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CIGRE US National Committee
2017 Grid of the Future Symposium

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

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## SUMMARY

In its effort to comply with the requirements of the FERC order on GIC, TVA requested ABB to perform a full GIC Assessment of its fleet of 500 kV Power Transformers. This involves the following three main assessment tasks:

Task – I: Assessment of the Susceptibility of the transformer fleet to effects of GIC under the NERC 1-in-100 years Benchmark GMD Storm

Task – II: Magnetic Assessment of the transformers on the fleet. This involves the calculation of the additional VAR demand and the current harmonics injected by the transformer into the power system as a result of exposure to GIC.

Task – III: Thermal Assessment of transformers on the fleet determined to be susceptible to windings and / or structural parts overheating under that GMD scenario.

This paper presents the results of Task – I; namely, the GIC Susceptibility Assessment. This assessment was applied to the 205 transformers on the fleet. The study shows the following:

- Only 27 of the total fleet of 205 transformers (13.2 % of all transformers) have a high level total susceptibility to effects of GIC. For these transformers, both magnetic modelling and thermal GIC capability would need to be performed.
- 65 of the 205 transformers (31.7 % of all transformers) have a medium level of susceptibility to effects of GIC and, therefore, magnetic modelling and thermal assessment of only the structural parts would need to be performed on these.
- The remaining 113 transformers (55.1 % of all transformers) are assessed to have a low susceptibility to effects of GIC and, thus, only magnetic modelling of these transformers would be needed.

## KEYWORDS

Geomagnetic Disturbance (GMD), Geomagnetically Induced Currents (GIC), GMD Impact Assessment, GIC Capability, Harmonics, Reactive Power

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## INTRODUCTION

Geomagnetic Disturbances (GMD) have the potential to cause power system – wide disturbances and equipment damage. Over a decade ago, there was some misconception in the electric power industry that GIC had caused, and would cause, significant damaging overheating to the majority (70%) of large power transformers installed on the power grid in North America. However, recent studies conducted by ABB concluded that, because of differences in transformer design, the level of GIC that transformers would be subjected to (as determined by its location and kV rating), and the short duration of high level GIC pulses, that a far less number of power transformers could experience damaging overheating.

ABB Engineers developed a process [1]; whereby a fleet of power transformers can be properly assessed to determine which of the transformers on the fleet would be susceptible to damaging overheating, which ones would be susceptible to only core saturation & moderate overheating, and which ones would have a low level of susceptibility to either effects. With this knowledge, utilities can focus their mitigating efforts on transformers in their fleet which are most vulnerable to effects of GIC; therefore, preventing system blackouts and possible damages to these transformers during future GMD events.

The IEEE "Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances", IEEE Std. C57.163-2015 [2], adopted the ABB process of GIC Susceptibility assessment with some enhancements. The IEEE process was used for assessing the magnitude of susceptibility of the TVA fleet of the 500 kV transformers to effects of GIC. TVA provided the ABB team with the list of the 500 kV transformers that are in operation along with the estimated level of GIC that each of these transformers is expected to experience during the NERC 1-in-100 years Benchmark GMD storm [3]. TVA developed a DC load flow model of the TVA service territory [4]. This involved gathering 500kV transformer data including core construction and dc winding resistance, as well as substation grounding resistance for all 500kV substations. The data was entered into a commercial power flow program with a GIC calculation add-on module. Earth resistivity scaling region data was obtained from the NERC TPL-007-01 documentation [5]. TVA then was able to calculate the GIC values for each 500 kV transformer using the NERC 1-in-100 years Benchmark geo-electric field strength of 8 V/km at the reference location scaled for latitude and earth resistivity per TPL-007-01 requirements.

The process used for performing the GIC Susceptibility assessment is described in detail below, followed by the results of the GIC Susceptibility assessment performed on the TVA fleet of 500 kV power transformers.

