investigated:

1. **Supply Characteristics.**

   Any modeling of the supply shall include the high frequency transient s occurring during switching device closing or opening. Distributed capacitance to earth (representing the line or cable capacitance) shall be used for proper transient modeling under switching operation.

2. **Switching components between switching device and transformers.**

   The connection between the SF6 HV switchgear is a single line or cable, or SF6 bus duct. The length of this can be obtained from Project Manager for each transformer bar. This Single connection component has a dominated frequency determined by the length of the connection and velocity of transient wave. Where transient has frequency component, this frequency is near one of natural frequencies of trafo. and if it is of sufficient magnitude and duration, it trigger resonance in the transformer winding and causes permanent damage to the transformer internal insulation- It is important to evaluate and recognize such a condition.

**Load Characteristics**

Mainly the following transformers are of concern.

- Unloaded transformers
- Lightly loaded transformer.
- Inductivity loaded transformers

Where the transient voltage produced by the system switching has significant oscillatory component coinciding with one of the natural frequencies of the transformer, it causes resonance in the winding.

**Impedance versus frequency characteristic of Transformer**
Each transformer design has corresponding unique impedance versus frequency characteristics. The following resonances are important.

- Terminal resonance
- Internal resonance (particularly at the Tappings of regulating winding)

The natural frequencies and mode shapes of a winding can be determined either, by measurements (FRA) or by calculations.

**Frequency response (FRA)**

FRA shows how the impedance of a transformer behaves over a specified range of frequencies usually 10 Hz through 250 KHz. Method of measurement refer **CL 23.12.18**

**Calculation of frequency response of transformer**

Transformer windings can be represented by an equivalent network of inductance which have mutual coupling, capacitance and frequency dependent resistances, representing various source of losses in the trafo.

Computer software for analyzing transient potential oscillations in trafo. Windings are available.

First, second, Third or fourth natural frequencies are of interest. The calculations can be checked against measurement according to **CL 23.12.18**.

**Internal voltage developed near Resonance.**

When the terminal is excited with 1 per unit oscillatory input, voltages at various points including tappings of the regulating windings shall be computed for frequency variation of 2 Hz. to 5 MHz These are to be compared with values measured during test to **CL 23.12.18.2**.

Normalized spatial voltage distribution within the transformer when excited with a 1 per unit oscillatory wave form of 60 Hz, first natural frequency and third natural frequency High values of voltage across part of the winding around the zones of the standing wave have to be considered for insulation withstand, insulation integrity under High frequency voltage stress.

Evaluation is required to compare the ability of a winding to withstand a standard factory test SI/LIL/LICL/ ACL. as specified in **CL 12.0** to of its ability to withstand the internal voltage and voltages at regulating winding tappings produced by a terminal voltage of oscillatory wave form. Further voltage gradients across parts of winding as described in the above item to be evaluated.

The use of surge arrestors connected directly to the H.V. terminals should be considered, to provide protection from transient voltages produced on the system. It is essential to compare the ability of a winding to withstand a factory full wave voltage impulse to that of its ability to withstand the internal voltages produced by a terminal voltage of oscillatory waveform.

The use of ZnO Varistors or Condensers to reduce the transient voltages across winding are not accepted.
### Methods to obtain required performance characteristics.

Before final design estimate of the impedance versus frequency and the transformer amplification factors shall be obtained by building an analytic model (Lumped parameter) of the transformer. Using this model one can compute its transient response (both terminals and internal along with its impedance versus frequency characteristic). Actual FRA measurement values can be compared with predicted values.

### Over voltages due to earth fault

The system parameters determine phase to earth over voltages affecting the other phases. The earth fault factor assumed in calculations shall be stated.

### Over voltages due to load rejection

Over load and full load rejection shall be considered. The value of V/Hz ratio as specified in CL 10.0 of this specification.

### Over voltages due to Ferro resonance

The length, type of cable, bus duct connection between transformer and switchgear can be had from COMPANY.

Over-voltages due to Ferro resonance in the following fault condition:

- Circuit breaker failure to break or close in one or two phases during switching operation.
- Rapture of one or two phase conductors during earth fault, short-circuit or due to mechanical stresses.

The over voltage due to resonance and Ferro-resonance should be limited by detuning the system from the resonance frequency, by changing the system configuration, or by damping resisters. Installing snubbers consisting of R-C elements.

### Wave shape sensitivity

Analysis / simulation to investigate the transformer’s response to non-standard wave shapes and VFTO, This shall be submitted to COMPANY for perusal and record.

### Voltage stress on LV winding during back-feed condition

GUT has large voltage difference between the low – voltage and high voltage windings. Capacitive and inductive coupling between the windings can cause remarkable voltage stresses on the LV windings during back feed conditions or by transients entering the HV terminals.

- **Multiple-ignition**

- **Transferred over-voltages from high-voltage windings**

  The voltage transformation ratio of the transformer at high frequencies (kHz) will be different than at normal frequency, with the attendant risk of high voltage transferred from one side to another, particularly if the transferred voltages are magnified by resonance effect.

  Transferred voltage can be in the following mode.

  - Inductive transfer.
  - Capacitive transfer.
  - Power-frequency transferred over voltage.
  - Oscillatory transfer through natural oscillations of primary and / or the secondary circuits of the transformer. The earth capacitance and the self inductances of the winding form the oscillation circuits.
Calculations and simulation of transferred over-voltages on the MV and LV windings due to transient surges and power frequency over-voltages coming form HV network shall be made. The calculations shall be in line with IEC-60076-3 and IEC: 60071-2. Additionally refer to Annex L.

Additionally calculations and simulation shall be submitted to COMPANY for perusal and approval. The calculations/simulation will be verified by measurements ref. CL 23.14.5 of COMPANY specification.

The following modes are to be considered.

1) When the L.V. windings are loaded.
2) When the L.V. terminals are isolated.

The voltages and surges transferred through the transformer can be decisive when the over-voltage withstandability and the protection of the transformer are designed. All the cases as cited in Annex E of IEC: 60071-2 shall be calculated / simulated and results submitted for perusal and approval of COMPANY. These values will be compared with the measured values during testing. Refer to CL 23.14.5.

The LV winding shall be of self protected type.

**Dielectric Withstandability and Insulation Design Review**

Dielectric withstand calculations shall be based on in-depth field analysis for the electrically stressed zones of oil and solid insulation areas.

The manufacturer should provide an insulation layout sketch. Each major region of the insulation structure i.e. main gap between windings, Shielding and /or ground insulation at winding to core, outer winding to tank, axial along windings should be identified with the test or operating condition which is most critical to its dimensioning and design. It is informed the clearances shall be suitable for LI W and switching surge wave of positive polarity. Refer to tests CL 23.12.0.

Further, Refer to Annex K, Annex M and Annex R.

**Field Analysis:** Numerical field analysis shall be used to determine electrical transient potential oscillations in transformer windings and electric fields of the windings configurations, the electric field distribution in winding configuration by computer program.

Field strength profiles on selected paths shall be compared with the strength of oil gaps along these paths. The ratio between the dielectric withstandability of an oil gap and the field strength shall be indicated.

The following information shall be submitted:

I. Windings details.

   - Details of LV winding construction.
   - Details of MV winding construction.
   - Details of HV winding (main) construction.
   - Details of HV winding (regulating) details of construction.

II. Winding arrangement. Refer Annex K

   - Axial clearances of each winding.
- Disposition of barriers and angle rings shall be given.
  - Disposition of static rings shall be given.
  - End clearance in top of window.
  - End clearance in bottom of window.
  - Disposition of angle rings.
  - Disposition of press-board barriers.

- Radial clearances of each winding.
  - Between LV or MV winding and core, where applicable.
  - Between LV winding and MV winding, where applicable.
  - Between LV winding and HV winding (main) or HV regulating winding.
  - Between HV winding (main) and HV regulating windings.
  - Between HV regulating windings of adjacent phases.
  - Between HV (main) and LV winding.
  - Between LV winding of adjacent phases.
  - Position of press-board barriers with dimensions.

III. Details of core

- Core diameter / Area of cross-section.
- Height of window.
- Center of limb to center of limb distance.
- Position of oil ducts and their dimension.
- Position of insulation sheets (0.1 mm thick) between steps.
- Calculation of hot-spot temperature.
- Number of outer steps slitted to reduce the losses due to stray flux.
- Type of joints and their sketches.

IV. The values of voltages and voltage stresses at strategic points for the following test over-voltages shall be indicated. Refer Annex K. lightning and switching impulses shall be positive polarity.

- FW impulse to line terminal in nominal and extreme tap positions.
- CW impulse to line terminal in nominal and extreme tap positions.
- FW impulse to neutral terminal in nominal and extreme tap positions.
- Switching impulse test for line terminals in nominal and extreme tap position.
- Separate source AC withstand voltage
- Short duration induced AC withstand voltage (ACSD).

V. For separate source AC withstand voltage and short duration induced AC withstand voltage.

- Actual stresses between core and MV, (where applicable) LV, between LV and HV (main), between HV (main) and HV regulating winding and between HV regulating windings of different phases shall be submitted.

VI. Voltage withstand for over-voltages as specified in item IV.
- Within the windings and between windings.
- LV to core or MV to core where applicable.
- HV to LV.

Voltage Transferred Characteristic shall be considered in reference to CL 23.14.5 of specification:

MV, LV winding shall be self protected type.

VII. End insulation Design.

The analysis may be done with "ELECTRO" a two dimensional, rotational symmetric electric field solver, based on the "Boundary Elements" method. The critical gaps (critical path) and critical creepage stresses shall be marked and checked and to be compared with Weidmann curves. The safety margin shall be ≥ 20% against worst stresses.

VIII. Integrity of insulation under high frequency voltage stresses, where a winding is excited near resonances, the internal oscillatory voltage produced is the dominating voltage component. The insulation layout shall be able to withstand such voltage stresses.

Protection by limitation of transient over-voltage
Transformers connected to overhead lines, or through high voltage cables, or through SF6 bus duct shall be protected by limitation of transient over-voltages by means of metal-oxide surge arrestors, connected between each phase terminal of transformer and earth.

The manufacturer shall simulate or calculate the protection level of surge arrestors and specify the MCOV, TOV and maximum discharge voltage ratings.

The safety margin between insulation level of the transformer and protection level of MO surge arrester shall be minimum 30%. To protect the equipment down the LV side, from transferred surges M.O. surge arresters with suitable MCOV, TOV and maximum discharge shall be specified.

The insulation withstandability shall be done for all test voltages, defined in layout A & B without considering protection or limitation by M.O. Surge Arresters.

External insulation at high altitude
The dielectric test values both LI/SI/PF shall be increased to take care of insulation withstand at higher altitude.

- Insulation Design Evaluation
The manufacturer shall describe insulation details with drawings and field plots at the design review meeting. The over-voltage withstandability shall be provided for all tap positions, for all operating condition specified for the locations listed below and for all dielectric tests defined in specification. The basis of the calculations shall be stated for all analysis. Additional calculated values for conditions of tests required by the specification shall be included in the insulation design evaluation analysis. If the prospective impulse wave shape voltage during testing does not meet the requirements stated in specification of the relevant IEC, their calculated data shall be provided for both the required and the prospective wave shapes. This information shall be used to determine the most stressful operating situations and the tap settings required for dielectric tests. Under these conditions, the magnitude and
location of dielectric stresses and the associated withstand capabilities shall be provided for the following regions or conditions:

1- Dielectric stress in the most highly stressed regions of oil, including leads and bottom region of bushings.

2- Dielectric stress in windings including the following:
   a) Voltage to ground of each terminal.
   b) Voltage to ground of each node (defined below).
   c) Voltage differential between adjacent nodes.
   d) Voltage differential across each high-low space.
   e) Voltage differential between adjacent line, crossover and tap leads.
   f) Voltage differential between critical leads and adjacent discs or layers.
   g) Voltage wave shapes producing the dielectric stresses in (a) and (b) above.

3- Description of how design limits were developed and applied.

The nodes referred to in (2) are defined as follows:
   a) The winding terminals and the connection points between the layers for a layer type winding.
   b) The winding terminals and the connection points between the disks representing no more than 10% of the total number of turns for a disk type winding.
   c) The winding terminals at the middle of the winding cylinder for a helical type winding.

The manufacturer shall provide a cross-section sketch of the transformer assembly. Each major region of the insulation structure (i.e. main gap between windings, shielding and or ground insulation at winding ends, inner winding to core, outer winding to tank, axially along windings, and around all EHV and tap leads) shall be identified with the test or operating condition which is most critical to its dimensioning and design. A brief summary of the dielectric stresses in the critical regions for each test or operating conditions shall be included with the sketch.

Before design review meeting, the following shall be submitted for COMPANY to review and points to be discussed during meeting:

AC Test Voltage Withstand

H.V. main winding, H.V. tapping winding and L.V. windings voltage distribution.
H.V. main-between disc pair.
H.V. regulating winding-along the winding and between taps.
L.V. winding between turns and between layers.
The maximum stress occurring (Emax) to be checked for:
   • Creep stress.
   • Edge stress on the conductor.
Against the permissible stresses (Eper).

**Voltage Withstand for Full Wave Impulse, for Chopped Wave Impulse and for Switching wave impulse.**

Voltage distribution in HV winding, HV regulating winding and transferred voltage to MV&LV winding (MV&LV winding isolated) for the following conditions.

1. Voltage distribution for LI full wave from HV line end at nominal tap, + max. tap and min. tap with respect to max. voltage to ground and max voltage along the winding.

2. Voltage distribution for LI chopped wave from HV line end, at nominal tap, + max. tap and – min. tap with respect to max. voltage to ground and max voltage along the regulating winding.

3. Voltage distribution for LI full wave from HV neutral end, at nominal tap, + max. tap and – min. tap with respect to max voltage to ground and max voltage along the winding.

Transferred voltage from HV to MV&LV winding when MV&LV windings isolated (open) at nominal tap, + max tap, - min tap with respect to max. voltage to ground and max. voltage along the winding.

The calculation or simulation shall be accompanied by the actual disposition of windings with respect to core and the position of the line terminals of windings.

4. Response to very fast transients – analysis/non-standard wave shape sensitivity with respect to max. Voltage to ground and max voltage along the main and regulating windings.

The dielectric withstand ability against over-voltages shall be based on

1. Voltage distribution in the winding against ground to check for internal insulation distance such as insulation (Oil + Pressboard) between winding and between winding and yokes.

2. Voltage distribution along the winding for insulation withstand against creep stress, edge stress between turns and stress in paper insulation.

**From The Field Plots, The Following Stresses Are To Be Calculated And Submitted:**

- Maximum points on LV stress ring on inside diameter of LV and the stress at the edge of top conductor and oil paths / creepage paths.

- Maximum points on LV stress ring on outside of LV and the stress at the edge of top conductor and oil paths / creepage paths.

- Maximum stress on HV stress ring on inside diameter of HV and the stress at the edge of top conductor (or disc)and oil paths / creepage paths.

- Creepage paths on barriers between phases

- Maximum stress on HV stress ring on outside diameter of HV and creepage path between stress ring and first angle ring.
- Maximum point stress on regulating winding stress ring on inside diameter of regulating winding and oil path.
- Maximum point stress on regulating winding stress ring on outside diameter of regulating winding and oil path.
- Maximum point stress on tie rod.
- Numerical field analysis required to determine field strength and/or width of oil gaps shall evaluate the critical oil gaps (critical path) and creepage stress shall be checked and compared with the Weidmann design curves.

The following design criteria to be checked.

- Maximum points stress …… Minimum safety margin of 20 %.
- Oil path / creepage compared with Weidmann PD inception field strength with a minimum safety margin of 20%.
- Disposition of press board barriers and angle rings shall be given.
- Pre compressed press board Psp 3052 DIN 7733 shall be used for barriers.
- Clamping rings for windings shall be from laminated pre - compressed board Psp 3052 for voltage class 245 kV, 420 kV and above. Resin laminated wood for 145 kV and below.
- Diagonal and cross-corrugated board for main oil ducts in the main gap.

