PARIS 2022

Study Committee A2

Power Transformers and Reactors

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Reverse Power Flow Impacts for Legacy Power Transformers

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Motivation

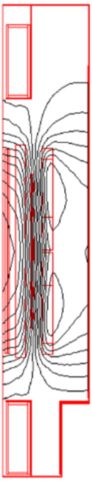
- Renewable generation and connection to existing power grids cause significant change to traditional flow of power
- Power can now flow in a different direction than the power grid and associated large power transformers were originally designed for
- Termed "reverse power flow" – can have unintended and large negative consequences to power transformers
- Note that new transformers can always be designed for reverse power flow if specified

Method/Approach

- IEEE Standard C57.12.00-2015 states power transformers are to be designed for step down operation unless stated otherwise
- IEC Standard 60076-1-2011 states flow of power to be indicated at the time of transformer specification
- Many legacy transformers were thus designed for power flow in one direction only
- Focus of this paper is on transformer thermal constraints caused by the reverse power flow
- Show by modelling the revised leakage flux pattern and recalculating the winding and core temperatures
- Demonstrated with various cases

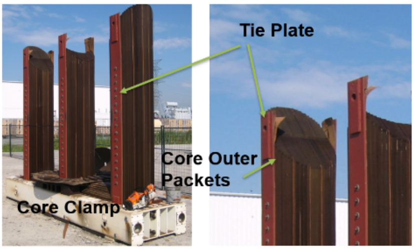
Objects of Investigation

- Impacts of reverse power flow best understood by changes to the transformer leakage flux pattern
- Used by engineers to calculate short circuit forces, transformer impedance and temperatures of winding hot spot / core outer packet / core tie plate / core clamp / tank / tank wall shield
- Reverse power flow can cause the leakage flux pattern to change dramatically and increase temperatures of winding hot spot, tie plates, core outer packets and core clamps



Discussion

- No difference with reverse power flow for simple 2 winding transformers (LV to HV, HV to LV)
- Can have large difference with reverse power if there are tap windings, extra voltage systems (i.e. TV or 2 LV's), or auto connection with LTC (very different leakage flux patterns and significant temperature increases in windings & core parts)
- Need to check accessories and tap extremes
- Loading scenarios (active and reactive power) should be examined
- Higher harmonics can increase stray and eddy loss



Conclusion

- Reverse power flow a real concern for legacy transformers
- Power flow can change direction and relative amounts of active vs reactive power
- Cases with detailed thermal calculations showed examples of increased winding and core clamping temperatures for reverse power flow and harmonics
- Transformers with same electrical parameters can be affected very differently by reverse power due to different winding arrangement, core type and leakage flux control
- Possible impacts:
  1. Leakage flux patterns leading to temperature increase in the core, core clamping, tie plates
  2. Winding heating
  3. Limits to tapping range
  4. Reduction in nameplate rating for different loading scenarios
  5. Increased harmonics
  6. More rapid/frequent changes to temperature
- Recommend legacy transformers have an engineering study performed by the Original Equipment Manufacturer (OEM)

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Reverse Power Flow Impacts for Legacy Power Transformers continued

Case Study 1

- 125 MVA, 230 – 28 – 28 kV, on load taps on HV, designed for step down (HV to dual LV's)
- Leakage flux plots show strong radial flux lines between the 2 LV's in reverse power flow which led to very high core outer steel and tie plate temperatures.
- MVA would have to be reduced to 32% of rated (LV to LV) with all cooling in operation to keep core and tie plate temperatures to a safe limit

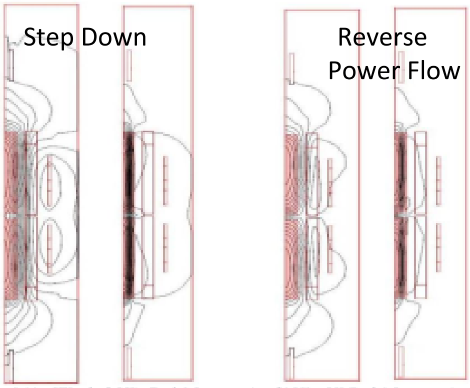

Figure 3 (a) – HV to both LV's (Real & Imaginary) (b) LV to LV (Real & Imaginary)

Case Study 2 -

- 125 MVA, 215 – 28 – 28 kV with on load taps in the HV, designed for step down (HV to dual LV's)
- Request to operate LV to LV and with high harmonics
- Load had to be reduced to 60% to operate safely

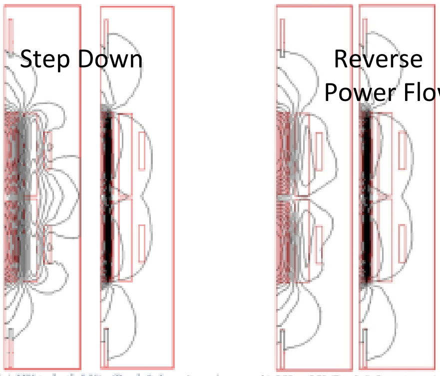

Figure 4 (a) HV to both LV's (Real & Imaginary) b) LV to LV (Real & Imaginary)

Case Study 3

- 125 MVA, 210 – 28 – 44 kV with off load taps in the HV – designed for step down (HV to LV's)
- Request to operate with step up and LV to LV
- Calculations showed it can operate at full load in reverse power flow due to shell form design
- Shell form core design is more flexible for reverse power flow

Case Study 4

- 83 MVA, 240 – 14.1 – 14.4 kV with on load taps in each LV, designed for step down where each LV could independently regulate the output voltage
- Reverse power flow load scenarios given (note they are much below 83 MVA) – all were found to be within allowed design limits

	LV1			LV2					HV
Scenario	P1 (MW)	Q1 MVAR	LV1 MVA	P2 (MW)	Q2 MVAR	LV2 MVA	PH (MW)	PH MVAR	H MVA
Original 1			41.5 (output)			41.5 (output)			83 (input)
2	8 (input)	0 (input)	8 (input)	32.4 (output)	5.3 (output)	32.9 (output)	24.4 (input)	5.3 (input)	25 (input)
3	16 (input)	5 (input)	16.8 (input)	16 (output)	1 (output)	16 (output)	0 (output)	4 (output)	4 (output)
4	20 (input)	4 (input)	20.4 (input)	10.2 (output)	4 (output)	10.9 (output)	9.8 (output)	0 (output)	9.8 (output)

Case Study 5

- 83.3 MVA, 245 – 26 - 26 kV with on load taps in the HV, designed for step down operation
- Request for generation in LV1 (24 MVA) and output on LV2 (20 MVA) and the HV (4 MVA)
- Calculations showed core outer packets would overheat
- Had to reduce loads by 5% and only in winter (20C lower ambient)

Case Study 6

- 10 MVA, 230 – 13.8 kV with off load taps in the HV, designed for step down operation
- Request to operate in step up with high harmonic content (due to new generation on the LV system)
- Calculations showed 9 MVA was possible