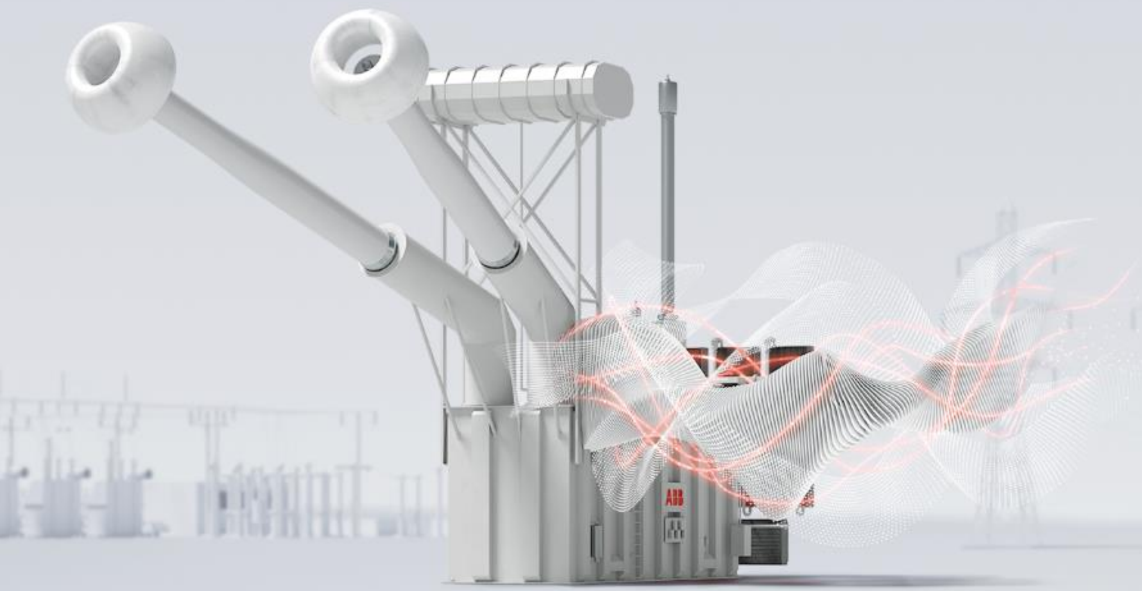


CIGRE / US NATIONAL COMMITTEE

GRID OF THE FUTURE (GOTF) SYMPOSIUM, OCTOBER 23-24, 2017, PAPER SESSION 2D

Susceptibility of TVA's 500 kV Fleet of Power Transformers to Effects of GIC

Authors: Dr. Ramsis Girgis, G. Burden, M. Bernesjo Ian Grant and Gary Kobet

Presenter: Gary Burden

ABB Power Grids Transformers – USA Tennessee Valley Authority (TVA) – USA

Outline of Presentation

- Background
- Purpose of Paper
- Process of GIC Total Susceptibility Evaluation
- Design – Based Susceptibility
- GIC – Level Susceptibility
- Study Case
- Next Phases of GIC Fleet Assessment

Background

- **Misconception in the electric power industry**
  - GIC has caused, and would cause, significant damaging overheating to a large majority of power transformers
- **Overreaction => Calling for:**
  - Conservative operating procedures (Unnecessarily reducing load at low levels of GIC)
  - Installation of expensive GIC Blocking devices
  - Paying more attention to thermal effects in transformers and not to the true issue of increased VAR Demand and effect of harmonics on power system components
- **A recent study by ABB confirmed that because of the nature of the GIC currents**:
  - Only a finite number of power transformers with certain design features could experience damaging overheating
  - A larger # of transformers would be susceptible to core saturation & some overheating
  - The rest of the transformers would not be susceptible to either core saturation or damaging overheating

Purpose of the Paper

- **Describes a process, where a fleet of power transformers can be properly evaluated to determine:**
  - Which Transformers would be susceptible to damaging overheating
  - Which Transformers would be susceptible to only core saturation & moderate overheating
  - Which transformers would have a low level of susceptibility to either effects of GIC
  - Which Transformers would not be susceptible to effects of GIC

ABB

Process of GIC Total Susceptibility Evaluation

- **Total susceptibility of a power transformer to effects of GIC is determined by:**
  - Transformer Design – Based Susceptibility
  - GIC Level – Based Susceptibility
- **Process was previously applied to a fleet of over 1600 $\geq$ 500 KV Large power transformers on the US Power Grid**
- **The TVA GIC Case Study includes 231 transformers****

  ** *Number of transformer was 205 at the time the paper was written*
- **Does not apply to shunt reactors and Specialty Transformers; such as Phase shifters, Rectifier transformers, Furnace Transformers, etc.**

Design – Based Susceptibility

- Design Classification A:
  - Transformers not susceptible to effects of GIC.
- Design Classification B:
  - Transformers least susceptible to core saturation, but susceptible to high magnetizing current.
- Design Classification C:
  - Transformers susceptible to core saturation and possible structural parts overheating.
- Design Classification D:
  - Transformers susceptible to both core saturation, as well as possible damaging windings and structural parts overheating.