**Short-circuit-impedance**: Refer to **CL 13.0 of this specification**.

**Voltage regulation**: Refer to **CL 17.0 of this specification**.

**Magnetic circuits**: Refer to **CL 19.0 of this specification**.

**Winding and leads**: Refer to **CL 18.0 of this specification**.

22.2.3 **ON-Load Tap-Changer / DE-ENERGIZED Tap – Changer**

Refer to CL 20.0 of this specification

22.2.4 **Thermal Design, Loading, Cooling And Cooling Control**

- Oil flow Analyses showing oil velocity profile and oil temperature profile shall be submitted
- Thermal design, cooling and cooling control refer to CL 15.0 of this specification.
- Loading refer to CL 8.0 of this specification.
22.2.5 Insulation Processing

- Moisture and, particle control, CNC processing center for insulation parts fully enclosed air conditioned, dust free workshop
  Humidity control, moisture and particle control dust proof hall for assembly of active parts.
- The processes of stabilizing the winding to the required axial dimension by heat and pressure, details to be furnished.
- Core and winding assembly.
- Terminal gear assembly.

Type of joints for high-voltage winding, tapping leads etc. shall be indicated. Soldered or crimped joints are not acceptable.

Drying and oil impregnation

Drying, degassing impregnation process adopted shall be described. Vapor phase drying process alone shall be used. However, conventional vacuum drying is permissible for voltage class of 66 KV and below with written permission of COMPANY. Total drying cycle shall be described. Final insulation drying temperature and time duration it is maintained to ensure full moisture evaporation from the deeper insulation layers shall be stated.

Criteria used for determining the dryness of insulation and its measurement shall be provided. Measurement of moisture content in insulation by power factor measurement shall be provided.

Drying may be controlled by software. Devices for measuring of process parameters shall be described.

After final drying the moisture content shall not exceed 0.1 % and this is to monitored by the analysis of moisture contents in the sample pieces of insulation paper installed on the coil assembly. During the subsequent work, however, the moisture content will gradually increase through exposure, the final value, after tanking of active part shall not exceed 0.4 %.
There shall be no exposure to air during oil impregnation.

22.2.6 Testing

Refer to CL 23.0 of this specification.

22.2.7 Accessories

Refer to CL 21.0 of this specification.

22.2.8 Transport, Handling And Storage

Transformer shall not be transported from the factory until all specified test have been successfully performed to the satisfaction of COMPANY and permission of COMPANY is obtained for transport or dispatch of transformer.
All necessary precautions shall be taken to insure transformer insulation is as dry as practicable upon both departure from factory and arrival at site. Where necessary the transformer shall be filled with dry air or nitrogen at 0.3 kgf/cm² for transport. The internal pressure shall be maintained through connection to gas cylinders with automatic pressure regulator.

The oxygen content and dew point of the gas in the tank after arrival of transformer at site shall be verified and checked jointly with COMPANY representative. If the dew point of the gas indicate humidity of less than 1 % and oxygen content is below 1 %, it may be safely assumed that the transformer has not been contaminated in transit.

All parts and accessories removed for transport shall arrive on site at the same time as transformer main tank.

Three way impact recorders one mechanical type and one electronic type shall be fixed on top of transformer cover, functional throughout the transport and up to installation duration. Impact recorder charts shall be examined jointly by owner and COMPANY. Any impact higher then 2g shall be ground for investigation; If the impact sustained is ≥ 3g, and the investigation shows movement of active part, it form basis for COMPANY not to accept the transformer and it may be basis for further investigation and rejection.

Impact recorder shall record shock and impact from all directions indicating the total number of impacts that have occurred, the magnitude, duration, the direction and the time at which they occurred.

Transformer shall be capable of storage for one year out-door.

23 **TESTS**

23.1 **General**

All measuring systems used for the tests shall have certified traceable accuracy and be subjected to periodic calibration according to the rules given in ISO: 9001.

All power transformers shall be tested generally in accordance with IEC: 60076 Standards, and as specified herein. No transformer shall be shipped until the test reports have been approved by the COMPANY Engineer.

The manufacturer shall submit the procedure for all the tests for the approval of COMPANY immediately after finalization of design.

The purchaser (COMPANY) has the right to conduct surveillance review of quality plans and of the contractors quality control including witnessing of quality related manufacturing activities at any stage of manufacture.

23.2 **Location of Tests**

All tests shall be carried out at the Manufacturer's factory. COMPANY reserved the right to test the transformer at any other laboratory even after test at manufacturer's works. In case of variation more than measuring error, the contractor is responsible for costs & consequence.
Type or special tests shall be carried out at an approved independent testing laboratory or at the Manufacturer's factory and be witnessed by a COMPANY representative. Where the manufacturer is not equipped to carry the test as specified, COMPANY may test it at any other Laboratory without any cost obligation on part of COMPANY.

23.3 Inspection

The COMPANY Engineer may wish to witness tests or to visit the factory during manufacture of any or all items covered by this Specification. Accordingly, the Contractor shall give the Engineer adequate notice of manufacturing schedules and one month’s notice of test schedules. The cost of all the tests shall be born by the contractor/manufacturer. The manufacturer shall submit the details of schedule of production and tests to the Engineer.

Where more than one transformer are ordered, COMPANY reserves right to chose any of the or any number of transformers for witnessing routine, type, special and short circuit tests for the acceptance of equipment.

23.4 Tests Requirements

Tests shall be performed at 60 ± 0.3 HZ only. The wave shape of the supply voltage shall be such that the total harmonic content does not exceed 5%.

The three phase supply voltage shall be symmetrical. The maximum voltage across each phase winding under test shall not differ from the minimum voltage by more than 3%.

Any inability of the manufacturer to perform the test or measurement at the rated frequency shall be stated by the manufacturer at the tender stage.

Frequency conversion of no-load losses, excitation current, load losses, impedances voltage etc shall be rejected.

Reference temperature shall be 75°C.

Transformers and their bushing shall be subjected to tests as specified herein.

The test field shall be preferably equipped with latest and modern measuring systems, equipments and instruments required to test large high voltage transformers. Some of required capacities of equipments that are expected is indicated against each test.

The test system accuracy for each quantity measured shall fall within the limits specified below.

<table>
<thead>
<tr>
<th>Quantity Measured</th>
<th>Test System Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Losses</td>
<td>±3.0%</td>
</tr>
<tr>
<td>Voltage</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Current</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Resistance</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Temperature</td>
<td>±1.5°C</td>
</tr>
</tbody>
</table>

It is obligatory on the test field to demonstrate the calibration of high voltage measuring equipment for AC dielectric tests and impulse test before starting the test.

For transformers of voltage class ≥ 36 kV, it is obligatory to apply filtering procedure to the oil in transformer and test the oil for particles content before proceeding with the acceptance tests.
All measurements and tests requiring power frequency supply shall be performed with the supply frequency within 1 % of the rated frequency of the transformer. The wave shape of the supply voltage shall be such that the total harmonic content does not exceed 5 %. If this condition is not satisfied, then the effect of the wave shape on the measured parameter shall be evaluated by the manufacturer and subject to approval by the purchaser. Loss measurements should not be corrected downwards to account for harmonics in the supply voltage except as allowed in CL 11.5 of IEC: 60076-1/2011 where a three-phase supply is used. The supply voltage shall be symmetrical. The maximum voltage across each phase winding under test shall not differ from the minimum voltage by more than 3 %.

The trafo. shall be completely assembled as in service in respect of all the elements that might influence the dielectric strength of the transformer. All Buchholz relays to detect free gas produced by faults in insulation shall be installed and monitored during test. If free gases are dedicated during the test, the nature and cause of the gases shall be investigated.

Any inability of the manufacturer to perform the test or measurement at the rated frequency shall be stated by the manufacturer at the tender stage and appropriate conversion factors agreed.

Where the test field is not properly equipped, COMPANY reserves the right to test the equipment at any independent laboratory at contractors / suppliers cost.

Test procedures shall be submitted for the approval of the COMPANY-Engineer at least two months in advance. All external components and fittings that are likely to affect the performance of the transformer during test shall be installed.

The following tests are to be considered as finger print tests:
- F R A.
- D F R A.
- Furfural Analysis.
- Single phase impedance measurements.
- Single phase excitation current.
- Particle contents in oil.

The above tests are to be used for diagnostic purpose of the Transformer.

Following completion of the tests, two certified copies of the test reports shall be submitted to COMPANY for approval. No transformer shall be shipped until the test reports have been approved by the COMPANY.

Tolerance on the measured values shall be in accordance to CL 10 of IEC: 60076 – 1/2011 except for impedance.

Tolerance on impedance:
- Measured short-circuit impedance for:
  - A separate – winding transformer with two windings.
  - A specified first pair of separate windings in a multi-winding transformer.
  - Principal tapping + 7.5 %, - 0 %.
  - Any other tapping of the pair ± 10 % of the specified value.
- The magnetization Mo of the core can influence the following measurement
  (1) Turns ratios (2) Single phase impedance (3) Measurement transient voltage the transfer characteristics (4) FRA. For these measurement the core shall be in de-Magnetized condition Mo = 0 Am-1.
23.5 Routine Tests

Routine tests shall be performed on every transformer to verify that the product meets the design specification.

All dielectric tests specified herein are classified as routine test and shall be carried out on all units

The frequency of the test source shall be 60±0.3 Hz.

The following tests constitute routine tests and they are not in specific order:

a) Measurement of winding resistance.

b) Measurement of voltage ratio and check of phase displacement.

c) Measurement of short-circuit impedance and load losses between pair of windings at rated frequency with approximately sinusoidal voltage.

d) Measurement of no-load loss and excitation current at 90%, 100%, 110% and 120% of rated voltage at rated frequency with approximately sinusoidal voltage.

e) Dielectric routine tests.

f) Measurement of capacitances and tan delta of winding to earth and between windings.

g) Measurement of capacitances and tan delta of capacitor bushings that are to be installed on the ordered transformers.

h) Measurement of Frequency response (Frequency Response Analysis - FRA).

i) Test on ON-LOAD TAP-CHANGER where applicable DE-ENERGIZED TAP CHANGER.

j) Magnetic balance test.

k) Measurement of single phase short circuit impedance of each limb with single phase 60 Hz, low voltage.

l) Measurement of single phase excitation current at low voltage at 60 Hz.

m) Check of core and frame insulation for oil immersed transforms with core or frame.

n) Winding insulation test, polarization index and absorption Index.

o) Transient saturation. In rush current test.

p) Tests on transformer oil. This shall be performed before starting tests on transformers.

q) Vacuum and pressure withstand test and leakage test (Leak testing with pressure (tightness test)).

r) Measurement of dissolved gasses in transformer oil.

s) Particle content in transformer oil test. This shall be performed before starting tests and at the end of temperature rise test and after all the tests.

t) Tests on auxiliary, control and protection equipment.

u) Check of the ratio and polarity of built in current transformers.

Sequence of test: Tests on transformer oil including the particle content in oil, the resistance, excitation current, impedance, no-load loss and load loss tests (and temperature rise tests, where applicable) should precede dielectric tests.

23.6 Type Tests

Temperature rise tests.
23.7 Special Tests

a) Measurement of the harmonics of the no-load current.

b) Determination of sound levels. (IEC: 60076-10) for each method of cooling for which a guaranteed sound level is specified.

c) Vibration test.

d) Measurement of zero-sequence impedance(s) on three phase transformers.

e) Measurements of the power taken by the fan and oil pump motors.

f) Determination and measurement of transient voltage transfer Characteristics.

g) Short-circuit withstand test.

h) Vacuum deflection test.

i) Pressure deflection test.

j) Vacuum tightness test on site.


Test system accuracy required; ± 0.5% for resistance measurement and ± 1°C for temperature measurement.

Transformer shall be tested out-side tank before final tanking with approximately 20% currents of its rated current. Infrared thermo-grams shall be taken. Further LV winding resistance shall be measured out side the tank. The results shall be included in record.

D.C. source – The supply to the measuring circuit shall be with a constant current source. Modern electronic switching power supplies, which are capable of providing a predefined current within a wide voltage range, shall be used. Filtered Rectifier may be used. Automatic recording of resistance data is required so that the time to saturation and the variability of the resistance readings after stabilization can be documented.

Measurement of Winding Resistance for all the windings and for HV winding at all switch positions, the value of current shall be Max. 1/10, Min. 1/20 of In of the winding, limiting it to 600 A dc. The minimum current shall not be less than 40 A. The test to be repeated at the end of all tests. The terminals between which it is measured and the temperature of the winding, shall be recorded. For Y-connected winding, it shall be measured between line terminal and neutral.

For closed Delta connected winding, the resistance shall be measured across each phase to phase Terminal.

For open winding delta as defined in CL 21.18.8 of this specification, the resistance measurement shall be performed across terminal bushings of each phase.

Three measurements for each phase to phase across terminals of LV winding at three different values of currents to be performed to obtain most accurate result.

- The winding resistance Measuring Bridge / meter shall have the following features as minimum.

- Three measuring channels with automatic resistance correction for temperature for measuring of three resistances simultaneously.

- Three temperature channels (with automatic resistance correction).

- High power DC supplies 100 A……0.025 A, user selectable.
o Fast discharge unit with Discharge indicator both visible and audible for discharge status.

o Fully automatic demagnetizing circuit.

o Data transfer to internal printer at selectable intervals.

o Fully automatic cooling curve analysis.

o Memory Storage; memory storage up to $10 \times 10^6$ complete test results.

o Details of Measurements Bridge /Meter shall be included in test record.

o The test is to be repeated after all the test.

o Preferable equipment:
  1) Raytec winding resistance meter WR50 – BR with "Heat – Run Test" software AHRT01.
  2) Transformer test system TETTEX: 2292 and TETTEX: 2285C. / Digital thermometer for temperature measurement. Data acquisition system (DAS) or power Analyzers (Type D6100- LEM – Norma). Four wires volt meter ammeter method is least preferred. However digital volt meter and ammeter shall be used.
  3) Regulated DC power supply 0-60 V / 0-250 A or 0-60 V / 0-600 A.

The temperature difference between top oil temperature and bottom oil temperature at the time of windings resistance measurement shall be less than 5°C. Deviation in resistance between phases shall be < 2%.

The effect of self induction shall be minimized during resistance measurement. Details of Measurement Bridge or instruments shall be included in test record. Digital thermometer for temperature measurement.

23.9 Measurement Of Voltage Ratios And Check Of Phase Displacement
(In accordance to CL 11.3 of IEC: 60076-1/2011 and CL 10 of IEC: 60076-8)

The voltage ratio shall be measured on each tapping. Volt meter method is not acceptable. Turns Ratio Bridge with automatic indication of actual ratio value and polarity indicating vector group shall be used. Preferable equipment TETTEX: 2791 or/TTR 2795 TETTEX Version 1.2.3. or TETTEX TEST SYSTEM 2285C. Ratio Bridge that provide phase angle correction.

23.10 Measurement Of Short-Circuit Impedance And Load Losses Between Pair Of Windings
(CL 11.4 of IEC: 60076-1/2011)

Power supply shall be 60 ± 0.3 Hz from synchronous generator set.

The duration of the test should be as short as possible to avoid any significant heating of the winding.

The short-circuit impedance and load loss for pair of windings shall be measured at rated frequency with approximately sinusoidal voltage applied to the terminals of one winding with the terminals of the other Winding or windings short circuited generally in accordance with CL 10.4 of IEC: 60076-1. Each pair of windings shall be sequentially tested.

For two winding Transformer

1) HV---LV open

For three winding Transformer

1) HV---LV1, LV2 open

For Four winding Transformer

1) HV----LV1, LV2 & MV open
2) HV----LV2, LV1 open
3) HV----LV1+LV2
4) LV1----LV2, HV open
5) MV----LV1, HV & LV2 open
6) MV----LV2, HV & LV1 open
7) MV----LV1+LV2 open
8) HV----MV, LV1 open

Tests for items 1, 2 and 3 shall be tested at 1.0pu, 1.1pu, 1.5pu or 1.3pu of load current at principal, plus extreme tap and minus extreme tap and tap measuring the max. load losses for ONAN and ONAN/ONAF. For OFAF/ODAF cooling with unit coolers, test shall be performed at 1.0 pu, 1.15 pu and 1.3 pu at principal tap, plus and minus extreme tap at tap measuring of the maximum load losses.

Tests to be performed at all other taps at 0.5pu load current. Tests of item (4) shall be performed at 1.0pu and 1.3pu or 1.5pu of load current at LV1 or LV2 power rating. For multi-winding transformer, measurement shall be made on different two windings combinations. The result shall be re-calculated allocating impedances and losses to individual windings in accordance to IEC: 60606 and IEC: 60076-8. Total losses for specified loading cases involving all these windings shall be determined accordingly.

The test shall confirm to CL 10 of IEC: 60076-8

Losses shall be measured with three watt meter method per fig 17 of ANSI/IEEE St. C 57.12.90 / 2010. Maximum error of the complete test system as determined, certified by an independent testing service shall not exceed 3%.

