Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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Giuseppe Simioli obtained his M.Sc degree in Electrical Engineering from Politecnico of Milan, Italy. From 1994 to 1999 he worked in ENEL in the Electric Research Department as a research engineer. He joined CESI Centro Electrotecnico Sperimentale Italiano in 2000 where he was project manager in projects relevant to HVDC systems, FACTS, Power Quality Devices and in general Power Electronics. From 2008 to 2011 he was in Wordenergy SA (Switzerland), responsible for the preliminary design and authorization procedures of the converter stations for the Greenconnector HVDC project (Italy-Switzerland). From 2012, he is in WEIDMANN as Power System manager, responsible for the consultancy activities relevant to Power Systems.

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Transformers and electric grid transient interactions – The phenomena and some topics to consider in insulation design

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A Member of the WICOR Group

WEIDMANN Transformer & Grid Interactions

INDEX

- Background
- Main reference document
- Digital simulation and modelling
- Network interactions
- New approach for transformer voltage assessment
- Transformer specification and studies
- Case study

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

WEIDMANN — INTEGRATED SERVICES

Background

Grid complexity

- Transmission systems
- Power plants
- Compensation systems
- Sub-transmission systems
- Industrial plants
- HVDC systems
- Distribution system
- Wind farms
- Photovoltaic plants

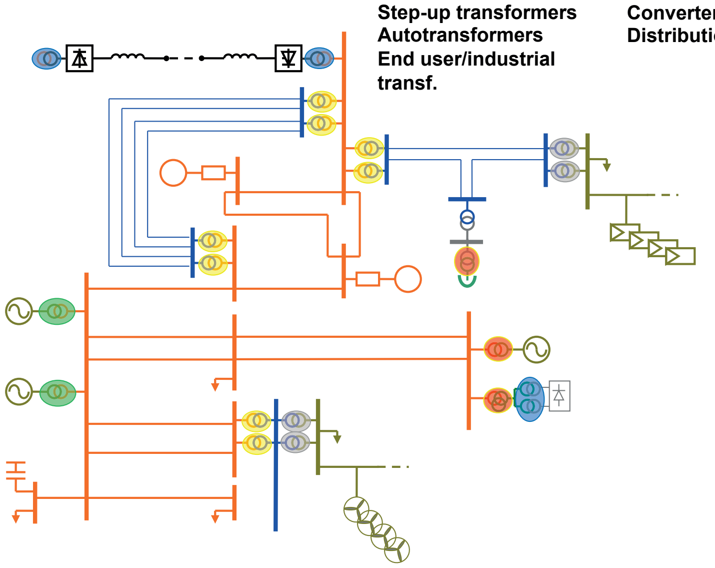
Transformer Life Management TLM 2014 — 3

WEIDMANN — INTEGRATED SERVICES

Background

Presence of transformers in the Grid

- Step-up transformers
- Autotransformers
- End user/industrial transf.
- Converter transf.
- Distribution transf.



Transformer Life Management TLM 2014 — 4

Dipl.-Ing. Giuseppe Simioli

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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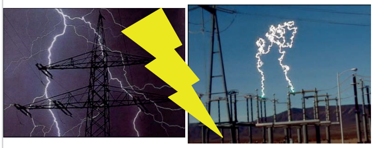

Background

Transient interactions between transformers and power systems can occur during switching operations (breakers and disconnectors), faults, transformer energization, lightning strokes, etc..

Possible transient overvoltages following the previous events can contain wave shapes and frequencies not directly addressed by the existing standards (IEC 60076-3, IEC60076-4, IEC 60060-1 or IEEE C,57-12,90, IEEE C57.12,00, IEEE C57-98) where Full Wave Lightning Impulse, Chopped Wave Lightning Impulse and Switching Impulse are dealt with.

Cases in the literatures have been reported relevant to transformer failures where transient overvoltages interactions with the power system seem to be the possible failure root cause.