Parameters Used for Evaluating Design–Based Susceptibility

- **Voltage Ratings**
  - Higher voltage transformers would be exposed to higher levels of GIC
- **Type of transformer (GSU vs. Auto transformers)**
  - EHV Auto transformers are Y - Y and typically have a Delta tertiary, which makes them susceptible to overheating in the Tertiary winding
- **Shell-form vs. Core Form**
  - Core form Transformers (Other than those with a 3 phase, 3 limb core) and Shell-form transformers are susceptible to core saturation
  - Some, prior to 1973, Shell form GSUs are susceptible to damaging winding overheating due to high circulating currents for GIC levels
- **Single-phase vs. three-phase and Core-type**
  - 3-Phase core form transformers with 3-limb cores are least susceptible to saturation due to GIC

ABB

GIC Level – Based Susceptibility

- **Level of GIC is determined by:**
  - Geographical region where the transformer is located
  - Location of transformer in the power system
  - Closeness to a large body of water (Ocean / Sea / Lake)
  - Resistance of the soil in that location
  - KV of HV side of Transformer
  - Direction of HV transmission lines
- **GIC – Level susceptibility divides transformers into 3 categories:**
  - Low (< 15 Amps / phase), Medium (15 – 75 Amps / phase), High ($\geq$ 75 Amps / phase)
- The TVA team performed GIC system modelling to calculate GIC levels that each transformer on their 500 kV fleet would be subjected to under the GMD Benchmark Storm

GIC Susceptibility Process Adopted by IEEE GMD Guide

	GIC Exposure Level (Amps / phase)		
Design – Based Susceptibility	Low Exposure (≤ 15 A)	Medium Exposure (> 15 to < 75A)	High Exposure (≥ 75 A)
Not Susceptible (A)	I	I	I
Least Susceptible (B)	I	II	III
Susceptible (C)	II	III	III
Highly Susceptible (D)	II	IV	IV

Category I: No, or minimal, susceptibility to effects of GIC = > No further action needs to be taken

Category II: Low level of susceptibility to effects of GIC = > only magnetic modelling needed

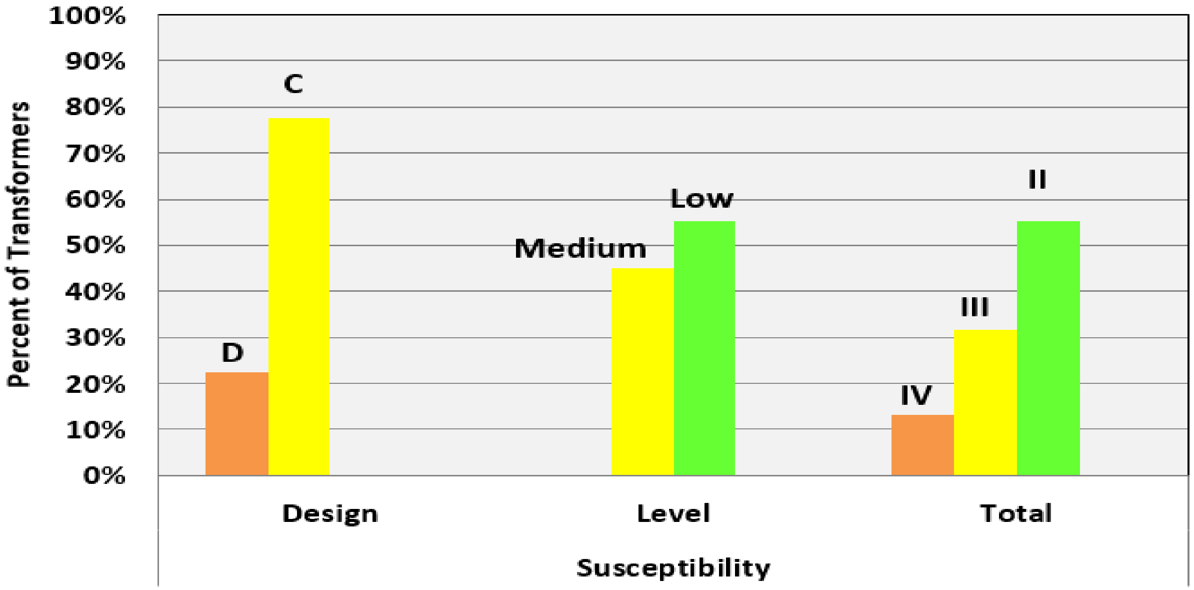
Category III: Medium level of susceptibility to effects of GIC = > Both magnetic modelling and thermal assessment of structural parts needed