Fundamental source of error in power transformer load loss measurement CL 10.3 of IEEE std. C57.12.90-2010 shall be taken into consideration.

All reactance measurements shall be to a repeatability of better than ± 0.2%

The best available measuring equipment such as zero-flux current transducers, capacitive voltage dividers, electronic blocking amplifiers and adjustable error compensation circuits, digital electronic power transducers etc. shall be used to so that the total measuring uncertainty shall be reduced to ± 2% or ± 3% at power factor of above 0.01.

For three winding transformer, calculation of the equivalent short circuit impedance per winding shall be submitted. Refer to CL 7.6 of IEC: 60076-8.

Correction of load loss measurement due to metering phase angle errors shall be in accordance to CL 9.4.1 of IEEE std. C57.12.90-2010.

Calculation of load loss per winding shall be submitted. Refer to CL 7.7 of IEC: 60076-8.

Where power analyzer is used, three watt meter method also be used and results of both measurements shall be submitted for comparing. For transformers with two secondary windings having the same rated power and rated voltage and equal impedance to the primary referred to as axial split dual secondary transformers, measurement to investigate the
symmetrical loading case shall be performed. The test shall be made with both secondary LV1 and LV2 short-circuited simultaneously with HV winding energized, refer to case (3) of multi winding. Test to be performed at principal tap and extreme taps. The values of current measured shall be recorded and submitted.

Preferable equipment: computer aided loss measuring system with 3 CTS", 3 PT’s Capacitance voltage dividers, Zero –flux current transformers and one frequency meter and Power Analyzer: NORMA 6100D or HAEFLEY LOSS measuring system TMS 584/100/4000 or TETTEX TMS 580.

The oil average temperature shall be measured and recorded.
The permissible uncertainty for loss measurement shall be ≤ 3%.

The relevant data for each test to be corrected from the main oil temperature at which test was performed to the reference temperature of 75°C. The temperature correction procedure as detailed in Annex E of IEC: 60076-1/2011 shall be used.

The report shall contain for each winding $I^2 R$ loss, axial eddy current loss, radial eddy current loss for principal tap, extreme tap and at tap measuring maximum load losses.

The report shall contain winding connection diagram with the direction of windings (i.e. clock wise or anti clock wise) shall be marked.

### 23.11 Measurement of No-load losses and Excitation current

For a three – phase transformer the selection of the winding and the connection to the test power source shall be as far as possible symmetrical and sinusoidal voltage across the three wound limbs in accordant to CL 11.5 of IEC: 60076-1/2011 and specific recommendation as laid down in IEC: 60076-8 CL 10.6.

Power supply shall be 60 ± 0.3 Hz from Synchronous Generator set.

The transformer shall be kept energized at 110% voltage for one hour to demagnetize the core before starting test. The connection of three phase transformer shall be made in such a way that the voltage applied across the different phases of the winding be as nearly sinusoidal as possible and symmetrical.

The measurements shall be made with three watt meter method even where power analyzer is used. The no-load losses shall be guaranteed using sinusoidal supply. Losses measured with distorted voltage wave shall be recalculated. Form factor correction for no-load losses shall be applied and calculations shall be submitted. Correction of the instruments and instrument transformers errors shall be carried out.

The measurements shall be made at 120%, 110% 100% and 90% of rated voltage at 60 Hz. For this test, the delta winding shall be closed and all other windings shall be open. The test shall be performed once before and once after all the dielectric tests.

Calculation for waveform correction of no load losses shall be included

After the completion of dielectric tests, the no-load losses shall be measured at 100% of rated voltage. The excitation voltage shall then be increased to 110% of rated voltage to demagnetize core and transformer left excited for one hour. The voltage shall then be reduced to 100% rated voltage and excitation losses measurement repeated. The last 100% rated voltage excitation loss measurement shall be the value used for evaluation of guaranteed losses. The difference between no-load loss before dielectric test and measurement after dielectric test shall not exceed 2.0%. Oil samples shall be taken before and after the one hour excitation test. The samples shall be subjected to gas analysis and comparison of result. The test record shall indicate the type of core 3+0 or 3+2.
Preferable equipment: Computer aided loss measuring system with 3 CT's, 3 PT's Capacitance voltage dividers. Zero –flux current Transformers and one Frequency meter: 
Preferable equipment: HEAFEELY LOSS measuring system TMS 584/100/400 which incorporates a power analyzer NORMA D6100D wideband power analysis systems or TETTEX 580 
- Digital thermometers for temperature measurement.

23.12 Dielectric Routine Tests

General:

Insulation requirements of transformers and the corresponding insulation tests specified with reference to specific windings and their terminals and apply to the internal insulation and external insulation.

The rules of dielectric testing depends on the values of Um. The highest voltage for equipment Um and its assigned rated withstand voltage determine the dielectric characteristics of a transformer which are verified by a set of dielectric tests.

The intent of dielectric test is to verify transformer integrity and withstandability against voltage stresses which can appear during normal as well as abnormal operation and also constitutes a check on the correct design of insulation.

All dielectric tests specified herein are classified as routine tests and shall be carried out on all units.

All transformers and windings with Um of 145 kV and below shall be designed and produced with uniform insulation.

The transformer shall be completely assembled as in service, including supervisory equipment. However, those elements which do not influence the dielectric strength of the internal insulation need not be fitted.

Transformers for cable box connection or dielectric connection to metal-enclosed SF6 should be designed so that temporary connection can be made for dielectric tests using temporary bushings if necessary.

The terms used here have the meanings ascribed to them in CL 3.0 of IEC: 60076-3.

The level of test voltages is identified by the highest voltage for equipment Um of a winding. The rated insulation level is characterized as follows:
- Um/SIL/LIL/LICL/ACL for the line terminals of each winding.
- Um/LIL/ACL for neutral terminal.

Tests shall be carried out in accordance with IEC: 60076-3 in line with guidance obtained from IEC: 60071, IEC: 60606, IEC: 60270 and IEC: 60076-4. Test levels and other test parameter as given in layout A and layout B and CL 12.0 of specification

Atmospheric correction factors for air gaps. The disruptive discharge of external insulation depends on atmospheric conditions, when test is not performed at a location as specified, the atmospheric correction factor Kt in accordance to IEC: 60060-1/2010 shall be applied. the test report shall always contained the actual atmospheric conditions during the test and in the correction factor applied.

It is mandatory to perform Dielectric tests to be performed immediately after temperature rise test in warm condition in sequence as indicated below. In order to keep the oil temperature near to the level during temperature rise test, the bottom throttle valves of Radiators and for
unit coolers bottom inlet valves of coolers shall be closed immediately after temperature rise test.

Tolerances on test parameters and values where specifically not given in this specification, then the values given in IEC: 60060-1 shall be used.

**The relevant applicable dielectric tests in sequence are as follows:**

- Full wave lightning impulse test for the line terminals (LIL).
- Chopped wave lightning impulse test for the line terminals (LICL).
- Full wave lightning impulse test for the neutral terminals (LIN).
- Switching impulse test for the line terminals (SIL).
- Applied voltage test (AV).
- Induced voltage withstand test (IVW).
- Induced voltage test with P.D. measurement (IVPD).

**23.12.1 Full Wave Lighting Impulse (LIL) and Chopped on Tail Lighting Impulse (LICL)**

**ON LINE TERMINALS**

The procedures for lightning and switching impulse testing shall be generally in line with IEC: 60076-4 and IEC: 60076-3.

Test technique are as recommended in IEC: 60060-1 and IEC: 60060-2. The voltage wave shapes to be used during lightning and switching impulse testing shall be in accordance to IEC: 60076-3.

Oscivogram of the current flowing to earth from the tested winding (neutral current) or the capacitive probe current i.e. the current transfer to the non-tested and shorted winding shall be recorded. This shall be used for fault indication.

The test shall be performed by direct application. The polarity of wave shall be positive.

(a) **Full wave lightning impulse test (LIL)**

It shall be generally in line with CL 13.2 of IEC: 60076-3.

Test voltage magnitude and wave shape.

The values of impulse test voltages as specified in CL 12.0 of this specification and as give in technical layout A and B.

(b) **Chopped on tail lightning impulse test (LICL)**

The peak value of the chopped wave lightning impulse shall be as per CL 12.0 of this specification.

It shall be generally in line with CL. 13.3 of IEC: 60076-3.

The rate of collapse: It shall be possible to obtain the highest rate of collapse. The time to first voltage zero after the instant of chopping shall not exceed 0.5 µs. The chopping time shall be between 3 µs and 6 µs.

The amplitude of reversed polarity of the chopped impulse (overswing) shall not be limited artificially to less than 40% of the chopped wave peak.
Sweep times should be on the order of 50 µs to 100 µs for full wave impulse, 5 µs to 10 µs for chopped wave and 100 µs to 600 µs for ground current measurements.

Impulse current traces, with a sweep time of 10 to 25 µs shall be recorded and compared before and after the chopped wave tests. It is important that the same recording time for the recording of the impulse current & voltage is used.

Trigatrons and multiple sphere chopping gaps with adjustable timing shall be used for LIC test. With these devices a high chopping steepness and chopping time tolerance of approximately ± 0.1 µs can be achieved. Plain rod to rod gap is not allowed.

IEC: 61083-2 shall be used in high voltage impulse testing of power transformers. A clear indication along with printout with respect to amplitude and time parameters should be given with respect to the evaluation of standard and non-standard wave shapes. Crest voltage tolerance for impulse test shall be + 0.5%.

The test facilities at manufactures test field shall be equipped with latest version of highly flexible impulse generator with out-put voltage from 200 kVp... 4800 kVp; energy storage shall be of range > 100... 500 kJ for transformers 100 MVA to 1500 MVA. At least two dumped capacitive impulse voltage dividers and impulse current shunts shall be available. M/s. HAEFLEY SGV Impulse voltage generator+ series E with Trigatron types 921 and 94 trigger devices multiple chopping gap, with the HIAS 743-2 and DIAS 733 HAEFLEY Impulse Analyzing system is preferable, Impulse voltage measuring system of DR-STRAUSS, Digital Measuring Instrument (DMI551), Digital Impulse Analyzer (MIAS) by HIGH-VOLT, voltage divider-PV & Shunt resistors. HIAS – 743 High resolution Impedance Analyzing system.

Evaluation of transformation ratio shall be by M/s. Haefley Ratio Meter type 430. Further reference Impulse Calibrator RIC 422 version shall be available. Periodic calibration of the divider ratio is a pre-requisite for flawless impulse test.

For recording, a multi-channel (at least six independent channel) precision impulse analyzing system of the highest performance class. Measurement evaluation and analysis of impulse voltages and currents shall be performed according to IEC: 61083, IEC: 60076, IEC: 600949, and IEC: 60230, the relevant standard for high voltage impulse testing.

Calibration facilities shall be available. To facilitate the assessment of the test results by comparison of oscillograms and digital recordings, facilities for super-position for voltage waves, impulse response currents etc., shall be available. These comparison records in different colors shall be submitted along with the test report.

Voltage oscillograms for all impulses and ground currents oscillograms and reduced full wave shall be included. Sweep time should be of the order of two 2 micro seconds to five 5 micro seconds for front-of-wave tests. 5 to 10 micro seconds for chopped wave test. 50 to 100 micro seconds for ground current measurement.

When report required oscillograms those of the first reduced full wave voltage and current the last 2 chopped waves and the last full wave of voltage and current shall represent a record of the successful application of the impulse test to the transformer.
Recording of Tests:

All impulses applied to transformer shall be recorded by suitable digital transient recorder.

Digital recording systems as given in IEC: 61083-1 and clause 7.5.4 of IEC: 60076-4 shall be used for the recording of lightning and switching impulse voltage and current response wave shapes. The Impulse Analyzing system shall comprise of:

- Calibration
  - Hardware (IEC: 1083-1).
  - Software (IEC: 1083-2).
- Analysis
  - Differences.
  - Parameter Tolerance.
  - Transfer.
  - Coherence.
- Functions
  - Comparison.
  - Sequencer, define sequence.
  - Sequencer, execute sequences option.
- Zooming
- Printing of result

Evaluation of wave shapes parameters and also for the assessment of test results, based on the comparison of recordings taken at reduced and full impulse voltage and switching voltage levels. Additionally, the recorded data may also be processed by wave analyzing algorithms, for example for fault analysis in recordings (See clause 10 of IEC: 60076-4).

Use of sphere gap for checking of scale factor of impulse peak voltage shall be available. The value of withstand voltages specified are based on standard reference atmospheric conditions. When a transformer tests at an altitude of less than 1000 meter is to be operated at an altitude above 1000 meter, atmospheric correction factors in accordance to CL 11.2 of IEC: 60060-1/1989 shall be applied. The voltage U to be applied during a test on external terminal is determined by multiplying the specified test voltage Uo by kt; U=Uo kt.

The test report shall contain the actual atmospheric conditions during the test and the correction factors applied.

The application of correction factors results in the withstand levels for higher level for the internal insulation, higher than at standard pressure, temperature and humidity as specified. The manufacturer shall design the transformer for test condition.

(c) Test Sequence and Test Criteria.

- The test connections during test on line terminals in accordance to CL 13.1.4 of IEC: 60076-3:
- Impulse test circuit similar to fig 1 of IEC: 60076-4 shall be enclosed.
- Impulse test terminal connections and applicable methods of failure detection to fig 2 of IEC: 60076-4.
The test sequences shall be in accordance to CL 13.3 of IEC: 60076-3 and as follows:
- One reduced level of LIL.
- One full level LIL.
- One or more reduced level LICL.
- Two full level LICL.
- Two full level LIL.

The test sequence for application of LI and LIC shall be U-Phase at Max. voltage ratio tap, V phase at Min. voltage tap and W Phase at principal tap.

The test set up shall have minimum four channels for recording:
- Channel 1 for voltage full wave.
- Channel 2 for HV neutral current.
- Channel 3 and 4 for LV terminal currents.

The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests.

(d) Records of tests.
The digital records obtained during calibration and tests shall clearly show the applied voltage with timings.

(e) The transferred surge method on low voltage winding shall not be accepted. These terminals / winding shall be tested by impulse directly applied.

(f) Failure:
Where that transformer fails any test in its test sequence and the transformer is reprocessed for any reason, all tests including those which were successful prior to the failure, shall be repeated.

23.12.2 Lightning Impulse Test on The Neutral Terminal

The test shall be in general in accordance to CL 13.1.4.2 of IEC: 60076-3.

Test impulses LIL as specified and as given in technical layout A and B shall be applied directly to the neutral with all line terminals earthed. A long duration of the front time is allowed up to 13 μs.

The impulse circuit and measuring connections shall remain unchanged during reference and full voltage tests.

One reduced and three full-waves of positive polarity shall be applied.

The tapping connection with the minimum turns ratio shall be chosen for the impulse test.

23.12.3 Lightning Impulses applied to two or more terminals simultaneously (LIMT).

Details of test Ref. Clause 23.14.7

23.12.4 Switching Impulse Test (SIL) For The Line Terminals
- The switching impulse test voltage of positive polarity that specified for
  the winding with the lightning Um value and as specified in in CL 12.1
  upto and including Um=36KV.

- The impulses shall be applied directly from the impulse generator. The
  specified test voltage shall appear between the line terminal and earth.
  The voltage shall be measured at the line terminal. Three phases
  transformer shall be tested phase by phase.

- The voltage impulse wave shape shall have a time to peak (Tp as
  defined in IEC: 60060-1) of at least 100 µs, at a time 90% (Td as
  defined in IEC: 60060-1) of the specified amplitude of at least 200 µs,
  and a time to zero Tz as defined in IEC: 60060-1 of a minimum of 1000
  µs. a time to zero of less than 1000 µs is permissible if as far as
  practicable full reverse saturation of the core is achieved.

- Tolerances
  - Value of test Voltage ± 3%
  - Time to peak ± 20%
  - Time to half-value ± 60%

- Test circuit shall be generally in line with CL. 5 of IEC: 60076-4, Fig 1, 2
  and 4 and calibration in accordance to CL. 6 of IEC: 60076-4.

- Test circuit shall be included in the record.

For failure detection, the examination of the raw data digital records of the applied
test voltage and impulse response current of winding shall be used for failure
detection. Different transients shall be recorded and used, separately or in
combination as shown in Fig 2 & 4 of IEC: 60076-4.

Digital processing that includes transfer function analysis shall be used as an
additional tool for failure analysis in line with IEC: 60076-4 Clause 10, Fig B17.

