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Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS1-10830

On-load tap changer monitoring and protection by extra power loss and circulating current analysis

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Motivation

- Power transformer reliability and availability are utmost important for uninterruptible power delivery
- On-load tap changers (OLTC) are responsible for more than one third of the major transformer failures
- On-line monitoring facilitates condition-based preventive maintenance of OLTCs and transformers
- Protection against incomplete tap operations

Soft-sensing based OLTC monitoring

- Circulating current during an OLTC operation causes extra power loss over the transition resistor(s)
- Monitoring parameters: the power and duration of the additional power loss due to a tap operation

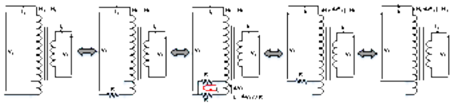

Figure 1. Operation steps of a common tap change operation scheme with two transition resistors (R)

- Detecting changes within a period of an oscillating signal cannot be performed by regular phasor analysis
- Amplitude fidelity << 1 % of nominal and time resolution ≤ 1 ms required
- Steady and oscillatory components in the power loss can be removed by subtracting the predicted loss

$$P_{loss}(t) = P^{HV}(t) - P^{LV}(t) = \sum_{phases}\left(V^{HV}(t)\, I^{HV}(t) - V^{LV}(t)\, I^{LV}(t)\right)$$

$$\Delta P_{loss}(t) = P_{loss}(t) - P_{loss}^{pred}(t)$$

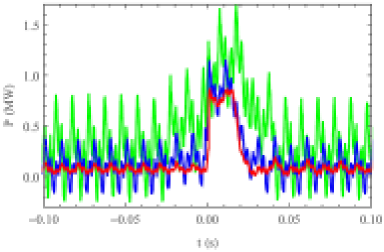

Figure 2. Bare total instantaneous power loss ($P_{loss}(t)$) of a 140/55kV, 60MVA transformer during tap operations at no load (red), 30% (blue) and 60% load (green)

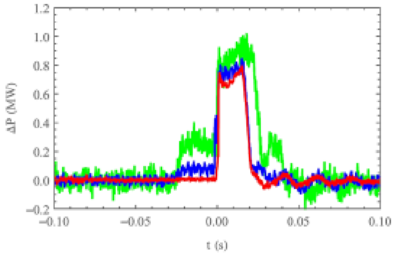

Figure 3. Instantaneous extra power loss ($\Delta P_{loss}(t)$) of the tap operations shown in Figure 2 after removing the predicted loss (at no load (red), 30% (blue) and 60% load (green))

Case study 1: selector-switch OLTC

- Arcing-in-oil, selector-switch type OLTC mounted on-tank of a 140/55 kV, 60 MV transformer
- About 7300 tap operation recorded over six years
- Between tap positions, subtle differences observed in mean power loss and commutation time
- Change of average commutation time associated with a shift in OLTC operation range observed

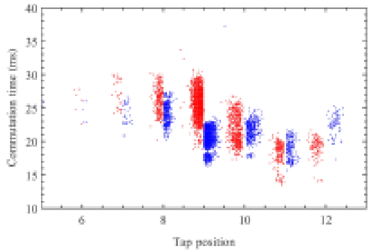

Figure 4. Commutation time of 7300 tap operations plotted against each tap position (blue – increasing and red – decreasing operations, data offset in proportion to the load current)

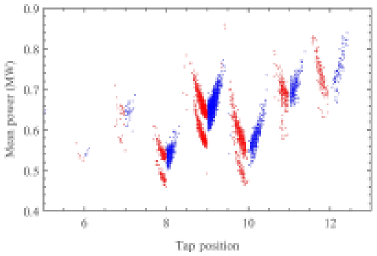

Figure 5. Extra power loss of 7300 tap operations plotted against each tap position (blue – increasing and red – decreasing operations, data offset in proportion to the load current)

