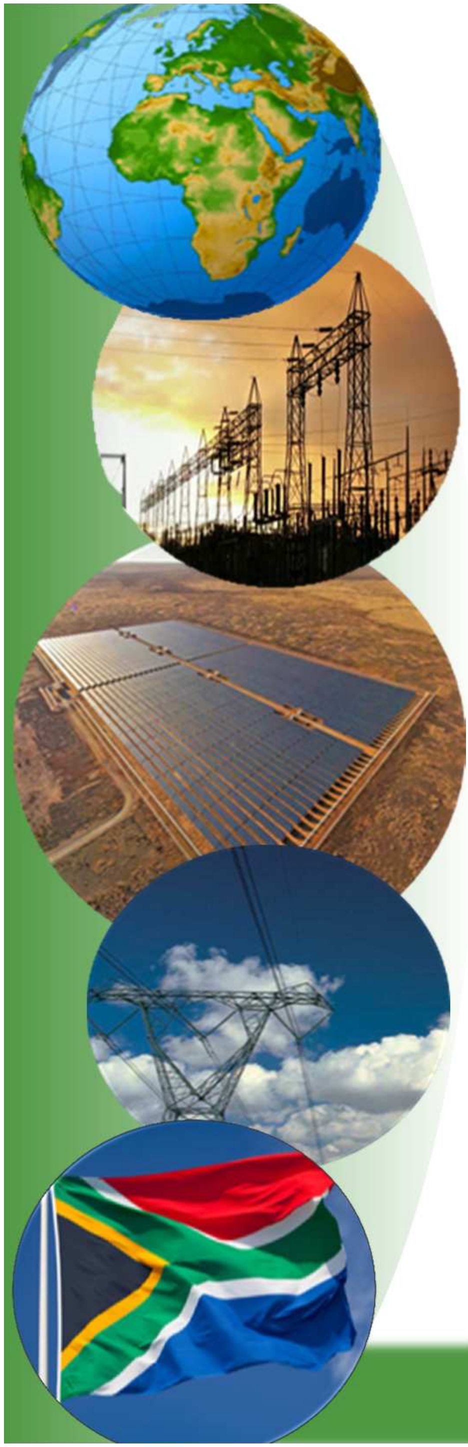

Transformers within photovoltaic generation plants: Challenges and possible solutions

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Content

- Introduction
- Background
- Problem Statement
- Identified Challenges
  - Harmonics
  - Loading
  - Other
- Simulation
- Recommendations
- Conclusion

Introduction

There has been a great drive for renewable energy IPPs since 2011, with the REIPPPP.

	Procured (MW)	Operational (MW)
Onshore Wind	3 357	1 360
Solar PV	2 292	1 474
Solar CSP	600	200
Other	74	17
Data reflected up to 31 March 2017 as in IPPPP Overview Report for quarter 4 of 2016/2017		

Independent Power Producer Procurement Programme

Introduction

- Resulted in the market expansion of renewable technologies.
    - Includes distribution equipment like transformers.

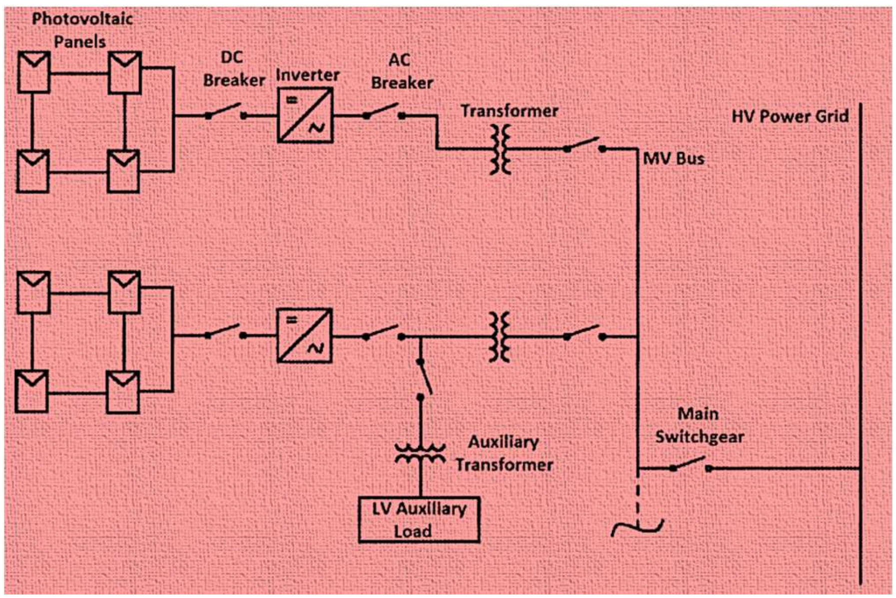
- The environment (wind and solar farms) poses some challenges for the equipment operating therein.