Before a test, an overall check of the test circuit and measuring system shall be
performed at a voltage lower than the reduced voltage level. Neither the
measuring nor the test circuit shall be altered during testing.

The polarity of SIL, LIL, and LICL shall be positive. Test shall be performed by
direct application, "transferred surge" method is not acceptable. Digital recording
systems in line with CL 7.5 of IEC: 60076-4 shall be used for recording of impulse
voltage and current response wave shapes. All impulses applied to a transformer
shall be recorded by suitable digital transient recorder. These tracing or
oscillograms shall include voltage tracing or oscillograms for all impulses and
ground current tracing oscillograms for all full waves and reduced full wave
impulses. Impulse test reports shall be in compliance to CL 11 of IEC: 60076-4.

Test sequence shall be phase U for maximum tap. Phase V for minimum tap and
phase W for normal tap.

The test sequence shall consist of one reference impulse of a voltage between
60% to 70% of the full test voltage and three impulses at full voltage.
Sufficient reverse polarity applications must be magnetization of the core is
similar before full wave impulse in order to make the time to first zero as uniform
as possible.
Digital / oscillographic records shall be made of the impulse wave-shape on the
line terminal under test and the current between the tested winding and earth.
Test facilities for Impulse Test

The test facilities at manufacturers test field shall be equipped with latest version of highly flexible impulse generator with output voltage from 200 kVp... 4800 kVp; energy storage shall be of range > 100... 500 kJ for transformers 100 MVA to 1500 MVA. At least two damped capacitive impulse voltage dividers and impulse current shunts shall be available. M/s. HAEFLEY SGV Impulse voltage generator series E with Trigatron types 921 and 94 trigger devices multiple chopping gap, with the HIAS 743-2 and DIAS 733 HAEFLEY Impulse Analyzing system is preferable, Impulse voltage measuring system of DR-STRAUSS, Digital Measuring Instrument (DMI551), Digital Impulse Analyzer (MIAS) by HIGH-VOLT, voltage divider-PV & Shunt resistors. HIAS – 743 High resolution Impedance Analyzing system.

To achieve a proper wave shape, recommendations as cited in CL 13.2.1 of IEC: 60076-3/2013 shall be implemented. Further principal of wave shape control as given in Annex A of IEC: 60076-4 to be followed.

Evaluation of transformation ratio shall be by M/s. Haefley Ratio Meter type 430. Further reference Impulse Calibrator RIC 422 version shall be available. Periodic calibration of the divider ratio is a pre-requisite for flawless impulse test.

For recording a multi-channel (at least six independent channel) precision impulse analyzing system of the highest performance class. Measurement evaluation and analysis of impulse voltages and currents shall be performed according to IEC: 61083, IEC: 60076, IEC: 600949, and IEC: 60230, the relevant standard for high voltage impulse testing.

Calibration facilities shall be available. To facilitate the assessment of the test results by comparison of oscillograms and digital recordings, facilities for superposition for voltage waves, impulse response currents etc., shall be available. These comparison records in different colors shall be submitted along with the test report.

Recording of Tests:

All impulses applied to transformer shall be recorded by suitable digital transient recorder.

Digital recording systems as given in IEC: 61083-1 and clause 7.5.4 of IEC: 60076-4 shall be used for the recording of lightning and switching impulse voltage and current response wave shapes. The Impulse Analyzing system shall comprise of:

- Calibration
  - Hardware (IEC: 1083-1).
  - Software (IEC: 1083-2).
- Analysis
  - Differences.
  - Parameter Tolerance.
  - Transfer.
  - Coherence.
- Functions
  - Comparison.
  - Sequencer, define sequence.
  - Sequencer, execute sequences option.
- Zooming
- Printing of result
Evaluation of wave shapes parameters and also for the assessment of test results, based on the comparison of recordings taken at reduced and full impulse voltage and switching voltage levels. Additionally, the recorded data may also be processed by wave analyzing algorithms, for example for fault analysis in recordings (See clause 10 of IEC: 60076-4). Interpretation of oscillogrames are digital recording to be performed according to CL 9 of IEC: 60076-4/2002.

Use of sphere gap for checking of scale factor of impulse peak voltage shall be available. The value of withstand voltages specified are based on standard reference atmospheric conditions. When a transformer tests at an altitude of less than 1000 meter is to be operated at an attitude above 1000 meter, atmospheric correction factors in accordance to CL 11.2 of IEC: 60060-1/1989 shall be applied. The voltage U to be applied during a test on external terminal is determined by multiplying the specified test voltage $U_o$ by $k_t$; $U = U_o \times k_t$.

The test report shall contain the actual atmospheric conditions during the test and the correction factors applied.

The application of correction factors results in the withstand levels for higher level for the internal insulation, higher than at standard pressure, temperature and humidity as specified. The manufacturer shall design the transformer for test condition.

23.12.5 Applied Voltage Test (AV)

- Test shall be made with single-phase alternating voltage generally in accordance to clause 10 of IEC: 60076-3. The sinusoidal voltage wave form requirements as specified in IEC: 60060-1.
- Test circuit shall be given in the test record.
- The test shall be carried out on each separate winding of the transformer in turn.
- The winding being tested shall have all its terminals joined together and connected to the line terminal of testing transformer. All other winding terminal and parts (including core and tank) shall be grounded.
- The voltage shall be started at 1/4 of the full value and be raised gradually to full value. After being held for specified time shall be reduced gradually before circuit is open.
- Test voltage at rated frequency must be adjusted using peak voltmeter. The peak value divided by $\sqrt{2}$ shall be equal to the total value.
- The full test voltage shall be applied for 60s.
- HAEFELY Single phase Resonant Test System or AC Resonant system by HIGH-VOLT may be used.
- Applied Voltage Test Bench by HIGH-VOLT.
- HV potential divider with AC measuring device shall be used.
- Potential divider shall be calibrated before test commences. Information on the type of voltage dividers their application accuracy, calibration and checking shall be submitted.
- Where 60 Hz transformer is tested with 50 Hz, the test time shall be 72 seconds.

23.12.6 Induced Voltage Tests (IVW and IVPD)

The transformer shall receive an induced- voltage test with the required test levels induced in the high-voltage winding.
The P D measurement is mandatory for long duration voltage test (IVPD) and as well as for short – duration induced voltage test (IVW).

The detection and the quantitative electrical measurements of impulsive (short duration) partial discharges magnitude shall be in accordance to IEC: 60270/2000, including measuring instruments, calibrator characteristics, test circuits, calibration procedure and partial discharge measurements during induced- voltage tests, the test circuit for detection and measurement of PD. as shown in fig 2 or fig 3. of IEC:60270/2000. The basis of measurement is apparent charge. The measuring system used may be a narrow band or wide band. Quantitative measurements of partial discharge magnitude by digital acquisition, is preferable. 8 Channel partial discharge detector shall be used.

The calibration of measuring system in the complete test circuit shall be made by injecting short duration current pulse of charge magnitude q0 = 50 pC, 100 pC and 200 pC into the terminal (HV) of the transformer. For calibration to remain valid, the calibration capacitor should not be greater than 0.1 Ca (test object). The signal amplitude read on the discharge meter should not deviate by more than 10% from a straight line for all the values injected.

Calibration shall br performed for each terminal bushing in accordance to IEC: 60270.

Recommendation: The rise time of injected impulse should be ≤ 60 ns, amplitude U0 between 2V and 50 V, selectable polarity and repetition rate 100 Hz.

During the PD test, the measuring system values shall read directly in pC. This pC reading is only valid for the specific calibrated bushing.

- The form of the voltage shall be as possible sinusoidal.
- Test voltage shall be partial discharge free. An impedance or a filter can be introduced to reduce back ground noise from power supply.
- Energized background noise level shall be measured and recorded, it shall not exceed 35 pC.
- PD measurement shall be performed on all high - voltage Terminals of 72.5 kV class and above.
- Calibrator out-put level shall be indicated in test record.

The following Voltage Levels shall be recorded:

- Partial discharge Inception voltage Ui [CL 3.7.1 and CL 8.3.1 of IEC: 60270].
- Partial discharge extinction voltage Ue [CL 3.7.2 and CL 8.3.1 of IEC : 60270].
- Partial discharge test voltage [CL 3.7.3 of IEC: 60270].

- Partial discharge measuring system characteristics, as defined in CL 3.9.0 of IEC: 60270.
- Digital partial discharge instruments. CL 3.10.0 of IEC: 60270.
- Test circuit and measuring systems CL 4. 0 of IEC: 60270.
- Requirement for measurement with digital PD instruments. – CL 4.4 of IEC: 60270.
- The PD measuring system shall be calibrated in accordance with the provisions of CL 5 of IEC: 60270 prior to testing.

I. Equipments:
- HAEFELY type 51 Precision AC – Peak Voltmeter.
- P.D. detector TETTEX type 9120, Biddle 27000 and 3700 detectors
- Power analyzer NORMA D6100.
- Measuring impedance: - Type: 9238.
- 3 No. Single phase filter 69 µ H.
- Power diagnostic ICM 8 channels partial discharge system.
- Ultrasonic PD. Detector.
  or, Digital partial Discharge measuring system LDS – 6 and LDIC.

23.12.6.1 Induced Voltage Withstand Test (IVW)

For three phase transformers with uniformly insulated and non-uniformly insulated high voltage windings, the following procedure to be followed:

- The voltage shall be measured on the highest voltage terminals. Before commencing test, calibration of voltage potential dividers at two standard voltage levels shall be done. If measurement at highest voltage is not practical, the voltage shall be measured at the terminals of the transformer connected to the supply.
- The principal tap shall be used for test.

23.12.6.2 Line terminal AC withstand test (LTAC)

It shall consists of three single phase applications of the test voltage between phase and earth with different points of windings connected to earth each time in accordance to Fig. 2 with partial discharge measurements. Energize one of the phase of LV side with frequency higher than 60 Hz, single phase power while keeping the HV terminals isolated.

The test levels, duration and time sequence of test voltage with respect to earth in accordance to Fig. 1 given below:

- Duration of test shall be minimum 60 seconds independent of the test frequency at voltage level U1.
- Preferable equipments
  - PD detector TETTEX Type 9120 or Biddle PD detector type 23500.
  - HAEFELY TRENCH PD Detector TE571.
  - ROBINSON DDX-9101 PD Detector.
  - Divider set with measuring instruments. Type MICAFIL SC 400 / TETTEX 9238.
  - HAEFELY P.T 220 kV / 100 V.
  - External calibrator and test tools / TETTEX PDG
    TETTEX  PD-Detector – DDX-9101
    HAEFLY PD-Detector - 571

- Six measurement channels are required.
- Measure, observe and record the following values.
  - Background noise level
Apparent charge "during the rising of the voltage up to the level of U2 and reduction from U2 down against possible partial discharge inception and partial discharge extinction voltages shall be noted.

Apparent charge measurement may be made on a wide – band or narrow-band basis as both systems are recognized and widely used.

The voltage source in the HV laboratory must be free from PD and the form of voltage shall be as nearly as possible sinusoidal. The peak value divided by √2 shall be equal to the test value. All objects in the test field close to the Trafo. under test must be earthed.

The following shall be given in test record:
- Test condition: Phase to ground.
- Circuit diagram.
- Calibration diagram.
- Test voltage and time.
- Sequence of test duration.

![Diagram of voltage sequence](image)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1Um/√3</td>
<td>U2 = 1.5 Um/√3</td>
<td>U2 = 1.5 Um/√3</td>
<td>1.1Um/√3</td>
<td></td>
</tr>
</tbody>
</table>

U start

<table>
<thead>
<tr>
<th>A = 5 min</th>
<th>B = 5 min</th>
<th>C = test time – 60 seconds</th>
<th>D = 5 min</th>
<th>E = 5 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1 = Test level as specified in layout A &amp; B and as follows: For Um = 420 kV, U1 = 630 kV.</td>
<td>For Um = 245 kV, U1 = 460 kV.</td>
<td>For Um = 145 kV, U1 = 275 kV.</td>
<td>For Um = 123 kV, U1 = 230 kV.</td>
<td>For Um = 72.5 kV, U1 = 140 kV.</td>
</tr>
</tbody>
</table>

U end

IEC272/2000

Figure 1 – Time sequence for the application of test voltage with respect to earth.

**Acceptance Criteria:**

- The PD level shall not exceed 100 pC at the continuous level of "apparent charge" at U2 during 5 min.
- No collapse of the test voltage shall occur.
- The partial discharge shall not show a continuously rising trend.
- The continuous level of apparent charges does not exceed 100 pC at U2 = 1.1 Um / √3.
23.12.6.3 Induced Voltage With Partial Discharge Measurement Test (IVPD)

- The test shall be carried with neutral terminal earthed and using a symmetrical three-phase test voltage.
- The principal tap shall be used.
- The form of the voltage applied to the terminals of windings shall be sinusoidal.
- The peak value divided by √2 and the r.m.s value of the induced voltage shall be measured and the lower of the peak value divided by √2 and r.m.s value shall be taken as test value.
- The test time of the enhancement voltage shall be 60s irrespective of test frequency.
- The duration of the test shall be independent of the test frequency.

Transformer Test circuit shall be in accordance to Fig 2, or Fig 3, of IEC: 600270.

a. The PD measurement is mandatory for long duration induced voltage (ACLD) for voltage class Um ≥ 36 kV.

b. PD test shall be performed in shielded laboratory.

c. Calibration shall be performed for each terminal bushing, in accordance to IEC: 60270. At least three separate charge repetitive impulses at 50 pC, 100 pC, and 200 pC injected to ensure that pd. measuring circuit is linear over the range of interest.

Recommendation:

The rise time of injected impulse should be ≤ 60 ns, amplitude Uo between 2V and 50V, selectable polarity and repetition rate 100 Hz.

d. During the PD test, the measuring system values shall read directly in pC. This pC reading is only valid for the specific calibrated bushing.
e. Any wide-band pass filter with lower and upper cut off frequencies
   \( f_1 \) and \( f_2 \), \( f_1 = 50 \text{ KHz} \) and \( f_2 = 150-400 \text{ KHz} \) can be used as a
   PD measuring system.

f. A multi-channel (minimum 8 No) PD measuring system capable of
detecting PD activity at all bushing simultaneously.

g. PD measurement shall be performed at each test voltage level. All
measured pC values at all bushings of the transformer should be
documented. During the long duration test period the PD shall be
measured every 5 minutes at each bushing.

**Test sequence**

The test sequence shall be as follows:

Refer to Fig 4.

- The voltage shall be switched on at a voltage not higher than 0.4 Um/√3.
- The voltage shall be raised to 0.4 Um/√3 and a background PD
  measurement shall be made and recorded.
- The voltage shall be raised to 1.2 Um/√3 and held there for long enough
to make a stable PD measurement.
- The PD level shall be recorded.
- The voltage shall be raised to the one hour PD measurement voltage 1.8
  Um/√3 there for a minimum duration 5 minutes.
- The PD level shall be measured and recorded.
- The voltage shall be raised to the enhancement voltage 2 Um/√3 and held there for time 60s.
- Immediately after the enhancement time, the voltage shall be reduced
  without interruption to the one hour PD measurement voltage 1.8Um/√3.
- The PD level shall be measured and recorded.
- The voltage shall be held at the one hour PD measurement voltage for
duration of at least 60 minutes following the PD measurement.
- The PD level shall be measured and recorded every 5 minutes during the
  60 minute period.
- After the last PD measurement in the 60 minute period, the voltage shall
  be reduced to 1.2Um/√3 and held there for long enough to make a stable
  PD measurement.
- The PD level shall be recorded.
- The level shall be reduced to 0.4Um/√3 and the background PD level shall
  be measured and recorded.
- The level shall be reduced to a value below 0.4Um/√3.
- The voltage shall be switched off.

The partial discharge level shall be continuously observed on all the measuring
channels for the entire duration of the test.
During the test sequence, the inception and extinction voltages of any significant PD activity should be noted to aid the evaluation of the test result if the test criteria are not met.

NOTE: It may also be helpful to record the PD pattern (phase angle, apparent charge and number) of any significant PD activity to aid evaluation.

![Diagram of test time sequence](image)

**Fig-4 Time sequence for the application of test voltage for induced voltage with partial discharge measurement (IVPD)**

**Partial discharge (PD) measurement**

Partial discharge shall be measured by a method according to IEC: 60270.

Each PD measurement channel including the associated bushing or coupling capacitor shall be calibrated in terms of apparent charge (pC) according to the method given in IEC: 60270.