Category IV: High level of susceptibility to effects of GIC => Both magnetic modelling and thermal GIC Assessment of windings and structural parts needed

Case Study

- 231 of the large power TVA Transformers in service
- 500 kV TVA Electric Power grid
- Included Core-form and Shell-form transformers
- Mostly single-phase transformers, but some 3-phase transformers
- Autotransformers, 3-winding transformers, and Generator Step-Up transformers
- 200 MVA – 448 MVA Power Ratings
- Locations in Tennessee, Alabama, Kentucky, and Mississippi.

Summary of Results of Case Study



Number of transformers	Total Susceptibility Categories				
	IV	**III**	**II**	**I**	**Total**
Actual Count	27	65	113	0	205
% of Total	13.2%	31.7%	55.1%	0 %	100%

Next Tasks of TVA GIC Fleet Assessment Project – Task 2

- **Perform Magnetic modelling of transformers in Categories II, III & IV (100 % of Fleet)**

  => Var Demand and main Current Harmonics (2^{nd}, 3^{rd}, and 4^{th})

- System analysts would use this data to perform system simulations to evaluate the response of the power system & its components during the GMD storm

  = > Proper contingencies can be built in the Power System for such magnitudes of VAR, so Voltage Collapse / grid black-outs can be avoided

  = > Increasing robustness of the network; including providing additional network protection and adjusting settings of relays / other susceptible equipment

  = > Developing special / proper operating procedures during a GMD storm

  = > Installation of appropriate GIC blocking devices, if needed

- System blackouts and possible damages to some transformers can be avoided in future GMD events

Next Tasks of TVA GIC Fleet Assessment Project – Task 3

- **Perform magnetic Modelling of transformers in Categories III and IV (45 % of Fleet)**

  => Calculate Windings & Structural parts Hot Spot temperatures due to GIC

- **For transformers determined to exceed allowed temperature limits:**

  = > Plan on load reduction during GMD storm

  => Remove transformer from service in case of high temperatures levels

Detailed results of Fleet GIC Susceptibility Assessment

				HV		LV (XV)		TV (YV)	GIC Susceptibility		
Manufacturer	Manuf. Serial Number	Year of Manuf.	Substation Name	MVA	kV	MVA	kV	kV	Design	GIC Level	Total GIC
ASEA	6015227	1967	Bull Run		500		161	13	C	Medium	III
	5982821	1967			500		161	13	C	Medium	III
ABB - Varennes Canada	1234507	2017			500		161	13	C	Medium	III
Hyundai	20959TI0003	2003	Choctaw	312	525	312	16		C	Low	II
	20959TI00020001	2003		312	525	312	16		C	Low	II
Daihen	GBK802201	2003		281	525	281	16		C	Low	II
ABB - Varennes Canada	12238-01	2010	Clay Sub	448	500	448	165.03	26.4	C	Low	II
	12238-02	2010		448	500	448	165.03	26.4	C	Low	II
	12238-03	2010		448	500	448	165.03	26.4	C	Low	II
	12238-04	2011		448	500	448	165.03	26.4	C	Low	II
ABB Westinghouse - Muncie, IN	ALM2286-1	1996	Cordova Sub	400	500	400	161	13.2	D	Medium	IV
	7003048	1983		400	500	400	165	13.2	D	Medium	IV
	7001615	1970		400	500	400	161	13.2	D	Medium	IV
	7001614	1970		400	500	400	161	13.2	D	Medium	IV
	7001613	1970		400	500	400	161	13.2	D	Medium	IV
ABB - Varennes Canada	12055-01	2002		448	500	448	165.03	13.2	C	Medium	III
	12055-02	2002		448	500	448	165.03	13.2	C	Medium	III
ABB - Varennes Canada	12259-02	2011	Cumberland	525	500	525	22		C	Low	II
Asea - Ludvika Sweden	6121032	1971	Cumberland Spare	450	500	450	20.7		C	Low	II
ABB - Varennes Canada	12259-03	2012	Cumberland GSU#2	525	500	525	22		C	Low	II
	12259-01	2012	Cumberland Spare	525	500	525	22		C	Low	II
	12281-01	2012		525	500	525	22		C	Low	II
	12281-02	2013		525	500	525	22		C	Low	II
	12281-03	2013		525	500	525	22		C	Low	II

ABB