- For transformers in photovoltaic plants:
    - Load variation
    - Harmonics (Inverters)
    - Voltage transients
    - DC bias, etc.

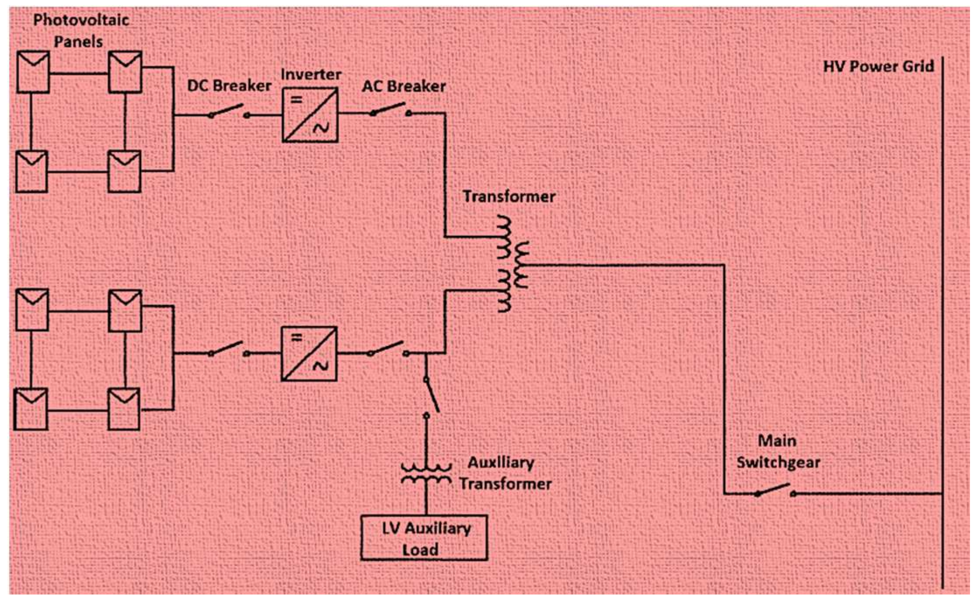
Background

- Transformers used to connect PV plant to grid
- Critical component for grid integrated PV plants

General photovoltaic systems:



Example with 2-winding transformers



Example with 3-winding transformer

Problem Statement

- Problem:
  - Transformers experiencing operational problems in photovoltaic plants

- Aim of this article:
  - Identify the challenges for transformers in a PV plant and make recommendations to improve compatibility of these units

