DEVELOPMENT OF INDIA'S FIRST COUPLING TRANSFORMER FOR STATCOM APPLICATIONS

By

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Outline of Presentation

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  - Effect of Core Joints and Core Hotspot Temperature
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STATCOM

- STATCOM is the state of art of technology in the reactive power system
- It is IGBT based Voltage Source Converter (VSC)
- VSC working is based on SPWM techniques
- It has the capability to generate and absorb variable reactive power
- Specifically meant for Reactive Power Compensation of Highly Dynamic Loads
- STATCOM does not require any passive components like capacitor or reactor for generating or absorbing reactive power
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Single Line Diagram of STATCOM

Mode-1: $V_{\text{STAT}} < V_S$, STATCOM absorbs reactive power (Inductive)
Mode-2: $V_{\text{STAT}} > V_S$, STATCOM injects reactive power (Capacitive)
Mode-3: $V_{\text{STAT}} = V_S$, STATCOM does not work (Zero current)

$V_S$ - Network Voltage
$V_{\text{STAT}}$ - STATCOM Output Voltage
VSC - Voltage Source Converter
STATCOM - Features

- Smooth and Ultra Dynamic Stepless Response
- Continuously maintain unity Power Factor (P.F.) within its dynamic range
- Dynamic range is in capacitive as well as inductive mode based on system demand
- Reactive power is generated in IGBT based VSC and therefore does not require any passive elements
- No harmonics generation for adoption of SPWM technique
- Integrated Active Harmonic Filter
- Suited to a hybrid solution of STATCOM plus switched capacitors
- Cheaper than SVC below 50 MVar
- Easy to install, less maintenance & Environment friendly

\[ +Q \quad -Q \]

\[ TSC \quad STATCOM \]
Necessity Of STATCOM Coupling Transformer

✔ Worldwide available STATCOM system voltage is less than 40 kV
✔ STATCOM cannot be directly connected to the high voltage grids like 220kV, 400 kV, etc.,
✔ Coupling Transformer is the intermediate device to connect STATCOM system and high voltage grid with bidirectional power flow
✔ The primary side of coupling transformer is connected to high voltage grid and secondary side is connected to the STATCOM system
✔ Coupling transformer does not require any tap changer since its voltage is controlled by the STATCOM system
✔ Coupling transformer step-up duty is too severe in STATCOM application and it must be specifically designed to meet those requirements
## STATCOM Coupling Transformer Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power (MVA) HV / LV</td>
<td>33.334 / 33.334</td>
</tr>
<tr>
<td>Rated No Load Voltage (kV) HV / LV</td>
<td>(400/√3) / 20</td>
</tr>
<tr>
<td>Rated Frequency (Hz) &amp; No. of Phase</td>
<td>50, Single Phase</td>
</tr>
<tr>
<td>Type Of Core Construction</td>
<td>3 Limb Core (1 Wound &amp; 2 Return Limbs)</td>
</tr>
<tr>
<td>Vector Group</td>
<td>YNd1 (3 Phase Bank)</td>
</tr>
<tr>
<td>% Impedance at rated MVA base HV – LV</td>
<td>12.5% with +/-5% Tolerance</td>
</tr>
<tr>
<td>Duty continuous</td>
<td>100% Capacitive &amp; Inductive Reactive Loading</td>
</tr>
<tr>
<td>Winding Insulation Levels</td>
<td></td>
</tr>
<tr>
<td>Full Wave Lightning Impulse Voltage (kVp) HV/LV/Neutral</td>
<td>1425 / 170 / 170</td>
</tr>
<tr>
<td>Power Frequency (kVrms) HV / LV / Neutral</td>
<td>630 / 70 / 70</td>
</tr>
<tr>
<td>Switching Impulse Voltage (kVp) HV / LV</td>
<td>1050 / --</td>
</tr>
<tr>
<td>Type of Cooling and Arrangement</td>
<td>ONAF2 and 2 x 50%</td>
</tr>
<tr>
<td>Name Of Project</td>
<td>400/220 kV Substation at NP Kunta, Andhra Pradesh, India</td>
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</table>
Design Features Of Coupling Transformer

- Coupling transformer must be designed and rated to carry 100% dynamic reactive power loadings.
- Due to high frequency switching of IGBT and the DC capacitor voltage, STATCOM produces DC current and harmonics in the secondary side of coupling transformer.
- Certain level of direct current and harmonic currents consistent with the most onerous operation of STATCOM should be withstood by the coupling transformer without loss of life.
- Presently very few manufacturers worldwide have made coupling transformers for 400 kV system voltages.
- The main design features of the coupling transformer to be considered are:
  - DC Current and Harmonics
  - Overfluxing
  - Effect of Core Joints and Core Hotspot Temperature
  - Winding Hot Spots
  - DC Effects on Flitch Plates, Tank, Thermal and Acoustic Noise
DC Flux Density Shift in Transformer Core