Transformer Life Management TLM 2014 5

WEIDMANN Transformer & Grid Interactions

INDEX

- Background
- Main reference document
- Digital simulation and modelling
- Network interactions
- New approach for transformer voltage assessment
- Transformer specification and studies
- Case study

Transformer Life Management TLM 2014 6

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Main reference document

•CIGRE WG 12-07 "Resonance Behavior in HV Transformers" – 1979

- ► Resonance phenomenon is not only due to transformers
- ► "External" source of oscillating voltages is required
- ► Transformer winding resonances occur if:
  - ♦ Excitation frequency is almost the same of the winding natural frequency
  - ♦ Amplitude and duration of oscillating voltage is sufficient to start the process

•CIGRE JWG 33/13,9 "Very fast transient phenomena associated with gas insulated substations" - 1988

- ► Resonance phenomenon due to oscillations transformer windings and GIS (several MHz if directly connected, otherwise around 1 MHZ)

Transformer Life Management TLM 2014 7

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Main reference document

•CIGRE JWG A2-A3-B3.21 "Electrical environment of transformers – Impact of fast transients" – 2005

- ► Waveforms for testing transformers were defined in details
- ► Lacking a complete description of VFT (very steep wave fronts) and of oscillating voltage waveforms matching natural frequencies of transformer windings
- ► Need of detailed studies for each particular case to assess transformer interaction with the mains
- ► Risk management methodology

Transformer Life Management TLM 2014 8

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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Main reference document

•CIGRE-Brazil JWG A2/C4.03 "Interaction between transformers and the electrical system with focus on high frequency electromagnetic transients" – 2011

- ► Primary task to understand oscillatory phenomenon resulting from interaction between transformer and electrical environment after a switching event
- ► Studies (transient simulations) performed for different voltage levels and different substation arrangement in the Brazilian network

•CIGRE WG A2/C4.39 "Electrical Transient Interaction between Transformers and the Power System" - 2014

Part 1 – Expertise

Part 2 – Case studies

Transformer Life Management TLM 2014 9

WEIDMANN — Transformer & Grid Interactions

INDEX

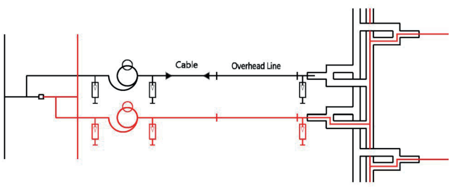
- Background
- Main reference document
- Digital simulation and modelling
- Network interactions
- New approach for transformer voltage assessment
- Transformer specification and studies
- Case study

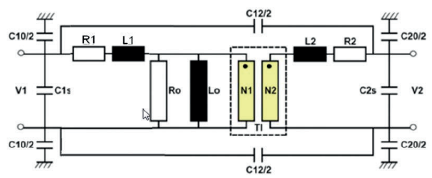
Transformer Life Management TLM 2014 10

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

Digital simulation and modelling

Capability to simulate the phenomena is of most importance but this requires a valid representation of network and its component for a specific frequency range corresponding to the particular event to be studied (from some hundred of kHz to some MHz) together with the transformer under analysis.





Digital simulation and modelling - Network

Due to the specific frequency spectrum to be considered (switching, lighting, very fast voltages), very important is the selected simulating model; i.e., the frequency dependence of the parameters should be taken into account in digital models for transmission lines, cables, substation buses (importance of stray capacitance to ground), GIS, power apparatus in general (again, importance of stray capacitance to ground), main network, etc..

Importance of the position in the layout of a station.

CIGRE WG A2/C4.39 "Electrical Transient Interaction between Transformers and the Power System", Part 1 – Expertise, at chapter 3 (with the listed references), provides an overview of the modelling approach for the different equipment according to the specific event to be simulated.

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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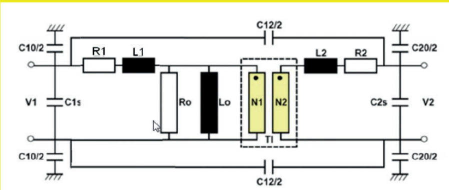
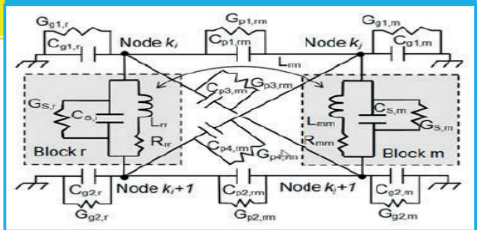
Digital simulation and modelling - Transformers

HOW TO PROPERLY MODEL A TRANSFORMERS FOR THE SPECIFIC PURPOSE?