Identified Challenges

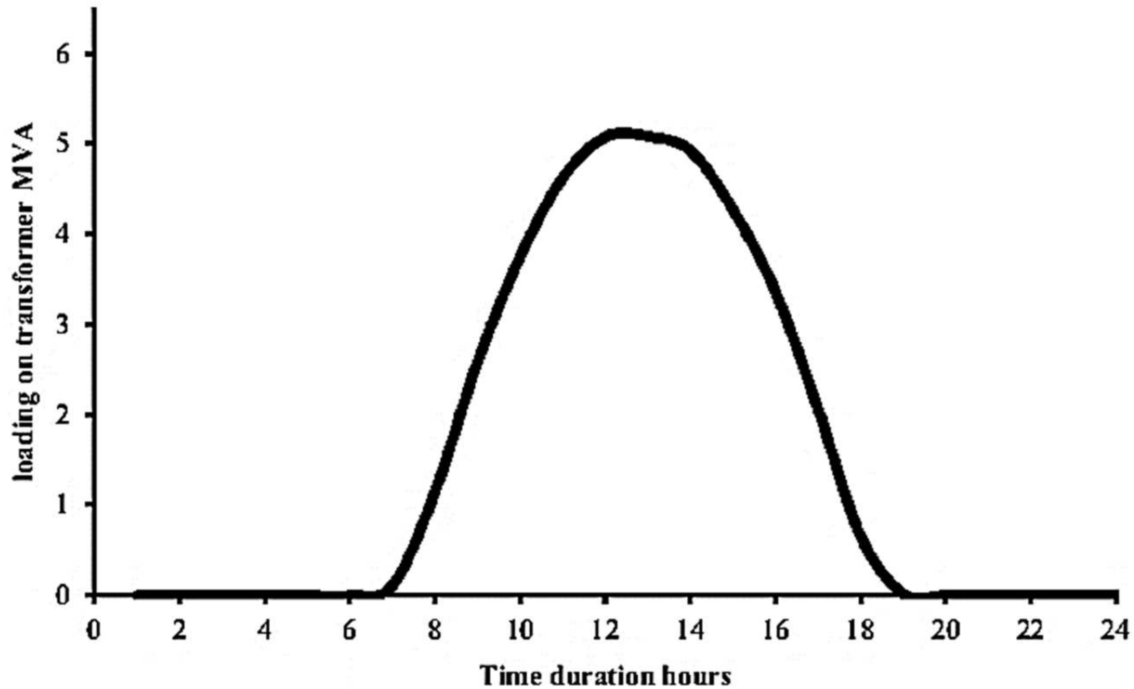
- Main challenges identified for transformers in PV plants include:
  - Inverter generated harmonics
  - Transformer loading
  - Other:
    - Voltage transients
    - Inrush current
    - Voltage regulation
    - DC bias

Identified Challenges

- Harmonics:
  - Generated due to electronic switching to convert DC to AC – Inverters
  - Voltage harmonics:
    - AC waveforms has a pulsed nature (inverter voltage to ground)
    - Can influence flux magnitude – Faraday's Law
    - Insulation
  - Current harmonics:
    - Add to losses (no-load & load) in transformer
      - I^2R, Stray and Winding Eddies
    - Increased operating temperature

Identified Challenges

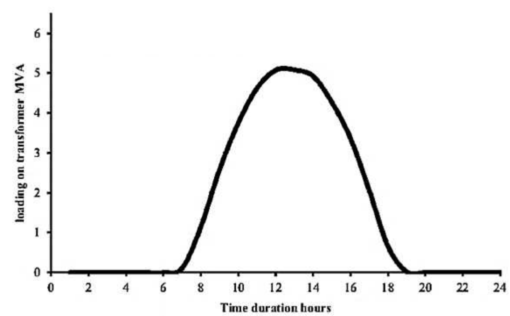
- Transformer loading:
  - PV plant capability directly proportional to irradiation (PV without energy storage).
  - Load follows irradiation curve



Identified Challenges

- Transformer loading:
  - Loading usually controlled by inverter
  - PV transformer loaded 14hrs in summer, 6hrs full load

  - Effect on transformer:
    - No-load losses could increase – Capitalisation
    - Transformer sizing – Optimal sizing (loading, harmonics, weather patterns – irradiation spikes)
    - Voltage regulations (tap changing)
    - Frequent switching (load/no-load)
      - Mechanical and thermal force cycling



Identified Challenges

- Other:
  - Voltage transients and insulation
    - Voltage harmonics – partial discharge
    - HV/MV Switching – re-ignition
    - Isolation between LV and HV through electrostatic shield
  - Inrush current
    - Switching operation – residual flux in core
  - Supply current and voltage unbalance
    - Load unbalance due to supplied inverter currents – 3-winding transformer
    - Current unbalance – Abnormal flux patterns and increased heating
    - Voltage unbalance – Excessive temperature rise and noise, core saturation