## ASSESSMENT OF TOTAL SUSCEPTIBILITY OF TRANSFORMERS TO EFFECTS OF GIC

The total GIC Susceptibility of a power transformer to effects of GIC is determined by the combination of the following two types of GIC susceptibilities:

1. The "<u>Design – based susceptibility</u>"; which defines the degree and magnitude of susceptibility of the individual design to effects of GIC as determined by its electrical and design parameters. This susceptibility is determined by factors; such as kV rating, Core – form vs. Shell – form, Core type, No. of phases, Winding Connection groups, Transformer manufacturer & Year of manufacture, etc. In this assessment, the transformers on the fleet are divided into the following four Design Classifications;

   A. Design Classification A: Transformers not susceptible to effects of GIC.

B. Design Classification B: Transformers least susceptible to core saturation but susceptible to high magnetizing current.

C. Design Classification C: Transformers susceptible to core saturation and possible structural parts overheating.

D. Design Classification D: Transformers susceptible to core saturation, as well as possible damaging windings and structural parts overheating.

2. The "GIC level susceptibility"; which is based on the estimated magnitude of the GIC levels to which a transformer would be subjected under the 1-in-100 years Benchmark GMD event. This is determined by factors such as the geographic location of the transformer (latitude, altitude, and proximity to large masses of water), the resistance of the soil where the transformer is located, the transformer kV rating, and configuration of the power system which the transformer is part of. The process of evaluating the GIC level-based susceptibility divides transformers into the following three exposure categories:

   A. High (Greater than or equal to 75 Amps / phase)
   B. Medium (Greater than 15 Amps / phase but less than 75 Amps / phase)
   C. Low (Less than, or equal to 15 Amps per phase)

From these two susceptibilities, the "Total GIC susceptibility" of a transformer is determined as described below. As a result of this assessment process, a transformer would belong to one of the following 4 categories of the degree of "Total GIC Susceptibility":

**Category I**

Transformers that are Design Classification A, or Design Classification B, and located in Low GIC level area. These transformers would have practically no, or minimal, susceptibility to effects of GIC, and therefore, no further action needs to be taken.

**Category II**

Transformers that belong to Design Classification B and are located in Medium GIC level areas, or Design Classifications C or D and located in Low GIC level areas. These transformers have a low level of susceptibility to effects of GIC and, thus, only magnetic modelling would be needed.

**Category III**

Transformers that are either in Design Classification B and located in High GIC level areas, or Design Classification C and located in Medium or High GIC level areas. These transformers have a medium level of susceptibility to effects of GIC and therefore, both magnetic modelling and thermal assessment of structural parts would be needed.

**Category IV**

Transformers that are Design Classification D and are located in High or Medium GIC level areas. These transformers have a high level of susceptibility to effects of GIC. For these transformers, both magnetic modelling and thermal GIC capability (winding hot-spot and structural parts hot-spot) should be performed.

The table below presents a summary of the GIC Susceptibility process as adopted by the IEEE GMD Guide.

| | GIC Exposure Level (Amps / phase) | | |
|---|---|---|---|
| **Design – Based Susceptibility** | **Low Exposure (≤ 15 A)** | **Medium Exposure (> 15 to < 75 A)** | **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 |

Magnetic modelling refers to the calculation of the additional VAR demand and the current harmonics to be injected by the transformer into the power system as a result of exposure to GIC. If high enough, these can cause system instabilities and blackouts.

Thermal Assessment refers to calculation of the temperature rise and final temperatures of transformer components (Windings and / or structural parts) as a result of exposure to GIC; considering the duration of the expected GIC high peak pulses.

## RESULTS OF GIC FLEET ASSESSMENT OF TVA'S 500 KV POWER TRANSFORMERS

In this study, 205 TVA transformers were assessed for their "Total susceptibility to effects of GIC". These transformers are located at substations or generating plants in Tennessee, Alabama, Kentucky, and Mississippi.

From design considerations alone (Design – Based Susceptibility)

- 46 of the 205 transformers would be highly susceptible to core saturation, as well as possible damaging windings and structural parts overheating due to GIC [Design Classification D]. The remaining 159 transformers would be susceptible to core saturation and possible structural parts overheating [Design Classification C].

However, to evaluate the total "GIC susceptibility" of these transformers to effects of GIC, expected levels of GIC that these transformers would be exposed to during a Benchmark GMD event would need to be considered to assess the GIC level – Based susceptibility.