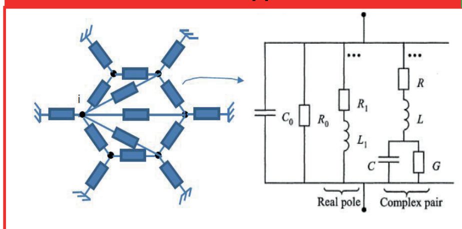
Conventional approach with simplified procedures



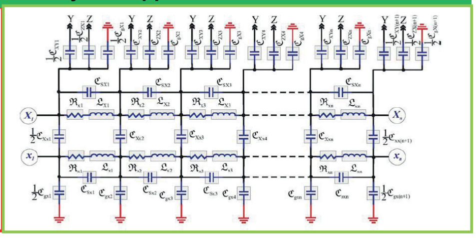
White box approach



Black box approach



Grey box approach (compromise Black&White)



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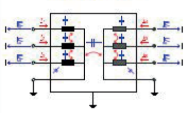
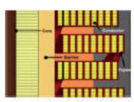
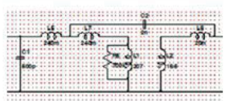
Digital simulation and modelling - Transformers

From CIGRE 577A

	Black Box	White Box	Grey Box
			
Typical applications	System interactions	System interaction and internal overvoltages	System interactions
Typical Model Bandwidth	up to 2MHz (depends on the measurements quality)	Approximately 20th natural frequencies, that is, up to 500k to 800kHz for large transformers	up to 500kHz
Very Fast Transients, above 2MHz	Difficult to obtain reliable measurements	Possible to be obtained, it depends on how each model element will be represented. The initial part of the winding should be well represented.	

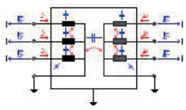
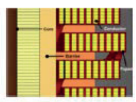
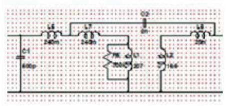
Transformer Life Management TLM 2014 14

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

WEIDMANN — Transformer & Grid Interactions

Digital simulation and modelling - Transformers

From CIGRE 577A

	Black Box 	White Box 	Grey Box 
Data Basis	Measurements	Design Geometry	Measurements and Design Data
Model Extraction	Optimization	numerical field analysis methods, analytical methods	Optimization
Model Complexity	Medium / High	High	Small / Medium
Simulation Time	Small	Small / High	Small/High
Integration with EMTP type software	Yes (RLC model or Convolution)	Yes	Yes, for linear representations

Transformer Life Management TLM 2014 15

WEIDMANN — Transformer & Grid Interactions

INDEX

- Background
- Main reference document
- Digital simulation and modelling
- Network interactions
- New approach for transformer voltage assessment
- Transformer specification and studies
- Case study

Transformer Life Management TLM 2014 16

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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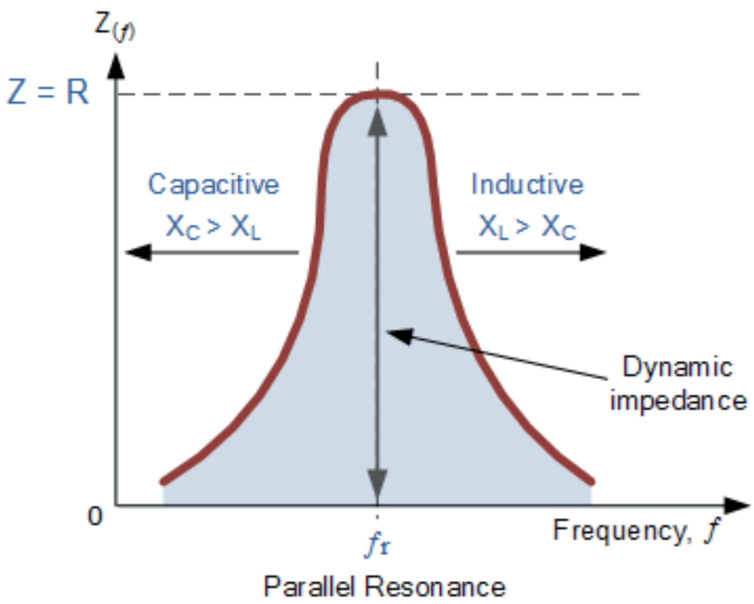

Transformer Life Management TLM 2014 17

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Network interactions – Typology of Electrical Resonances

•Switching operations relevant to:

- Cable+transformers networks
- Closing of a circuit breaker
- Fault initiation
- Opening of a circuit breaker

Network interactions – Other type of overvoltages

•Restrikes in circuit breakers (mainly vacuum circuit breakers)

•Disconnector switching (inside GIS systems)

Transformer Life Management TLM 2014 18

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

INDEX

New approach for transformer voltage assessment

JWG A2/C4-03 proposed the introduction of a new parameters (see "Electrical Transient Interaction between Transformers and Power System" – Part 1 Expertise):

the **Time Domain Severity Factor (TDSF)**.
Defined as the ratio of the max voltage drop between disks along the windings, due to transient events in the system, and the same max voltage drop due to standard dielectric tests.

the **Frequency Domain Severity Factor (FDSF)**.
Defined as the ratio of the voltage transient calculated from the transient analysis to the voltage transient associated with the standard impulse waves.