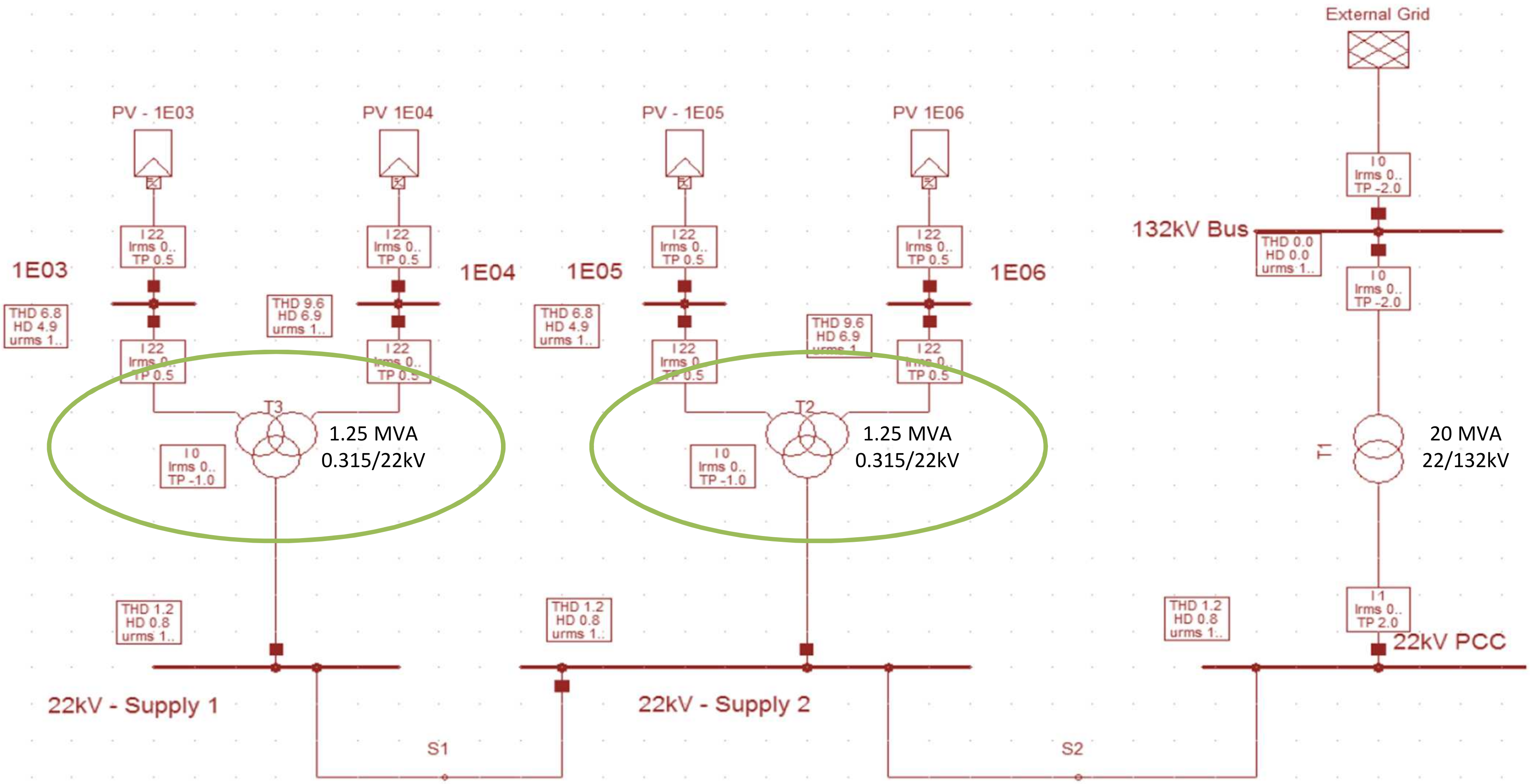
Identified Challenges

- Other:
  - Voltage regulation
    - Increased tap-changer maintenance – frequent regulation
    - LV tap changer to accommodate PV panels deterioration
  - DC bias
    - Caused by DC components of inverter supplied current
    - Leads to increased magnetising current and saturated core – increasing circulating currents, temperature and sound

It is important to supply detailed information of site and planned operation in order to identify the applicable challenges for the transformers

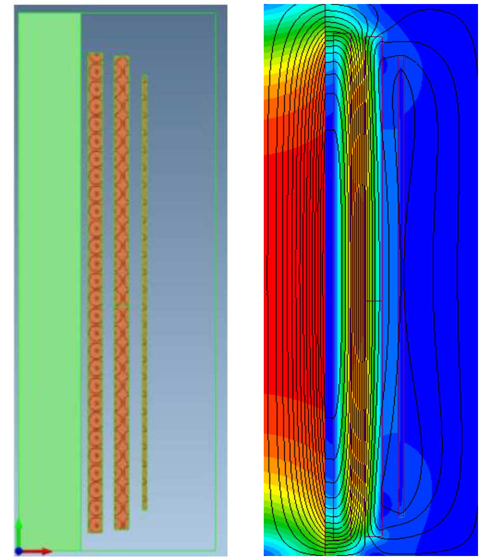
Simulation – Effect of harmonics

Typical PV plant electrical reticulation simulation to identify effect on losses within the transformer due to harmonics