The PD measurement shall be given in (pC) and shall refer to the highest steady-state repetitive impulses indicated by the measuring instrument.

Occasional bursts of high partial discharge level may be disregarded.

For each required PD measurement step in the test sequence, PD measurement shall be made and recorded on all the line terminals equipped with bushings with Um≥ 72.5 kV, during the test, however if there are more than 6 such terminals, then only 6 measurements need to be made (one on each of the highest voltage terminals) unless otherwise specified.

**Test acceptance criteria**

The test can only be considered valid if the measured background PD level does not exceeds 35 pC at both the beginning and the end of the test.

The test is successful if all the following criteria are fulfilled:

1. No collapse of the test voltage occurs.
2. None of the PD levels recorded during the 60 minute period exceed 100 pC.
3- The PD levels measured during the 60 minute period do not exhibit any rising trend and no sudden sustained increase in the levels occur during the last 20 minutes of the test.

4- The measured PD levels during the 60 minute period do not increase by more than 25 pC.

Preferred equipments:

I. P.D. Multiplexer
   - P.D. Detector Type 571
   - P.D. Coupling quadripole AK V 572

Manufacturer: HAEFLEY TRENCH AG.

II. Digital partial discharge measuring system LDS-6

Manufacturer: LEMKE DIAGNOSTICS GmbH

Radeburgerstrasse 47
01468 VOLKERSDORF/Germany

23.12.7 Measurement Of Capacitance And Tan Delta Of Windings To Earth & Between Windings

Insulation power factor is the ratio of the power dissipated in the insulation in watts, it is the product of the effective voltage and current in amperes when a sinusoidal voltage is applied to the prescribed condition.

Test shall be performed in accordance to CL 10.10 of ANSI/IEEE C57.12.90/2010 table 4 shown below. Method II – guard circuit method is preferable.

Calculation of individual capacitance shall be included in the test record.

Preferable equipment: Capacitance and Dissipation tan-delta Bridge type 2809 of TETTEX or DOBLE M2H or DOBLE M4100 or Tettex C Instruments Type 2818/5283.

Drawing showing disposition of winding with respect to core and with respect each other shall be enclosed with test report

Measurements to be made from windings to ground and between windings as given below:

<table>
<thead>
<tr>
<th>Method I Test without guard circuit</th>
<th>Method II Test with guard circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-winding transformers</td>
<td>Two-winding transformers</td>
</tr>
<tr>
<td>HV to LV + Ground</td>
<td>HV to LV + Ground</td>
</tr>
<tr>
<td>LV to HV + Ground</td>
<td>LV to HV + Ground</td>
</tr>
<tr>
<td>HV + LV to Ground</td>
<td>HV + LV to Ground</td>
</tr>
<tr>
<td></td>
<td>LV to Ground, Guard on HV</td>
</tr>
<tr>
<td>Three-winding transformers</td>
<td>Three-winding transformers</td>
</tr>
<tr>
<td>HV to LV1+LV2 + Ground</td>
<td>HV to LV1 and Ground, Guard on LV2</td>
</tr>
<tr>
<td>LV1 to HV + LV2 + Ground</td>
<td>HV to Ground, Guard on LV1 + LV2</td>
</tr>
<tr>
<td>LV2 to HV + LV1 + Ground</td>
<td>LV1 to LV2 + Ground, Guard on HV</td>
</tr>
<tr>
<td>HV + LV1 to LV2 + Ground</td>
<td>LV1 to Ground, Guard on HV + LV2</td>
</tr>
<tr>
<td>HV + LV2 to LV1 + Ground</td>
<td>LV2 to HV + Ground, Guard on LV1</td>
</tr>
</tbody>
</table>
Average oil temperature shall be measured and recorded. Values of insulation power factor to be corrected for 20ºC. Refer to Annex S.

Test circuit and capacitance module diagram shall be included.

Voltage to be applied, 2 kV to 12 kV in steps of 2 kV with preferably Schering Bridge or any suitable type of bridge. However, the voltage applied shall not exceed half of separate source AC withstand voltage as given in CL 12.0 of SEC specification. The type of Bridge used shall be indicated in test record.

The test to be performed once before dielectric tests and once after dielectric test. Both test records to be submitted.

The power factor shall be less than 0.5% when measured between 10ºC to 30 ºC corrected to 20ºC winding temperature. Result and a description of the method used shall be recorded in the test report. Correction factor shall be included.

Multiplier for use in converting power factors at test temperatures to power factors at 20ºC shall be as per ANSI/IEEE C 57.12.90/1993. Ref. Annex – S.

23.12.8 Measurement Of Capacitance And Tan Delta Of Capacitor Bushings

Main Capacitance C1 (Capacitance between high voltage Conductor and test tap) and tan delta of condenser bushings in voltage range of 2kV to 12kv in step of 2 kV shall be measured on each capacitor bushing that are going to be fixed on the transformer at site. The temperature at the time of measurement shall be recorded in the test report.

The bushings with tan delta> 0.4% at temperature of 30ºC shall be rejected.

Tap Capacitance C2 (Capacitance between test tap and mounting flange) and tan delta of condenser bushing in the range of voltage 0.5 kV and 1.0 kV shall be measured on each capacitor bushings that are going to be fixed on transformer at site.

The dissipation factor varies with temperature of insulations.

The measured dissipation factor value shall be temperature corrected according to the correction factor given in Annex U.

The corrected dissipation factor (tan δ) shall be compared with the value on the rating plate or in the test report.

Both C1 and tan δ1 and C2 and tan δ2 shall be compared with the manufacturer's data. Mean oil temperature to be recorded. Tan δ1 and Tan δ2 to be corrected for temperature of 20 C and 30 C and correction factor to be stated. Refer Annex U.

Further, the temperature correction factor as recommended by the manufacturer of bushing shall also be included for comparison purposes.

Test circuit shall be included.

Preferable equipment: Same in CL 23.12.6.

23.12.9 Test On On-Load Tap-Changer

Refer to CL 20.6.4.
23.12.10 Magnetic Balance Test

The core shall be in demagnetized condition

The manufacturer to check the healthiness of core and winding at low voltage by performing this test. Single phase voltage 220…380V, 60 Hz be applied to each phase and neutral of HV or LV1 or LV2 or MV line terminals by turn and the voltages induced in the other phases of the same winding are to be measured and reported in tabular form.

Test circuit shall be given in test record.


The core shall be in demagnetized condition, further it is essential that the 60 Hz measuring source wave form shall be same for each impedance test.

It is important that the single-phase impedance measurement include only the winding on that leg.

Short-circuit impedance (often referred to as leakage reactance) per phase basis, between each pair of winding from the HV as well as LV, LV1 & LV2 side. Measurements shall be performed for all tapings position.

The measuring digital instruments must have the demonstrated capability of giving reproducible readings within an accuracy of ± 0.1%. The measurement at a current sufficiently high that the magnetizing impedance is insignificant, and to ensure that shorting leads of sufficiently low impedance, particularly when testing transformers with large turn's ratio.

The measurement of short-circuit impedance of each limb of the transformer with single-phase voltage at rated frequency with approximately sinusoidal voltage applied to the terminals of one winding with the terminals of other winding or windings short circuited. Each combination given below shall be sequentially tested.

For HV winding with tappings, tests to be performed at all tappings.

Details of voltage applied and measured current and impedance in ohms shall be given against each measurement in tabular form.

<table>
<thead>
<tr>
<th>For two winding Transformer</th>
<th>For Three winding Transformer</th>
<th>For Four winding Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- HV-LV OPEN</td>
<td>1- HV-LV1, LV2 OPEN</td>
<td>1- HV-LV1, LV2&amp;MV</td>
</tr>
<tr>
<td>2- LV-HV OPEN</td>
<td>2- LV1-HV, LV2 OPEN</td>
<td>2- LV1-HV, LV2&amp;MV</td>
</tr>
<tr>
<td></td>
<td>3- HV-LV2, LV1 OPEN</td>
<td>3- HV-LV2, LV1&amp;MV</td>
</tr>
<tr>
<td></td>
<td>4- LV2-HV, LV1 OPEN</td>
<td>4- LV2-HV, LV1&amp;MV</td>
</tr>
<tr>
<td></td>
<td>5- HV-LV1 + LV2 OPEN</td>
<td>5- HV-LV1+LV2, MV OPEN</td>
</tr>
<tr>
<td></td>
<td>6- LV1+LV2 – HV OPEN</td>
<td>6- LV1+LV2-HV, MV OPEN</td>
</tr>
</tbody>
</table>
7- LV1-LV2, HV OPEN 7- HV-MV, LV1&LV2

8- LV2-LV1, HV OPEN 8- MV-HV, LV1&LV2

LV2&HV OPEN

LV2&HV OPEN

LV1&HV OPEN

LV1&HV OPEN

HV OPEN

HV OPEN

Voltage: Single phase 380V -------- 5000V, 60 Hz
Preferable Equipment:
  - Maxwell Bridge
  - Power Analyzer NORMA: D6100
  - HAEFLEY LOSS Measuring System TMS 584/100/400 D

Test circuit shall be given in test record.

23.12.12 Measurement Of Single Phase Excitation Current At Low Voltage 60 Hz

The core shall be in demagnetized condition.
Single phase low voltage 220…380V, 60 Hz shall be applied preferably between HV line terminal and neutral terminal by turn and the magnetizing current is measured.

All other winding left open. The terminals normally grounded in service should be grounded during test, except for the particular winding energized for test. The tap changer should be set to principal tap and extreme taps. Test voltage should be the same for each phase.

This test is complementary to above mentioned test (CL 23.12.9).
Preferable equipment: Power Analyzer NORMA: D6100D.

23.12.13 Measurement Of Core and Frame Insulation

This test shall be performed at 3.5 kV DC for 1 min. without breakdown by a Megger instrument from core to core clamp, core to earth and core + core clamp to earth.
Preferable equipment: MEGGER BM 25. or MEGGER MIT 520.

23.12.14 Winding Insulation Resistance Tests, Polarization Index And Absorption Index
Insulation resistance shall be made in accordance to CL 10.11 of IEEE std. C 57-12-90/2010.

This test shall be performed at 5 kV DC by a Megger/Mega meter. The tests shall be made to determine the insulation resistance from individual windings to ground or between individual windings commonly measured in Megaohms. Average oil temperature shall be recorded prior to measurement. Time resistance method where the IR values shall be recorded for 15 sec, 60 second and 600 sec is one of the best methods. The reading to be corrected for 20°C. Polarization index and Absorption index shall be calculated. For temperature correction factor, refer to Annex T.

Absorption Index : 60/15 Sec.
Polarization Index : 10/1 Min.

Test circuit shall be given in test record. The temperature correction factor shall be indicated. Curve indicating correction factor of insulation resistance for 20°C shall be included.

The ratio R60/R15 called absorption ratio is normally in the range 1.3 to 3 in dried transformers.

The R600/R60 called polarization index < 1, the insulation condition unsatisfactory.

The R600/R60 called polarization index > 2, the insulation condition good.

Preferable equipment: MEGGER BM25

23.12.15 Vacuum And Pressure Test

Refer to CL 21.2.0, CL 21.3.0 of this specification.

23.12.16 Dissolved Gas Analysis (DGA) in accordance to IEC: 61181/2007

- Sampling of oil shall be carried out using apparatus and methods complying with IEC: 60567 in a gas-tight glass syringe of suitable capacity and fitted with a three-way sampling cock.

- Sampling location:

  Draw oil from main oil stream from return oil circuit of each group of radiators or battery of coolers for DGA analysis.

  See CL 21.8.0 (oil sampling devices).

  For OFAF and ONAN/OFAF cooling, where oil pumps are installed, they shall be operated 2h before the first oil sample is taken and kept running until the last oil sample is taken except for any period the test condition require the pumps to be turned off.

- Sampling frequency:

  Oil samples for DGA shall be taken before the test begins and after conclusion of the tests in the following schedules:
- Before start of tests.
- Before start of temperature rise test.
- Before start of over-load temperature rise test.
- At the end of over-load temperature rise test.
- Before dielectric tests.
- At the end of dielectric tests.
- 24 hours after the tests is completed.

Gases dissolved in oil should be extracted and analyzed by gas chromatography in accordance with IEC: 60567 with detection limits of the overall determination indicated in Table 1.

Table 1 – Required detection limits for factory tests

<table>
<thead>
<tr>
<th>Gas</th>
<th>Concentrations</th>
<th>μl/l</th>
<th>μmol/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>2</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>0.1</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>10</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>500</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>2000</td>
<td>84</td>
<td></td>
</tr>
</tbody>
</table>

Oil samples should be analyzed as soon as possible after being taken and in no case later than seven days afterwards.

The admissible limits for gas rate increases shall be in accordance to table D-2 of IEC: 60076-2/2011. In case the values of rate of increase determined by gas analysis before and after the temperature rise test exceeds the limits of the first series, the temperature rise test to be started again for a longer duration.

Test record shall contain type and brand of oil and equipment used.

23.12.17 Particulate content in transformer oil test in accordance to IEC: 60970

The test shall be conducted preferably by automated particle counters working on the light interruption principle in accordance to IEC: 60970/2007.

Particle analysis test shall be performed for all transformers rating ≥ 6.3 MVA.

Sample from a transformer where possible should preferable be taken during oil in-circulation or from return circuit of Radiators or coolers (before oil entering in to bottom of tank). Confirmatory or follow up samples should therefore always to be taken from the same point. See CL 21.8.0.

Oil sample for transformers in service, oil from bottom sampling value shall be collected.

Automated particle counters fitted with a sensor operating on the light interruption principle shall be suitable for counting within the range of 2.0 μm to greater than 200 μm.
Measurement of particles content in oil shall be performed as follows.

1. Before start of tests.
2. At end of overload temperature rise test.
3. After completion of all the tests.
4. Before energizing transformer after installation & commissioning.
5. Six months after loading of the transformers. Here oil sampling from bottom sampling value shall be collected.

Oil shall be filtered such that particle counts are made to be less than the following levels, based on 100 ml samples size before testing the transformer:

Particle size shall be according to ISO 11171 in µm.

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Number/100 ml</th>
<th>particle size range p µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 2</td>
<td>8102</td>
<td>2 µm &lt; p ≤ 5 µm</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>3832</td>
<td>5 µm &lt; p ≤ 15 µm</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>1017</td>
<td>15 µm &lt; p ≤ 25 µm</td>
</tr>
<tr>
<td>&gt; 25</td>
<td>323</td>
<td>25 µm &lt; p ≤ 50 µm</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>105</td>
<td>50 µm &lt; p ≤ 100 µm</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>87</td>
<td>p &gt; 100 µm</td>
</tr>
</tbody>
</table>

The standard for calibrating particles shall be based on the ACFTD method of ISO 11171 and ASTM method D6786.

Trace metal analysis shall be performed and confirmed to four elements, iron, copper, lead and zinc.

Type and designation of testing equipment shall be stated.

Method of analysis and the calibration standards as to be specified when quoting results.

Preferable Equipment: PAMAS S40 Portable.

23.12.18 Test on Auxiliary, Control and Protection (ACP) Equipment

All ACP equipment shall be checked for proper function before dispatch. Equipments and their wiring shall withstand the following 60 Hz, one minute test voltages. Test voltages to ground shall be 2.5 kV rms for equipment rated up to 250 V dc and 1.5 kV rms for other voltage ratings. Tests voltage across open contacts shall be 1.5 kV rms for contacts rated for tripping and 1.0 kV rms for contact not rated for tripping.

Insulation of Auxiliary wiring:
All auxiliary wiring within the transformer tank (all wiring not tested by another test in this standard) shall be tested at the manufacturers works at 2.5 kV AC to earth for 1 minute after all internal connections are made and the transformer is filled with liquid. The test is passed if no voltage collapse or other sign of breakdown occurs.

The wiring for auxiliary power and control circuitry outside the transformer tank shall be subjected to a 1 kV DC insulation resistance measurement. The minimum measured resistance shall be 1 MΩ. The test shall be carried out at the manufacturer’s works, unless the transformer is to be installed on-site by the manufacturer in which case the test shall be performed on-site. The 1 kV DC test may be substituted by a 2.5 kV AC test as above.

The wiring for current transformer secondary windings shall be tested at 205 kV AC to earth for 1 minute. The test shall be carried out at the manufacturers works, unless the transformer is to be installed on-site by the manufacturer in which case the test shall be performed on-site. If the current transformer knee-point voltage exceeds 2 kV, the test shall be performed at 4 kV AC. The test is passed if no voltage collapse or other sign of breakdown occurs.