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

New approach for transformer voltage assessment

Time Domain Severity Factor (TDSF).
TDSF in order to assess the severity of the stresses along transformer windings.

TDSF requires:

1. A terminal model (black box model) of the transformer to assess the transient voltages at transformer terminals following a transient voltage coming from the mains;
2. A detailed model (white box model) of the transformer to assess internal transient overvoltages along the windings following an external overvoltage.

Standard impulse waveforms represent correctly the system stresses if TDSF is lower than 1.

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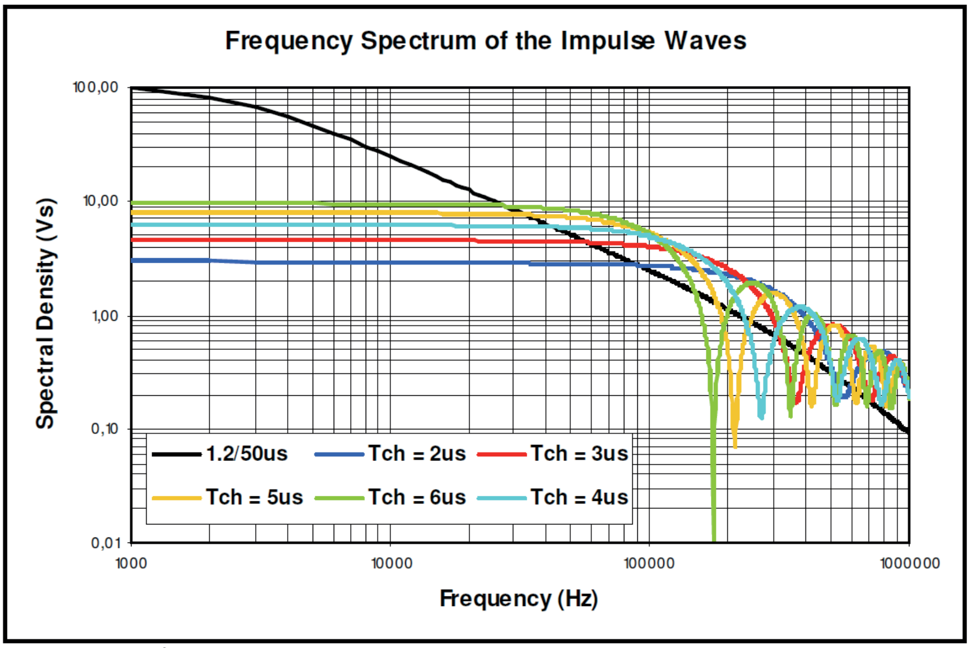

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

WEIDMANN Transformer & Grid Interactions

INDEX

Transformer Life Management TLM 2014 23

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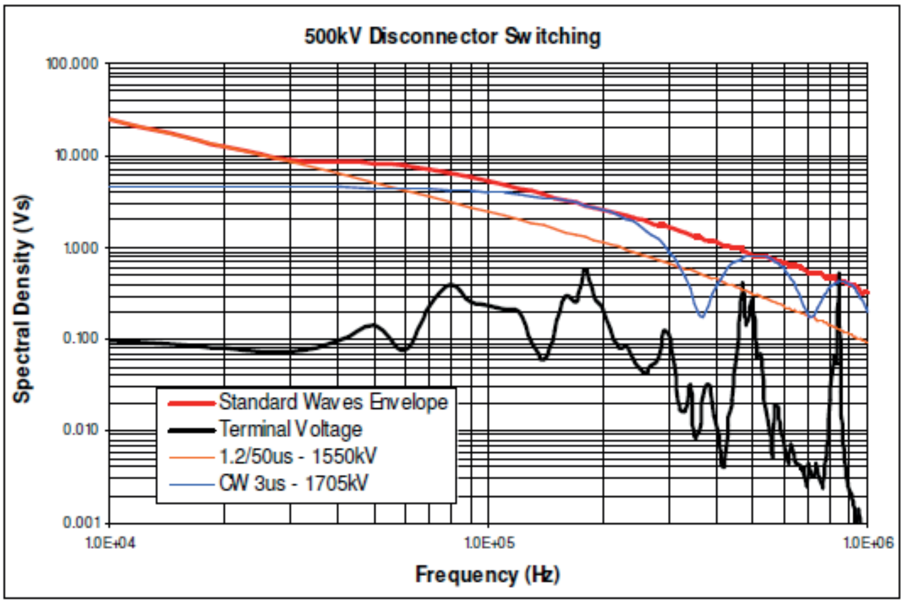