Simulation – Effect of harmonics

Calculate losses through FEM simulation



Simulate harmonics

Determine harmonic loss factors

- Winding Eddy Loss Factor
- Stray Loss Factor

$$F_{HL-WE} = \frac{\sum_{h=1}^{h=h_{max}} \left(\frac{I_h}{I_1}\right)^2 h^2}{\sum_{h=1}^{h=h_{max}} \left(\frac{I_h}{I_1}\right)^2}$$

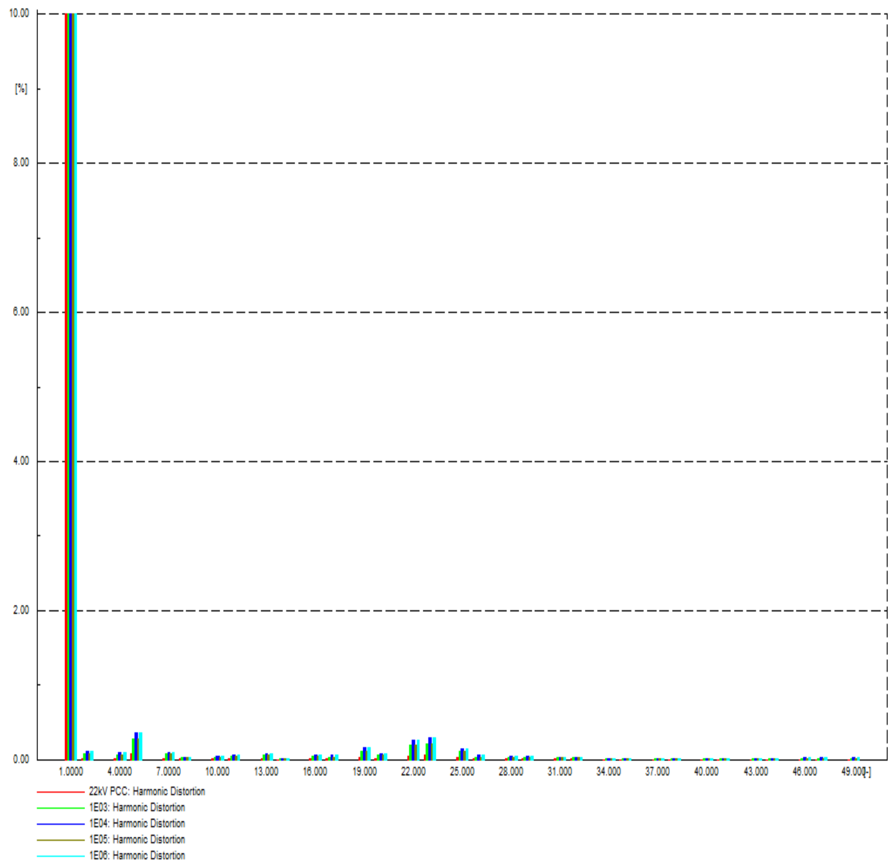
$$F_{HL-STR} = \frac{\sum_{h=1}^{h=h_{max}} \left(\frac{I_h}{I_1}\right)^2 h^{0.8}}{\sum_{h=1}^{h=h_{max}} \left(\frac{I_h}{I_1}\right)^2}$$