Motors and other apparatus for auxiliary equipment shall fulfill insulation requirements according to the relevant IEC standard (which are generally lower than the value specified for the wiring alone, and which may sometimes make it necessary to disconnect them in order to test the circuit). All solid state and microprocessor based devices shall be excluded from the test circuit. All three phase under voltage relays and withdrawable type devices shall be removed from the test circuit.

Note: All the auxiliary winding should be checked on-site at 1 kV DC before energization.

23.12.19 Measurement of Frequency response (FRA)


Purpose of FRA Measurement

FRA measurement are made so that frequency response analysis can be carried out.

The frequency response analysis is an effort to understand the condition or change of condition of a transformer by analyzing the transformer frequency characteristic, both input impedance and transfer function. The primary objective of a frequency response analysis is to determine how the impedance of a transformer behaves over a specified range of frequencies.

Principle of FRA measurements

The resonant conditions exist in transformer windings which can be recognized from both terminal and internal measurements. The internal resonance which can cause local amplification of transient is of most concern in transformer design. The magnitude, phase and frequency of this resonance can be determined experimentally by exciting the network at the input terminals with a sine wave voltage and varying the excitation frequency over any range of interest. Annex B of IEEE C57.142 – 2010 outlines the method for determining the natural frequencies and mode shapes by computing the eigenvalues and eigenvectors of the system matrix.

The test shall be performed on all transformers in demagnetized core condition, preferably after no load loss measurement after dielectric tests. FRA measurement on transformers shall be performed either by:
1) Sweep frequency response Analysis (SFRA)
or by

2) Impulse voltage (IFRA)

(1) **Sweep frequency method (SFRA).** Where a frequency response is measured directly by injecting a signal of sinusoidal voltage of variable frequency by software controlled sine-wave generator, via a signal coax cable at one terminal and measuring the response at another, measured with a third coax cable using a high performance digitizer to determine directly by measurement of the amplitude change and phase shift of the response voltage over a range of frequencies.

It is advisable to choose coax cable all of the same length in order to compensate for phase lag and damping. All cable shields shall be connected to ground in the shortest possible way, at both the transformer terminals and the measurement device. The input impedance of the measurement device shall typically chosen to equal to the wave impedance of the cables (e.g 50 Ω) in order to minimize signal distortion due to reflections at the cable ends.

(2) **Impulse Voltage Method (IFRA).** Where a frequency response measured directly by injecting an impulse signal of particular shape at one terminal and measuring the response at an other, and then transforming the time domain measurement in the frequency domain result. The low voltage step generator shall have capability of generating step wave having a rise time not more than 1.0 μs.

In principle, it shall be possible to obtain the same results by either, Impulse or sweep frequency method.

The report shall contain the method and equipment used.

FRA amplitude may be expressed in dB, However reports shall be other unit like ohms….etc along with frequency.

**Resonance Frequencies:** The frequencies corresponding to any local maxima or minima in the measured amplitude response shall be indicated.

Test shall be performed in accordance to proposal of CIGRE Technical Broacher No. 342, at principal tap, extreme + tap and extreme – tap.

The frequency range: preferably 2 Hz to 250 kHz with frequency increment that shall be sufficiently small to clearly reveal all maxima and minima.

The affect of tests leads shall be eliminated preferably by the use of wideband width leads whose characteristic impedance shall be matched to input impedance of the measuring equipment so that reflection do not occur at the instrument and with separate leads to apply and measure the signal at input terminal.

**Measurement Procedure:**

**General Description**

The following test procedures must be followed in performing the FRA test.

- Core ground bushings should be connected to ground.
- All windings should be tested in accordance to **CL.23.12.18.1**.
- Test on winding with tap changers are to be measured in principle tap, extreme plus tap and extreme minus tap. Tap position should be indicated on the test report for each test.
- Disconnect all bushings not involved in the measurements and leave them in open circuit.

- Ground all the bushings not involved in the measurements with short grounding cables to the reference ground. This is the preferred method for on-site measurements since it insures safety, provides linearity at low injected power, and helps avoid antenna mode coupling.

- The secondaries of internally mounted current transformer shall be shorted and earthed.

- Test coaxial cable shields involved in the measurements must be grounded at both ends (at the base of the test bushing flanges and at the BNC connection to the test set).

- The test set ground should be directly connected to the transformer ground.


- Measuring performance check shall be performed in accordance to CL 4.3.4.

- The details of connection and connection method shall be given in the measurement record the FRA shall be displayed on a logarithmic scale plot.

All tests must be performed by qualified personnel.

- Temperature of average oil shall be recorded during FRA.

Test connection protocol

In General FRA tests require measurements of transfer function of the following.

- For each high and low voltage winding (injecting the signal at the beginning of the winding and observing the response in the other terminal of the same winding).

- If the transformer is connected in a Y, between a winding terminal and the neutral for all three phases of the high or low voltage windings.

- Between high voltage and low voltage windings on the same phase of the transformer for all three phases.

- Where a delta winding is completed externally it should be left as three separate windings if possible.

- If only one corner of the delta is brought out, it should be completed during tests on other windings; this ensures a degree of symmetry for those test on other windings.

The connection of the transformer defines the number and the type of FRA measurements to be performed. It is possible to define two groups of transformer types.

- Three phase transformers (normal).
- Three phase transformers with tertiary (normal).
Additionally, in the case of three phase transformers, the connection between windings can be Wye (Y) or delta (D), with or without a neutral.

All these connection possibilities each require a specific protocol of measurements. For example table below shows a list of measurements for an YNd connected transformer under IEC nomenclature. As mentioned earlier, during each measurement the terminals that are not involved in the test can be left either floating or grounded. It is essential to use the same configuration as that of the reference measurement to which a particular FRA result is to be compared. Refer to Annex P.

The test can be performed with the untested terminals open or short-circuited. Open circuit tests are performed on a winding with all other connections floating and disconnected. NOTE: the only exception to this is where a delta has one corner completed external to the tank. Short circuit tests are performed on a HV winding but shorting together the LV connections, but without grounding them. The neutral is not included in the shorting process.

FRA measurements and reporting and presentation of FRA
Both the amplitude and phase of the voltage ratio shall be recorded during frequency measurement. Comparisons shall be made between the responses of the individual phases for the a three phase transformer at same tap position by overlapping the tracing in three different colors on the same sheet.

Trace comparison is the usual method for the analyses of FRA results. Comparisons can be made against baseline measurements or previous measurements of the same unit, or measurements on other phase of other units. Assuming the test equipment provides repeatable results, the initial expectation is that any data comparison should result in near perfect overlays. Field experience from qualified test personnel is an invaluable asset for interpretation.

23.12.19.1 Terminal Frequency Response.

Terminal resonance having a condition of terminal current maximum and a terminal impedance minimum. In a physical system, there are a large number of resonances. First four are of practical importance. The test record shall indicate the values of impedance and corresponding natural frequencies.

Terminal resonance corresponding to series resonance and terminal anti resonance corresponding to terminal current minimum and terminal impedance maximum is referred as parallel resonances also called anti-resonance.

The test show the influence of resonance on the transient response of winding.

The following measurements shall be performed (Refer to Annex P)

1. Measurement for each + extreme, - extreme and principle switch positions for all the three phases:
   1) End to End open winding measurements
   2) End to End short circuit measurements (load impedance versus frequency characteristics).
   3) Capacitive inter-winding measurements
   4) Inductive inter-winding measurements
o Measurement of open circuit voltage transfer functions magnitude and phase angle against frequency. It is the ratio of voltage measured on the open circuited terminal to input voltage. It is acceptable to give the voltage transfer function in the case of delta winding between the delta-connected winding with one corner grounded and the other windings that would have one terminal grounded. Neutral terminal (s) shall be grounded (s).

o Step function response

o The low voltage step wave applied shall have a rise time of not more than 1.0µs. The measurement of voltage response at all open circuited terminals for step wave applied to the input terminal. Neutral terminal(s) shall be earthed. The terminal combination will be submitted by COMPANY-Engineer before testing

o Parameters at resonance points of plot with reference to frequencies shall be given in report against each plot.

o Tests to be performed in various combinations of terminals and surge impedance/capacitance at its terminals to represent impedance at line terminals. Combinations shall be submitted for approval of COMPANY-Engineer or the Engineer may submit the requirements of test.

The presentation of the results and tracings shall be in terms of frequency as base. dB as base is not acceptable. Plotting shall be frequency vs magnitude / phase angle

23.12.19.2 Internal Frequency Response At Regulating Winding Taps

The internal resonance in a transformer winding play key role in the winding's response to pulse excitation, the termination of the non-excited winding influences the full winding and internal resonance. This test to be performed on one transformer of new design of each order.

The terminal response does not necessarily bear a direct relation to the internal response for a particular part of a winding. The transfer function from HV terminals to regulation winding taps shall be measured at all taps range. This test shall be performed on assembled active part before tanking. The taps will be available for direct measurement.

The result shall indicate resonance frequencies and maximum amplification factor shall be given in tabular form.

o Step function response

The low voltage step wave applied shall have a rise time of not more than 1.0µs. The measurement of voltage response at all open circuited terminals for step wave applied to the input terminal. Neutral terminal(s) shall be earthed.

Test circuits, with type of instruments and combination of tests with surge impedance / capacitances connected to the terminal, shall be submitted for approval of Engineer at least two months in advance.
In FRA protocol, indicate the type and length cables employed during test.

Preferable Equipment:
- Maker: Dr. Strauss. Input signal: Impulse specification: 25 MS/S
- Maker: Doble (M5300). Input signal: Sweep frequency specification: 10Hz to 250 kHz sine wave.

### 23.12.19.3 Dielectric Frequency Response Analysis (DFRA)

This test shall be performed to assess the integrity of transformers insulation system. It is the measurement of the dielectric properties such as capacitances, loss and power factor of the transformer insulation over spectrum of frequency rather than at a fixed frequency. The frequency Range may be from 1 m Hz to 1.0 kHz.

Dielectric Frequency response test (DFR) is recently developed insulation system testing. It is series of power factor measurements at multiple frequencies, as it provides information that makes it possible to distinguish properties of both the cellulose and oil insulation separately. The dielectric properties of the insulation system are more pronounced at low frequencies, the measurement frequency range to be 1,000...0.001 Hz. The instruments shall be capable of measuring the complex impedance of the transformer winding insulation.

Variable frequency voltage in range 10000 Hz to 0.001 Hz shall be applied to transformer and the complex calculations are performed by digitizing and processing voltage and current signals. Plotting of frequency v/s capacitance and loss generated are included in test record. Knowledge of transformer design is helpful in identifying the test set up and connections. Hence insulation layout and test configuration shall be included in the report. The test shall be performed on switch position that includes all the turns of the windings (i.e. switch position one (1)). The tests shall be performed in the all combinations as for the measurement of capacitance and tan delta for winding as in CL Method II.

The shape and frequency shift of the spectra are the main elements used for diagnosis.

Preferable Equipment:
- IDA200 Dielectric Response measurement system. Manufacturer General Electric.
- DIRANA, Manufacturer OMICRON. The main feature of the measurement procedure is a combination of PDC and FDS measurement. Here both the techniques are combined.

### 23.12.20 Test on Bushings

The tests on bushings shall be performed separately from transformer. Test shall be in accordance with IEC: 60137, IEEE standard. C57.19.0 and IEEE standard C57.19.01. These tests to be carried out before and after the dielectric tests in order to check whether damage has occurred.

The following measurements for each capacitor bushing shall be performed and values corrected at temperature of 30°C: The correction factor shall be as per
IEEE standard. Further, correction factor as recommended by the manufacturer of bushings shall also be submitted for comparison: Ref. to Annex U. The maximum permissible values of tan δ and for increase of tan δ with voltage shall be in accordance to table 8 of IEC: 60137/2008.

- Measurement of HV main capacitance C1 (Capacitance between the high-voltage conductor and the test tap), Test voltage from 2 kV to 12 kV in step of 2 kV (60 Hz). These values form reference for measurement carried out later when the bushing is in operation and maintenance.

- Dielectric dissipation factor (tan δ) – percent V/S test voltage 2 kV to 12 kV in step of 2 kV

- Tap Capacitance C2: measurement of capacitance C2 of Bushing tap to mounting flange of bushing at 0.5 kV or 1.0 kV for 1 minute AC, 60 Hz.

- Dielectric dissipation factor (tan δ) at = 0.5 kV and 1.0 kV.

- Test circuit shall be included in the report and temperature correction factor used shall be included.

Preferable Equipment: DOBLE M4100

23.13 Type Tests

23.13.1 Temperature Rise Test (TR)

Short-circuit Method

The temperature rise test shall demonstrate that cooling equipment is sufficient for dissipation of maximum total loss on any tapping and that temperature rise of top oil, winding and hot-spot of winding over external cooling medium of any winding at any tapping does not exceed the specified maximum value.


The transformers shall be tested in the combination of connections that feeding the highest load losses that usually occurs at minimum ratio plus no-load losses. Test tap with highest voltage ratio, that include all the turns of the winding (HV) shall be selected for injecting maximum loss. (Highest load losses at 1.0pu, 1.1pu, or 1.15pu, and at 1.3pu, or 1.5 pu, measured at highest load loss tap).

If the installation site is more than 1000m above Sea level, but testing factory is not, the losses to be fed according to CL 8.7.4.

The temperature rise test shall be carried out generally in line with IEC: 60076-2/2011 Clause 7 (short-circuit method) with loads at rated frequency as defined in data sheets layout A and B. For loading beyond rated power test generally in line with IEC: 60076-7, IEEE Std. C57.119-2001 and as specified in clause 8.1.0 of this specification.

Exponents for the corrections of temperature rise test results

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<th>Distribution transformers</th>
<th>Medium and large power transformers</th>
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<td>ONAN</td>
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The core losses, tertiary winding losses (where applicable) and changes in copper losses shall be added to feeding losses during the test.

The top oil level temperature shall be measured by a suitable thermocouple or suitable thermometer immersed in thermometer pocket. The average oil temperature shall be taken equal to the top oil temperature minus half the difference in temperature of moving oil at the top and the bottom of the radiators or unit coolers.

Preparatory to the standard temperature rise test and overload temperature rise test, thermo-couples shall be installed on end frames and areas of probable hot spots. The location of these thermo-couples shall be agreed with the Engineer, to check the most critical areas with respect to leakage fluxes and thermographic scanning.

Thermographic infra-red scanning of the transformer tank walls, bushing turrets and covers shall be performed at the end of the overload peak (i.e. test is to detect external hot spots). Thermograms with hottest spot marked shall be submitted with records along with Measuring Report of Thermography.

Temperature Rise Test shall be performed for the following combinations wherever applicable. For ONAN, ONAN/ONAF, ONAN/ONAF/OFAF, ONAN/ONAF/ODAF cooling and OFAF/ODAF (with unit coolers) cooling.

For Multi-winding                                   For three-winding                                   For two-winding
1- HV-(LV1+LV2+MV) shorted                         HV-(LV1+LV2)                                      HV-LV1 shorted
Or
2- HV-(LV1+LV2) shorted.                            HV-(LV1+LV2)                                      HV-LV1 shorted
                 MV – open.

The temperatures rise test to be performed for the following load and Cooling combination for HV-(LV1+LV2) shorted for three winding and HV – LV shorted for two winding transformer. For multi winding HV – (LV1+LV2+ MV) shorted for loaded tertiary HV-(LV1+LV2) shorted and MV open for unloaded Tertiary. Test to be performed for the following cases. The temperature rise requirements refer to rated power in all windings.

(a) ONAN 1.0pu load with 100% ONAN cooling.
(b) ONAN 1.1pu load with Spare ONAN cooling included.
(c) ONAN 1.0pu load + ONAF 1.0pu load with 100% ONAN + 100% ONAF cooling.
(d) ONAN 1.1pu load + ONAF 1.1pu load with spare ONAN cooling and spare ONAF cooling included.
(e) ONAN 1.1pu load + ONAF 1.1pu load + OAF 1.1pu load with spare ONAN cooling, Spare ONAF cooling and OAF Cooling included.
(f) OFAF/ODAF1.15pu load with spare OAF/ODAF cooling (with unit coolers)
   Loading in excess of the nameplate rating.
(g) 1.3pu for transformers > 100 MVA or 1.5pu for transformers ≤ 100 MVA load with preceding 100% ONAN+100% ONAF cooling (without spare cooling).