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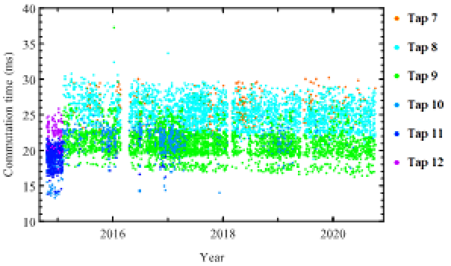

Figure 6. Time evolution of commutation time of 7300 tap operations over six years (initial tap position designated by colors)

Case study 2: diverter-switch OLTC

- Arcing-in-oil, diverter-switch type OLTC mounted in-tank of a 140/11 kV, 40 MV transformer
- About 900 tap operations recorded over one year
- This type has only two distinct contacts, classified as 'odd' and 'even'
- No significant difference observed between odd and even operations

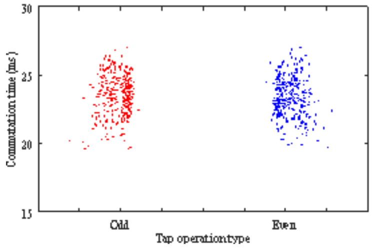

Figure 7. Commutation times extracted from 900 tap operations (of a diverter-switch type OLTC) classified into odd and even operations (data offset in proportion to load current)

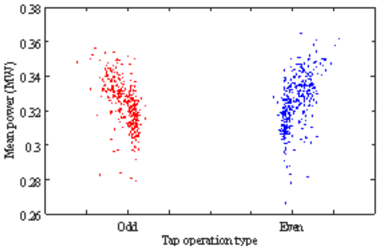

Figure 8. Mean power loss extracted from 900 tap operations (of a diverter-switch type OLTC) classified into odd and even operations (data offset in proportion to load current)

Incomplete tap operation protection

- Incomplete commutation lets the large power loss continue, causing overheating and most probably transformer failure
- A protection function with a reaction time substantially less than a second is required
- Energy (E), in the form of a "floating" integral of power loss, meets such stringent requirements of protection functions

$$E_n \leftarrow E_{n-1}\left(1-\frac{dt}{T_{int}}\right)+P_{loss}\,dt$$

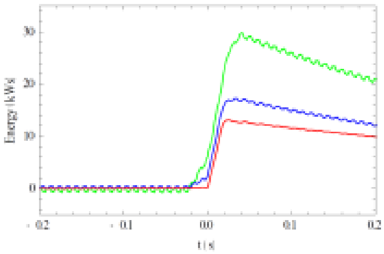

Figure 9. Floating integral of the three tap operations shown in Figure 2. T_{int} = 0.5 s and a constant value subtracted to account for the persistent loss

- Influence of instrument transformer inaccuracies can be alleviated by subtracting a constant value
- Maximum energy vs real power should follow a parabolic shape, verified in Figure 10

$$E_{max} = 3t_c\frac{(\delta U)^2}{2R} + 3t_0\left(\frac{P/3}{U}\right)^2 R$$

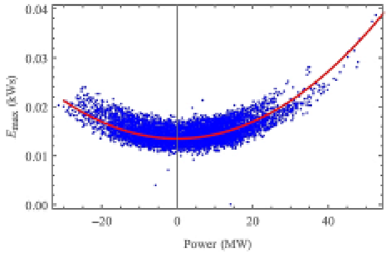

Figure 10. Maximum value of energy integral as a function of transmitted power for the same 7300 operations presented in Figures 4 & 5

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Discussion

- Monitoring
  - Signal analysis technique indicates a higher accuracy than the scatter in estimated parameters
  - Averaging techniques can provide high enough resolution for trend detection
- Protection
  - Proposed protection scheme is not affected by relative instrument transformer ratio errors
  - Trip threshold can be calculated and set based on the nameplate parameters

Conclusion

- Soft-sensing based OLTC monitoring is possible using available electrical signals in modern substations
  - In most cases , no additional sensors, dedicated acquisition hardware or outage required
  - Enough precision to observe subtle differences or trends in estimated parameters
- Protection against incomplete tap operations is feasible with floating power loss integral
  - Such a protection function can be implemented in a numerical protection relay
  - Relatively high safety margin for tripping can be set due to no intrinsic time delay associated