Based on the data received from TVA:

- 92 of the 205 transformers would be exposed to medium levels of GIC and the remaining 113 transformers would be exposed to low levels of GIC. None of the transformers on the fleet is expected to be subjected to levels of GIC ≥ 75 Amps / phase.

Accounting for both the Design – Based Susceptibility and GIC Level – Based Susceptibility:

- Only 27 of the total fleet of 205 transformers (13.2 % of all transformers) have a high level total susceptibility to effects of GIC [Category IV]. For these transformers, both magnetic modelling and thermal GIC capability (winding hot-spot and structural parts hot-spot) would need to be performed. An example of such a study is presented in Reference [6].
- 65 of the 205 transformers (31.7 % of all transformers) have a medium level of susceptibility to effects of GIC [Category III] and, therefore, magnetic modelling and thermal assessment of only the structural parts would need to be performed on these.

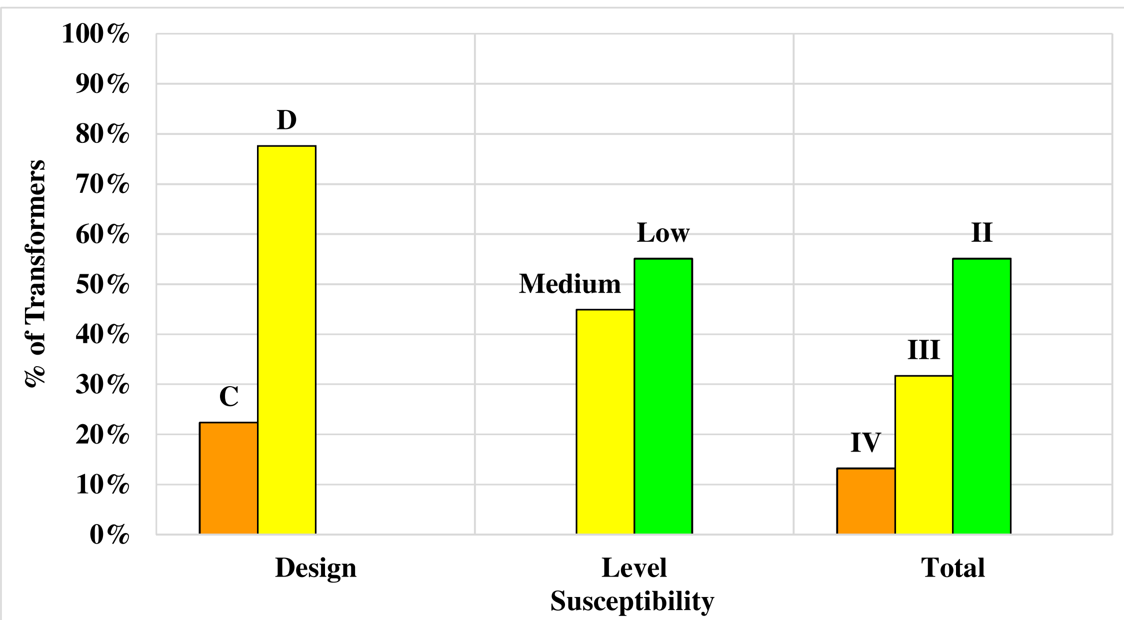
- The remaining 113 transformers (55.1 % of all transformers) are assessed to have a low susceptibility to effects of GIC [Category II] and, thus, only magnetic modelling of these transformers would be needed.

The table below presents a summary of the results of the GIC Susceptibility assessment of the total fleet of TVA's 500 kV Power transformers.

| **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 % | 0.0 % | 100 % |

***Final results of Total GIC Susceptibility Assessment of TVA's fleet of 500 kV Power Transformers***

The summaries presented in the text and table above are presented again in a bar chart format in the Figure below. The figure demonstrates the whole process of assessing the true total susceptibility of transformers to effects of GIC; using both the Design – based Susceptibility and the GIC Level – based Susceptibility to determine the Total GIC Susceptibility.




***Summary of results of GIC Susceptibility Assessment of TVA's fleet of 500 kV transformers***

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