- Flux density shifts in the core caused by $I_{DC}$
- The magnitude of $\Phi_{DC}$ depends on the magnitude of the dc, No. of turns in the windings carrying $I_{DC}$ & reluctance path of $\Phi_{DC}$
- The result is the $\Phi_{DC}$ adds to the $\Phi_{AC}$ in positive half-cycle and subtracts from the $\Phi_{AC}$ in the negative half-cycle

DC flux = $N I_{DC} / R$
Half–Cycle Saturation of Core under Effect of DC Current

- When the $\Phi_{DC}$ is max or transformer design “B” is high, the core peak “B” moves to the magnetic core pre-saturation range in the positive half cycle, resulting in core saturation for a small part of a cycle is called half-cycle or part-cycle saturation.
- For higher magnitudes of dc, the core provides a much higher reluctance to the DC Ampere-Turns.
- It results in a smaller incremental increase in the flux density shift and a higher peak magnetizing current pulse.
- B – H characteristics of the coupling transformer core materials is inherently extremely non-linear.
DC Current and Harmonics

- STATCOM – DC Current & Harmonics
- (Half-Cycle) Transformer Saturation

**Increased Reactive Power Losses**
- Increased System Loading
- Voltage Collapse and Blackout

**Harmonics Waveform Distortion**
- Relay Misoperation
- Line / STATCOM tripping

**Stray Fields**
- Heating
- Transformer Damage / Tripping
- Power Shortage

**System Vulnerability**

**Component Vulnerability**
**Overfluxing**

- Voltage / Frequency ratio is called overfluxing factor
- V/F ratio is generally constant, if “V” increases above nominal & “F” decreases below nominal, core reach under saturation

**Designing of minimum flux density for coupling transformer**

- Incremental flux density due to DC current
- Frequency variation
- Coupling transformer flux density variation due to STATCOM system
- Capacitive loading, leading to increase in flux density in the core
Effect of Core Joints and Core Hotspot Temperature

- Mitred joint has a greater reluctance than a step-lap joint

- Core magnetic material & core joint type have some influence on core saturation characteristics. However, this influence is small & depends on the core type & the operating flux density in the core

- Typical temperature distribution in the core considering the effect of dc and harmonics of the STATCOM
Winding Hot Spots

- Winding hot spots are determined with the help of eddy loss distribution which is governed by leakage field plot.
- The flux lines are predominantly axial in the central part.
- At the winding ends, due to fringing flux, the flux lines tend to bend radially & there will be a radial component of eddies in addition to axial eddies.
- Due to natural convection, temperature at top part will be higher.
- F. O probes are located within the LV & HV windings, on transformer core and oil.
- The probes are to be monitored throughout testing process and services.
DC Effects on Flitch Plates, Tank, Thermal and Acoustic Noise

- \( I_{DC} \) increases, the magnetic “B” in the tie-plates increases linearly until it reaches the magnetic saturation level of the tie-plate material.

- To reduce tank stray losses, CRGO magnetic shunts are provided on the shorter side of HV & LV windings of the tank.

- The height of CRGO magnetic shunts should be higher than the height of windings.

- Higher eddy & circulating current losses in the windings & the structural parts of the coupling transformer; increasing their temperatures, which will require extra cooling.

- Part-cycle of core saturation operating region as the result of dc bias will produce greater levels of acoustical noise & tank vibrations.

- Noise can be reduced by lowering “B” & by other means.
Factory Testing
CONCLUSION

This coupling transformer technology, development, design and manufacturing is based on Make in India concept and sell them anywhere in the world.

Coupling Transformer should be designed and withstand the behavior of STATCOM as mentioned below:

- Dynamic reactive power variation from capacitive to inductive & vice versa
- DC and harmonics generated by STATCOM
- Incremental flux density due to dc current
- Significant rise of losses and system voltage instability
- Increased reactive power consumption

The rise of internal hotspots, increased noise levels and tank vibrations are the effects of STATCOM on the coupling transformer.

The successful design, manufacturing process, factory testing and installation of this 400 kV coupling transformer will establish a “future-proofing” milestone for technology development in India in the field of high voltage equipments for DRPC applications.
REFERENCES


[8] WG 12.06 Large transformers “Final report of WG 06 of Study Committee 12 (Transformers)”. ELECTRA No. 82, May 1982, pp. 31 – 46.
Thank you
QUESTIONS ???