For ONAN/ONAF/OFAF and OFAF (with unit coolers) Cooling, 1.3pu load
without spare cooling. The over-load test shall be for duration of 4 hours with proceeding load of 1.0pu continuously. Refer to Clause 8.1.0 of this specification.

See Fig. 2.

For ONAN/ONAF: Cooling possible sequence of Loading for temperature rise test.

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<tr>
<td>1.1 x ONAF ONAN</td>
<td>1.0 x ONAF</td>
<td>Overload</td>
<td>1.1 x ONAN</td>
<td>1.0 x ONAN</td>
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Connections (for 4 hours)

HV - LV
Or
HV - LV1 + LV2
Or
HV - LV1+LV2+MV
Or
HV- LV1+LV2 (MV open) for unloaded tertiary.

Sequence (1) ONAF 1.1pu (with ONAN, ONAF with spare cooling for both ONAN, ONAF), 1.15pu for OFAF with unit coolers.
Sequence (2) ONAN 1.0pu (without both ONAN and ONAF spare cooling). 1.0pu for OFAF with unit coolers.
Sequence (3) Over load 1.3pu or 1.5pu with both ONAN and ONAF without spare Cooling). Over load 1.3pu OFAF without spare coolers.

The hotspot temperature of winding shall not exceed 98°C at a designed ambient temperature of 50°C for combination (a), (b), (c), (d) and (f).

For case (of over - load) the hot-spot temperature shall not exceed 140°C at designed ambient temperature of 50°C.

(i) **OFAF/ODAF cooling with unit coolers:**

Total losses at 1.15pu at lowest tap shall be injected with all OFAF/ODAF cooling. Test to be continued until steady state top oil temperature rise is established. The remaining tests to be same as above. The hot spot temperature shall not exceed 98°C

(j) **ONAN/ ONAF/OFAF cooling.**

Test to be performed for the following cases:

a. ONAN 1.0p.u load with 100% ONAN Cooling.
b. ONAN 1.1p.u load with spare ONAN cooling included.
c. ONAN 1.0p.u load + ONAF 1.0P.u load with 100% ONAN+ 100% ONAF cooling.
d. ONAN 1.1p.u load + ONAF 1.1Pu load with spare ONAN cooling and spare ONAF cooling included.
e. **ONAN 1.1p.u load + ONAF 1.1p.u load + OFAF 1.1p.u load with spare ONAN cooling, spare ONAF cooling and OFAF cooling included.**

**Loading in excess of the nameplate rating.**

f. **1.5pu or 1.3pu load with 100% ONAN + 100% ONAF +100% OFAF/Odaf cooling (without spare cooling).**

g. **1.3pu load with 100% OFAF/ODAF cooling (without spare cooling).**

The over load shall be for a duration of four hours with a preceding load of 1.0 pu continuously.

At each stage of the temperature rise test the transformer may be switched off to permit measurement of winding resistance. Resistance measurement shall be made simultaneously on all windings. The average oil temperature shall be taken to be equal to the top oil temperature in the cooler minus one half of the difference in temperature of the moving oil at the top and bottom of the coolers.

The average temperature of winding shall be determined by the resistance method using measurement of resistance simultaneously in accordance to **CL 23.8.0.**

Readings should be taken as soon as possible after shut-down, allowing sufficient time for the inductive effects to disappear as indicated from the cold resistance measurement but not more than four minutes after shut-down. The time from instant of shut-down for each resistance measurement shall be recorded. Fans and pumps (where used) shall be shut off during shut down for resistance measurement.

**Temperature correction to instant of shut down.**

Winding resistance measurement after shutdown shall be in accordance to Annex C of IEC: 60076-2/2001. The instruments used for the measurement shall be automatic recording analogue or digital.

Extrapolation of winding temperature to the instant of shutdown shall be in accordance to Annex C of IEC: 60076-2/2011.

A series of measurements of resistance shall be made for duration of 20 minutes on one phase of each winding and the time recorded for each reading. The resistance time data shall be plotted on suitable co – ordinate paper and the resulting curve extrapolated to obtain the resistance at the instants of shut down. This resistance shall be used to calculate average winding temperature at shutdown.

The following data shall be recorded / calculated:

- Bushings stud temperatures at the end of over-load heat run test.
- to: average oil time constant.
- two: winding time constant.
- to: Oil time constant shall be calculated according to IEEE std C 57.92-1981.
- two: The increase in resistance shall be measured as specified above in **CL 23.8.0.**

Dissolved gas-in-oil analysis by gas chromatography test shall be as specified in **CL 23.12.15** of this specification. The results shall be included in the test record.

Correction of temperature rises for differences in altitude shall be as per **CL 11.4.**

**Balanced loading for axial split winding.**

This test can be preferably performed at this stage. Ref **CL 23.10.0** of this specification.

Preferable equipment:

Power analyzer: NORMA D6100.

Transformer test system: TETTEX 2292.

Thermocouples: I type.

Temperature recorders

Measurement of winding resistance by Bridge: It shall have three channels for measuring three resistance simultaneously: Raytec winding Resistance Meter WR 50 BR with Heat Run Test” soft ware AHRT 01 is having this facility.

### 23.14 Special Test

#### 23.14.1 Measurement Of Total Harmonics Content Of The No-Load Current And Voltage (L-L) In Three Phases

Sinusoidal voltage shall be applied at rated frequency. The voltage required for the measurement shall be adjusted using-average-voltage voltmeter. The voltage shall be gradually increased from zero to full voltage.

The no-load current shall be recorded and analyzed as voltage signal on an ohmic resistor inserted in the secondary circuit of the current transformer for the no-load current measurement.

Measurement shall be made at 100%, 110% and 120% of rated voltage and to be expressed as a percentage of the fundamental component.

The following harmonics to be measured:

1, 2, 3, 5, 7, 9, 11 and 13.

Type of equipment for measurement shall be recorded in test report.

Preferable equipment:

1- Power analyzer NORMA D 6100.

2- 3560A Dynamic signal analyzer by Hewlett Packard.

3- HAEFELY TMS 584, power Analyzer NORMA D6000.

Oscillograms of wave shapes and spectral harmonic content distribution of phase currents at 100%, 110% and 120% of rated voltage shall be recorded.

#### 23.14.2 Determination Of Sound Levels

The frequency spectra of the audible sound pressure level consisting of primarily of even harmonics of the power frequency shall be measured at the factory by using type 1 sound level meter complying with IEC: 61672-1 and IEC: 61672-2 and calibrated in
accordance with 5.2 of ISO: 3746. The measuring equipment shall be calibrated immediately before and after the measurement sequence. If the calibration changes by more than 0.3 dB; the measurements shall be declared invalid and the test repeated.

The background noise level before and after test shall be measured. The transformer shall be located and oriented as illustrated in fig 8 of IEC: 60076-10-1, so that no acoustically reflecting surface is within 3m of the microphones, other than the floor or ground.

The clauses referenced here are in accordance to IEC: 60076-10/2001-05.

Choice of test method
Sound level determination by sound pressure method in accordance to CL 11 shall be preferred.

However, sound level determination by sound intensity method in accordance to CL 12 may be used if equipment for above mentioned method is not available.

Load condition
No-load current condition on principal tapping excited at the rated voltage of sinusoidal wave form and rated frequency.

Prescribed contour in accordance to CL 8 with.

1- Forced air cooling auxiliaries out of service, the prescribed contour shall be spaced 0.3m away from the principal radiating surface.
2- For measurement made with forced air cooling auxiliaries in service, the prescribed contour shall be spaced 2m away from the principal radiating surface.

The height of prescribed contour horizontal plan shall be in accordance to CL 8.

Micro phone positions shall be in accordance to CL 9.

The combination of tests shall be follows:

a. Transformer energized, cooling equipment out of service.
b. Transformer energized, cooling equipment in service.

Diagram showing the location of micro phone location for measuring shall be enclosed with report similar to Fig 1 and Fig 2 of IEC: 60076-10 or Fig 30 of ANSI/IEEE std. C 57.12.90-2010.
Calculation of sound power level in accordance to CL 13.
Presentation of results in accordance to CL 16.

Details of type of equipment used shall be given in report. The sound pressure level shall not exceed 85dB(A) at a distance of 0.3M from the equipment at no load. The sound pressure level shall not exceed the value indicated in layout A and B.

Preferable equipment:
BRUEL & KJAER 2233 type sound level meter. Frequency Analyzer
Calibrator type 4230. Bruel & Kjaer 2260
4145 Condenser microphone. HAEFLEY TMS 584
Power analyzer NORMA D6100 Power Analyzer Norma D6000
Or BRUEL & KJAER Type 1
23.14.3 Vibration Test

Preparation for tests.
The transformer shall be completely assembled in normal operating condition with cooling equipment, gauges and accessories mounted and connected.

Method of Measurement
The vibration shall be measure by transducers optical detectors or equivalent measuring devices. The measuring equipment shall be accurate within ±10% at the second harmonic of the exciting frequency. The peak to peak amplitude shall be determined by direct measurement or calculated from acceleration or velocity measurements. The calculation shall be submitted.

Test conditions, the transformer shall be energized at:

- Rated Voltage and rated frequency.
- 110% rated voltage and rated frequency.

Vibration Amplitude Levels
The average amplitude of all local maximum points shall not exceed 60µm. The maximum amplitude within any rectangular area shall not exceed 100µm peak to peak. Details of instruments used shall be given in Report. Diagram showing the locations of transducers locations for measuring vibration on the tank and lid shall be enclosed.

Preferable equipment:
- BRUEL & KJAER type 2513
- Power analyzer NORMA D6100

23.14.4 Measurement Of Zero-Sequence Impedances On Three Phase Transformers

The measurement shall be carried out at rated frequency (60±0.3) Hz. between the line terminals of star-connected winding connected together and its neutral terminal in accordance to CL 11.6 of IEC: 60076-1/2011. The zero-sequence impedance shall be given in ohms per phase as well as percentage of the rated phase impedance. The type of core i.e. three limb or five limbs shall indicated. The test shall be at principal tap, at extreme plus tap and at extreme minus tap. Measured values of current and voltage shall be indicated together with the temperature, in report.

The zero sequence impedance shall be measured as:

- An open circuit zero sequences impedance with all other windings terminals open.
- A short circuit zero sequence impedance with terminals of at least one other winding system are shorted.

The zero-sequence impedance is dependent upon the physical disposition of the winding and magnetic parts and measurements on different windings. Hence sketch showing the magnetic core and the disposition of windings shall be enclosed with the report.

- The measuring current must not be higher than 30% of the nominal current. The test current per-phase shall be stated in test report.
- The applied voltage must not exceed the phase to neutral voltage which occurs during normal operation.

The values of measured impedance shall be given with the connection and combination of windings connections.
Equivalent zero –phase –sequence net work for transformer with one externally available neutral shall be given in test report. The report shall contain type of core i.e. 3+ 0 & 3+ 2 and disposition windings with respect to core.

Preferable equipment: Power analyzer NORMA D6100.
Or HAEFELY LOSS Measuring System TMS 584/100/9000.

23.14.5 **Determination And Measurement Of Transient Voltage Transfer Characteristic**

**Purpose:**

The surges can be transferred through the transformer from one winding system to another. In certain cases, the surge can be transferred also between the phases which can increase the stress in an adjacent phase which is already being subject to a direct surge. The voltages transferred are mainly fast-front or slow front over voltages.

The transferred over-voltages to be considered are either transient surges or over voltages. The magnitude of the transferred voltages depends on the construction of the transformer, especially the construction of the windings-discs, inter-leaved winding etc. and their order of disposition around the core limbs as well as the leakages inductances, damping of the winding, capacitances of the transformer turns, (Transformation) vector group, connection to the Net work, etc. In addition, the shape of the incoming surge has an important role. Some of the constructional factors influencing the magnitude of transferred surges is difficult to calculate.

Therefore, the most practical method to get a quantitative estimate for the magnitude of these surges is to measure them e.g. with Re-current surge generator measurement. These measurements are decisive when the over-voltage of the transformer is designed. Distribution of the voltage along the primary winding is time dependent.

The measured valued are to be checked against calculated or simulation of transferred over voltages on the LV/MV winding (potential oscillations inside the windings).

**Test:**

The surge arrester on HV side and LV or MV side shall not be considered. LV/MV line terminals condition at time of test. Ref: Annex L. Measurements are to be made with:

- Capacitance of surge absorber …µF.
- Capacitance of surge absorber and generator…µF.
- LV/MV terminals isolated.
- LV/MV Terminal earthed.

The applied surge shall have (1) LI with minimum possible time to front (high steepness) and (2) LI chopped on tail wave.

The tests shall be performed for

1. Surge on one phase only without earthing of neutral. Wave shape LI & LIC positive polarity.
2. For equal surges of opposite polarity on two phases. Without earthing neutral, wave shape LI & LIC.
Connection for tests shall be in accordance to Fig. E.2 of IEC: 60071-2/1996 and as per Annex L.

Where impedances of LV/MV terminals are not available, condition of LV/MV open terminals (isolated) shall be considered.

Test to be performed in various combinations of terminals and surge impedance / capacitance at its terminals to represent impedance at line terminals. Measurement and test results shall be tabulated as shown in Annex L.

Calculations shall be submitted for approval of Engineer, or the Engineer may submit the requirement of test circuits. The type of instruments and combination of tests shall be submitted for approval of Engineer at least two months in advance.

The test report shall include connection diagram. It is to be stated whether the entry of line terminal at the top of HV winding or the middle of HV windings.

Preferable equipments:

2 No. HAEFLEY RECURRENT SURGE GENERATOR Type 481

10 Channel 100 Mhz Digital storage Oscilloscope.

23.14.6 Short-Circuit Withstand Test

In pursuant to clause 16 above COMPANY at its own discretion may order any one transformer of each type in the tender for short-circuit withstand ability test at any of the International high power laboratories

This is in additional to theoretical evaluation of ability to withstand the dynamic effect of short-circuit.

Demonstration of ability to withstand short-circuit to be considered in two parts:-

1. Thermal ability to withstand short-circuit. Thermal behavior of the transformer shall be determined by calculation

2. Ability to withstand the dynamic effects of short-circuit.


General:

- The maximum fault current for each winding shall be determined from calculation for fault types specified, and at switch position measuring the lowest measured impedance with -5% tolerances. The maximum short-circuit current calculated shall be increased by 10% as a safe margin to calculate the dynamic forces & thermal with stand ability.

  Calculation of short circuit current shall be in reference to CL 5.0 of BS IEC: 60076-8/1997 also.

- The peak value of the first cycle asymmetrical short-circuit-current shall be calculated in accordance with the equation in CL 7 of IEEE Std. C.57.12-00-2010.

- The test shall be performed with the highest calculated short-circuit-current holding the maximum asymmetry as regards phase under test. The tolerance on asymmetric peak not be more than 5% and symmetrical current by more than 10% from the respective calculated and specified value.
During testing each winding of each phase shall be subjected to its maximum calculated fault current.

The thermal ability to withstand short-circuit shall be demonstrated by calculation in accordance with CL 7 of IEEE Std .C.57.12.000-2010. The duration of short-circuit shall be 5 seconds.

The frequency of the test shall be 60 ± 0.3 Hz.

Fault type:

- For three phase's transformer, three phase power supply should be used.
- For three phases, multiple winding transformer it may be required to perform both three phase and single phase short-circuit tests to ensure that all significant winding condition and connection have been investigated, subjected to negotiations between the manufacturer (transformer designer) and COMPANY Engineer. In absence of prior agreement, the combinations of windings for short-circuit test as specified for four windings shall be applicable.

Calibration Tests:

Preliminary adjustment test carried to obtain the initial peak value of the current in the phase winding under test shall be carried out at between 65% to 70% of the calculated/specified current to check the proper functioning of the test set-up with regard to the moment of switching on the current setting, the damping and the duration by means of synchronous switch. In order to check the values of test current peak value \( i \) and symmetrical short circuit-current \( I_{oc} \) oscillographic record or digital records shall be taken. In order to obtain the maximum asymmetry of the current in one of the phase windings, the switching on shall occur at the moment the voltage applied to this winding phases through zero.

To produce this fully asymmetrical current wave, a synchronous switch shall be used to control the timing of fault application.

Number of Tests:

Each pair of winding or each combination of windings of each phase of the transformer shall be subjected to three shots of full asymmetrical short-circuit test current.

Tap-Connection for test:

Test satisfying the asymmetrical current requirements shall be made on the tap connection that calculations predict will produce the most severe stresses, the same tap connection shall be used for all the three phases, generally at tap position giving the lowest impedance. The same tap connection shall be used for all the three phases.