Use factors to determine losses

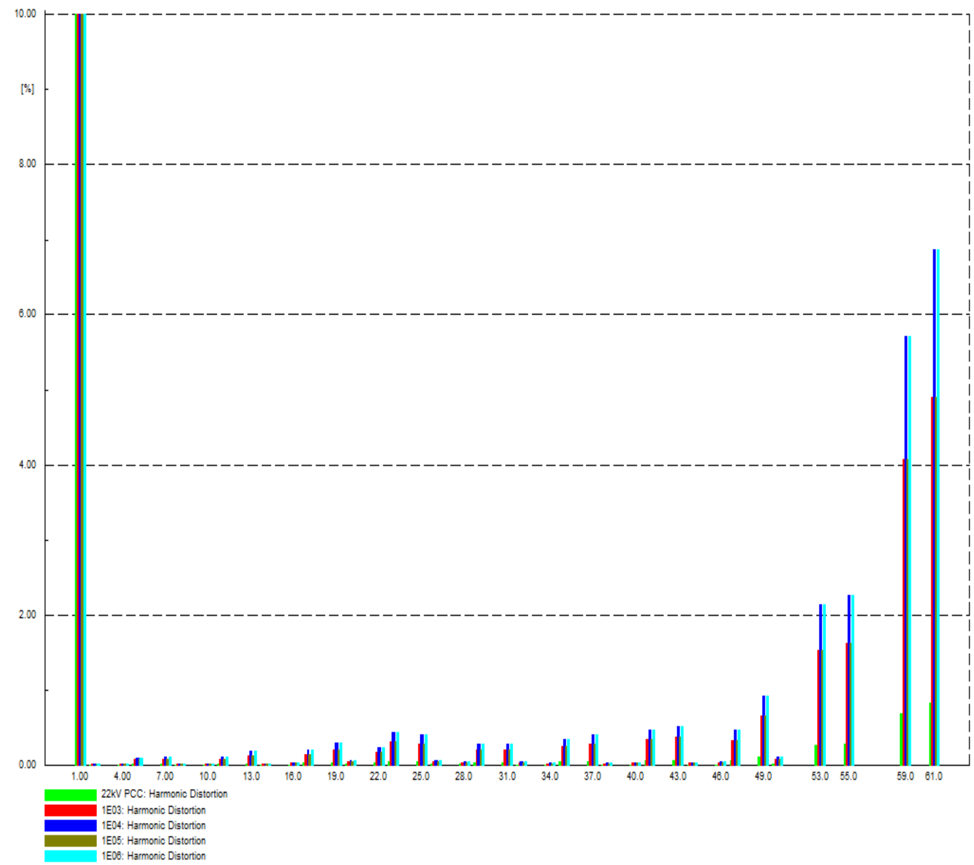
Simulation – Effect of harmonics

Harmonic Currents Spectrum:

Inverter Spectrum (Case a)



Measured Spectrum (Case b)



Simulation – Effect of harmonics

- Results (Case b) for each transformer

	Transformer 1 (20 MVA) 132/22 kV			Transformer 2 (1.25 MVA) 315 V/22 kV			Transformer 3 (1.25 MVA) 315 V/22 kV		
	Factor	Losses	Losses (H)	Factor	Losses	Losses (H)	Factor	Losses	Losses (H)
DC Losses	1.00	108.00	108.01	1.00	10.64	10.68	1.00	10.64	10.68
Winding LV1	1.47	5.10	7.50	17.27	0.14	2.44	17.28	0.14	2.44
Winding LV2				32.88	0.27	8.98	32.88	0.27	8.98
Winding HV	1.47	3.90	5.73	1.47	0.34	0.49	1.47	0.34	0.49
Winding Reg.	1.47	0.00	0.00						
Structural Parts	1.00	5.10	5.12	1.12	0.85	0.95	1.12	0.85	0.95
Total		**122.1**	**126.4**		**12.2**	**23.5**		**12.2**	**23.5**

Simulation – Effect of harmonics

- Results (Case b)
  - Losses
    - 20 MVA – 3% increase
    - 1.25 MVA – 92% increase
  - Increase in losses influences:
    - Transformer design
    - Increased temperatures - cooling design

Note: Even though THD at PCC are below 3%, harmonics could effect transformer losses with THD of around 9% on LV

Recommendations

- Client:
  - Harmonic analysis study
    - Incorporated in cooling and losses
  - Site evaluation study and operational study to minimise effect of load variation
    - Improve capitalisation
- Manufacturer:
  - Apply results of studies to the design of PV transformer
  - Guide client in required data

Conclusion

- A PV transformer is not a normal distribution step-up transformer
- Various challenges: Harmonics, Load variation, etc.
- Challenges could be addressed through proper communication and studies (data analysis)
- Designs to be adapted per application
- Both parties to be aware and address challenges to ensure a effective and compatible PV transformer

THANK YOU!

Acknowledgements:

Powertech
Transformers