Spectrum of transformer terminal voltage for disconnector switching.

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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INDEX

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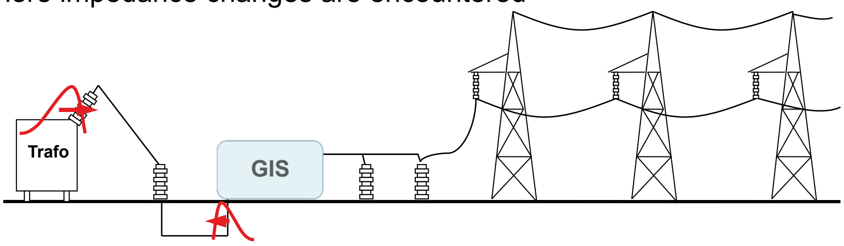
Case study

Very Fast Front Overvoltages in a 400 kV GIS

- Disconnector switching operation in a GIS may produce fast transient overvoltages due to the voltage collapse across the disconnector/ circuit breaker poles at striking
- The global waveshape in a given point is the result of subsequent wave reflections and refractions of the initial voltage step at all points where impedance changes are encountered



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Case study

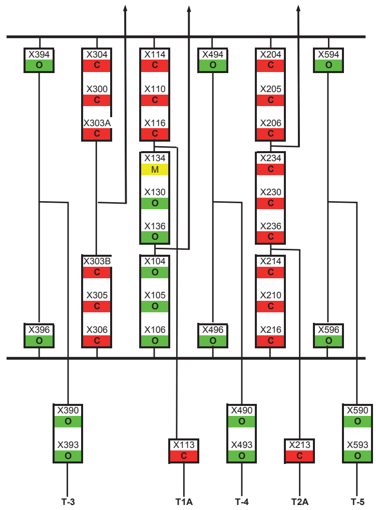
Very Fast Front Overvoltages in a 400 kV GIS

- Two different phenomena were analyzed in detail:

  Circuit breaker switching operations
  Disconnector switching operations

- CB and DS can cause restrike during opening operations

- **Voltages are relevant only to the transient part ΔV(t) of the total overvoltage**



Transformer Life Management TLM 2014 27

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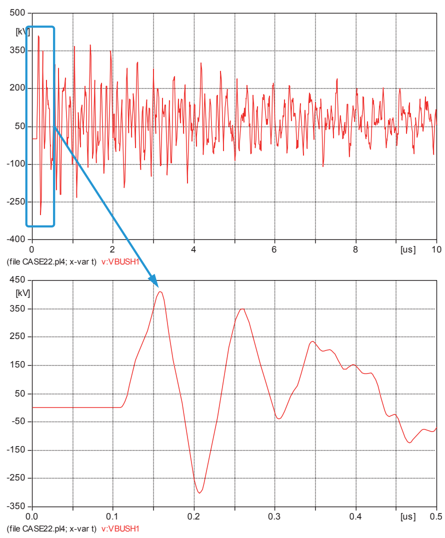
Case study

Very Fast Front Overvoltages in a 400 kV GIS

Simulation results:

- No critical VFFO peak values on the 400kV GIS station
- The highest value, about 2.2 p.u., obtained in case of disconnector operation, must be considered within the normal limits and the encountered frequencies, about 10 MHz, are as expected
- Voltage peak values, slightly less than 3 p.u. calculated as a consequence of circuit breaker operation



Transformer Life Management TLM 2014 28

Berücksichtigung des Zusammenwirkens von Transformatoren und Netzen in der Planungsphase

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Case study

Very Fast Front Overvoltages in a 400 kV GIS

- Failure cause:
  - Investigations in the HV bushing
  - Post-mortem analysis shown defects in the insulation system of the bushing giving rise to the fault and the subsequent explosion

Transformer Life Management TLM 2014 29

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Thank You
QUESTIONS?

30