Duration of Test:

Duration of each asymmetrical current test shall be 0.25 seconds with a tolerance of ±10%.

Fault Location:

The short-circuit shall be applied on the secondary terminals.

In order of preference, the test may be conducted by either of the following:

A) Closing a breaker at the fault terminal to apply a short-circuit to the previously energized transformer.

B) Closing a breaker at the source terminal to apply energy to the previously short-circuited transformer.
Prior to short-circuit tests, the transformer shall be subjected to the routine tests in accordance to CL 23.5.0 as specified in SEC specification in addition to FRA (Terminal Frequency Response) record in accordance to CL 23.12.18.1.

The measurement of single phase leakage impedance of each limb with single phase 60 Hz at low voltage in accordance to CL 23.12.10 for the tapping position at which short-circuit tests will be carried out. The reactance measurements shall be to a repeatability of better than ±0.2%.

The measurement of winding resistance in accordance to CL 23.8 for the tapping position at which short-circuit tests will be carried out.

Current measurements shall be in accordance to CL 12.4.5 of IEEE std. C57.12.90/2010. The measured symmetrical and asymmetrical current in the tested phase(s) shall not be less than 95% of the required current.

Report containing the result of the above tests shall be available at the beginning of short-circuit test.

Testing with single phase supply shall not be accepted.

Short circuit testing procedure for transformer with two windings

Test procedure shall be in line with CL 4.2.5 of IEC: 60076.5 third edition 2006 with following deviations:
- Testing with a single phase supply is not acceptable.
- Pre set short circuit method shall be used.
- The switching – on shall occur at the movement the voltage applied to this winding posses through Zero.
- The number of tests shall be three for each phase in the position corresponding to the highest current, generally at the tap of lowest impedance.

Short-Circuit testing procedure for transformers with more than two windings

- Fault location and type
  The maximum fault current for each winding shall be as already mentioned in CL 23.14.6. Each winding shall be subjected to its maximum calculated fault current on three tests.

  A given fault type and location may not produce the maximum fault-current in more than one winding, so it will be necessary to make tests with several different connections to fault evaluation the capability of all windings. In principal, for multi winding transformers each pair of winding to be tested for short circuit, other remaining windings open. Number of test application three for each combination.

Three Winding Transformers:
For a three winding transformers for each phase the test to be performed in the following sequence:-

- Tests on V phase:
  3 tests → HV (energized) → LV_1, shorted and LV_2 open (for axial split winding, LV_1 shall be bottom winding) and for radial split winding LV1 nearer to core.
  3 tests → HV (energized) → LV_2 , shorted and LV_1 open (for axial split winding LV_2 shall be top winding) and for radial split winding LV2 away from LV1.
3 tests → HV (energized) → \( LV_1 \) & \( LV_2 \) both LV1 and LV2 shorted.

3 tests → \( LV_1 \) (energized) → \( LV_2 \) shorted, HV open.

Same test sequence shall be followed for U and W phases.

**Four Winding Transformers:**

For four winding transformers for each phase the test to be performed in the following sequence:-

- **Tests on V phase:**

  2 tests → HV (energized) → \( LV_1 \), shorted MV and LV2 open (for axial split winding, LV1 shall be bottom winding) and for radial split winding LV1 nearer to core. Open and \( LV_2 \) shorted.

  2 tests → HV (energized) → \( LV_2 \), shorted MV and LV1 open (for axial split winding LV2 shall be top winding). And for radial split + winding LV2 away from LV1 open and LV1 shorted.

  2 tests → HV (energized) → \( (LV_1 \& LV_2) \) shorted, MV open.

  2 tests → LV1 (energized) → \( LV_2 \) shorted, HV& MV open.

  2 tests → MV (energized) → \( LV_1 \) shorted, HV& \( LV_2 \) open.

  2 tests → MV (energized) → \( LV_2 \) shorted, HV& \( LV_1 \) open.

  2 tests → MV (energized) → \( (LV_1 \& LV_2) \) shorted, HV open.

  2 tests → HV (energized) → \( MV \) shorted, LV1& LV2 open.

  Same shall sequence shall be followed U and W phases.

**Proof of Satisfactory performance, detection of faults and evaluation of test results shall be generally in line with CL 4.2.7 of IEC: 60076-5/2006 and CL 12.5 of IEEE C57.12.90/2010.**


2. Wave shape of terminal voltage and current.

   Before & during each test (including preliminary test) oscillographic or digital recording shall be taken of:
   - The applied voltages.
   - The currents.

   After each test, the oscillograms taken during test shall show no abrupt changes in the terminal voltage or short circuit current wave shapes during any test (comparison by super imposition).

All the impedance measurements shall be to a repeatability of better than ± 0.1%.

The measured impedance on a per phase basis after the test shall not differ from the measured before the test by more than 1%.

Measurement from both the HV as well as LV side shall be made at the switch position at which the short circuit tests have been carried out.


Measured value after the test series shall not increase above that measured before test series by more than 5%.


6. FRA - Terminal frequency response analysis test.

The test shall be performed in accordance with CL 23.12.18.1 of this specification.

7. Transfer function analysis.


Comparison of digital or oscilloscope traces LV1 current taken before and after each short-circuit shall show no significant change in wave shape.

Further refer to CL 12.5.5.1 and CL 12.5.5.2 of IEEE C 57.12.90/2010.

9. Dielectric tests at 100% of the prescribed test values CL 23.12 shall be repeated.

Dielectric tests in accordance with CL 23.12.0 of specification.

10. Dissolve gas analysis before and after test Refer CL 23.12.15.


12. Analysis of Test Results.

Generally it shall be in line with 12.5 of IEEE C57.12.90-2010.

**SITE TESTS**

The CONTRACTOR shall submit for approval a comprehensive quality control plan covering the erection, testing and commissioning activities. This document shall identify the degree of inspection and testing to be carried out by his personnel.

The following minimum witnessed tests shall be conducted by the Contractor after installation of the equipment.

(a) Pressure test on tank (if transformers are not shipped with initial oil filling)
(b) Measurement of voltage ratio at all tap positions.

(c) Check of vector group (the voltmeter method shall be applied).

(d) Measurement of capacitance and power factor of transformer winding and comparing with factory result.

(e) Measurement of winding resistance at all switch positions at 50 A on HV, at 100A on LV, LV1 & LV2. MV. Winding resistance range after installation shall be within + 5% vs factory test result.

(f) Measurement of single phase no-load current at 380 V, 60 Hz and comparing with factory results.

(g) Measurement of break down voltage, moisture content, IFT, NN, particle content of oil.

(h) Measurement of neutral currents in no-load condition and load condition

(i) Measurement of the insulation resistance at 5000V, DC R 15, R 60 & R 600 shall be measured and polarization index calculated.

(j) (a) Recalibration and current injection test on winding temperature indicators.

(b) Calibration of temperature indicators.

(k) DGA to be performed after three days and after one month of energization.

(l) (a) Functional tests on OLTC / DETC.

   Functional test on control and supervisory equipment & control.
   
   - Check on cooler control system.

(m) Measurement of capacitance and tan delta of transformer windings and capacitor bushings at voltage 2 kV to 12 kV in step of 2 kV.

(n) Measurement of single phase impedance of each limb with single phase voltage, in accordance to CL 23.12.0 of COMPANY specification.

(o) Core insulation resistance at 3.5 kV for one minute.

   - Checking of correct earthing of core.

(p) Terminal Frequency response analysis (FRA) and dielectric frequency response analysis test. Refer CL 23.12.18 of COMPANY specification.

(q) Particle Content of transformer oil after all the test and three days of energization.

(r) Magnetic balance test.

(s) Test for the determination of 2 – furfural and related components dissolved in transformer oil by high performance liquid chromatography (HPLC) in accordance to IEC: 61198 after one month along with DGA test.

(t) Particle contents in transformer oil after six month of loading the transformer.

The Contractor shall supply all necessary test equipment and shall be responsible for calibration of test instruments, where required.
The installation and commissioning shall be carried out under the supervision of experienced Engineer under witnessing of COMPANY Engineers.

The site test or measurements ensures that all equipment and site works are carried out and completed in compliance with the relevant specifications. For further details refer to section GEMSS-G04

25 CHARACTERISTIC DATA REQUIRED FOR AN OVERVOLTAGE AND SYSTEM STUDY

The following characteristic data are required:

- Single line diagram of the – GIS and their connections to other substations and to the generator transformers.
- Earth fault factor (referred to line-to-earth voltage acc. To IEC Publ. (71) of the system.
- Isoceraunic level of substation surrounding area.
- Power configuration and data of the outgoing overhead lines up to the third tower seen from the GIS (Tower configurations indicating the exact location of conductors and earth wires for the 3 last tower, line profile average sag, maximum tower footing resistance of these towers, type and number of insulators of the insulator strings or their critical flashover voltage).
- Location of installation and type of surge arresters (if already fixed).
- Provide arrangements of surge arresters at overhead line entrances and generator transformers (ground plans and profiles to allow evaluation of electrical length of connecting lines).
- Type, design and length of connections between GIS and the generator transformers such as bus duct, or cable etc.
- Characteristic data of the generator transformers (rated power, winding ratios, short circuit impedance of positive and zero sequence system, kind of earthing of high-voltage neutral, switching (SIL) and lightning (BIL) insulation levels of high-voltage windings and neutral, surge capacitances of high voltage terminals per phase).
- Characteristic data of the generators (rated power, rated voltage, power factor, sub-transient and transient impedance).

26 MISCELLANEOUS

26.1 Drawings And Information

The following items shall be submitted to the Engineer for approval.

1. Details of Manufacturing and Test Schedules.
2. Certified dimensioned drawings for the transformer.
3. Electrical drawings including the control and protection for the tap-changer, pumps, cooling fans and protective devices.
4. Factory Test Reports.
5. Maintenance Manuals.
6. Transportation/Delivery Proposals.
7. Equipment power consumption (such as, fans, pumps, Heaters, Lamps and auxiliary equipment.)
(8) Equipment cabling list.
(9) Control and layout.
(10) Wiring connection diagram.

The following drawings shall be supplied along with the manual on hard and soft (CD copies) media, before commencing the production of the transformer for approval of COMPANY:

a) Complete core.
b) LV&MV winding.
c) HV main winding. Drawing to include HV interleaved arrangement.
d) HV coarse winding.
e) HV fine winding. Drawing to include interleaved Fine winding when used.
f) LV&MV winding connections.
g) HV main & regulating winding connection.
h) Vacuum connections.
i) Bushing drawing HV, HV-N, LV with test certificates.
j) Fixing arrangement of core & winding at tank bottom and top to prevent movement during transport.

Submittals

- Sizing calculations of the transformer.
- Technical details – layout A and layout B. This shall be submitted along with technical offer.
- Over voltage study report.
- Calculation and simulation of Transferred voltages, both impulse and power frequency.
- Short circuit current calculation.
- Short circuit thermal calculation.
- Short circuit dynamic withstand ability calculations.
- Dynamic and thermal withstand ability of LV Bus bar and support insulator for 50 kA short circuit current in accordance to DIN EN 60865-1, Classification VDE 0103.
- Circulating current during unbalanced load on LV1 or LV2 side.
- Voltage Wave sensitivity analysis.
- Test certificate of all capacitor bushings showing the values of capacitance, tan delta, current & loss.
- Dimensional drawings of all bushings.
- Connection diagram & rating plate drawings.
- General arrangement drawing.
- Erection and commissioning manuals.
- Factory tests reports and test certificates of all equipment.
- Operating and maintenance manual.
- Quality control program.
26.2 Loss Capitalization

Transformer losses shall be capitalized at the following rates:

No-load Loss € 3,000/- as given in layout A & B per kW
Load Loss   € 2,000/- as given in layout A & B per kW

Losses will be capitalized at the above rates at the main tap and taken into account when Tenders are being compared. The bidders are required to quote the maximum guaranteed losses in the technical data sheets.

The losses shall be measured during the routine tests. In the event of either the iron or load loss exceeding its guaranteed values as stated in the TECHNICAL SCHEDULES, allowing for the tolerance stated in IEC: 60076-1, the relevant rate above shall be applied to the excess and the resulting amount shall be deducted from the Contract Price. where the transformer is purchased separately and is not part of the overall scope of project

No negative tolerance on rated power and impedance is allowed.
No positive tolerance on noise level is allowed.
No positive tolerance on temperature rise is allowed.
No negative tolerance on Impedance value is allowed.
For all the other values the margins stated in IEC standards are applicable.

26.3 Rejection

- Where HV winding of voltage class 72.5 kV and above is not designed and manufactured as fully interleaved or partially interleaved winding in according to CL 18.0 of COMPANY specification.
- Where the manufacturer does not agree for performing short circuit test at any of international laboratories when COMPANY Opt for such test.
- The Contractor shall submit at least three offers of manufacturers of International repute and recognized by COMPANY. The offers shall be meeting COMPANY specification accompanied by Technical Layout A&B and Design Data, Annex M. COMPANY reserves the right to select any of the manufacturer not necessary the lowest cost manufacturer.
- COMPANY reserves the right to reject any transformer if during tests or service any of the following conditions arise.
- Compliance with IEC standard or any of the cited standard or codes does not of itself confer immunity from legal obligations.
  - Current density in the windings exceeds 2.5 A/mm².
  - Flux density in case exceeds 1.6 or 1.65 as given in Layout A and B.
  - No-load loss exceeds the guaranteed value by 20% or more.
  - The difference in impedance values of any two phases during single phase short-circuit impedance test exceeds 0.5% of the average value guaranteed by the Contractor.
  - Oil or winding temperature rise winding hottest spot temperature exceeds the specified value. No positive tolerance allowed.
  - Transformer fails on dielectric tests (LI, SI, ACSD, ACLD...etc) three times.
- Transformer is proved to have been manufactured not in accordance with the agreed COMPANY specification and not designed and manufactured to meet the duties required.
- Transformer fails in current inrush test.
- Transformer fails on short-circuit test.
- Where the test field is not properly equipped, as required by COMPANY specification and where test results are unacceptable. COMPANY reserves the right to test the transformer at any independent laboratory at contractor/supplier cost.
- The transformer is proved to be designed as under rated unit.
- Where tests performed does not meet the requirement of COMPANY specification or evidence of manipulation of test results, either during test or afterward and test does not comply with COMPANY specification.
- Site tests results not satisfactory.

COMPANY reserves the right to retain the rejected transformer and take it into service until the contractor replace at no extra cost to COMPANY the defective transformer by a new transformer meeting the specification. Where the contractor has offered transformers from more than one source, COMPANY reserves the right to select transformer from any of the manufacturer without assigning any reasons.

26.4 Installation

The installation shall be done by the manufacturer under guarantee. Where sub-contractor is hired, approval of COMPANY shall be obtained.

The installation shall be generally in line with guidance of IEC: 61936-1 (2002-10), IEEE Std. C 57.93 and C 57.91.

Receiving the transformer at site, the following to be inspected:
- The way in which the transformer has been secured on the trailer.
- That the delivery is complete according to order confirmation.
- Compare the packing list with the goods received.
- The transformer nameplate.
- External damage e.g. cracks in bushings.
- Impact recorders indications.

Transformer shall not be allowed to energize until and unless all protection of transformer including that of surge arrestors are connected, tested, functional and performing.

26.5 Spare Parts

The price of transformer shall include the cost of the following spars.

The following spare parts shall be supplied for each transformer.
- The working spare parts for operating and commissioning shall be supplied.
- 20% spare terminals on the terminal block shall be provided.
- H.V. Bushing Line Terminal - 1 No.
- L.V. Bushing - 1 No.
- Set of Gaskets - 1 No.
- Winding temperature Indicator dial type - 1 No.
- Top oil temperature indicator dial type - 1 No.
- Fans (in case of ONAF cooling) - 2 No.
- Dehydrating breather one of each type - 1 No.
- Rubber Diaphragm for conservator, where used - 1 No.
- Buchholz relay one of each type - 1 No.
- Oil level indicator for main tank - 1 No.
- Oil pump for one each for ONAN/ ONAF/ OFAF and OFAF transformer.

Transformer to be evaluated with cost of spares.

The Spares shall be clearly identified on drawings and in the maintenance manual.

Spares parts shall be delivered suitably packed and treated for long periods in storage. Each package shall be marked clearly with a description of the contents (with part numbers) in Arabic and English.

26.6 Quality control and quality assurance

refer to section GEMSS-05