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Magnetic and Thermal Impact of GIC on Power Transformers: A Case Study

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SUMMARY

Supported by AltaLink's GIC system study results, ABB performed full magnetic and thermal GIC assessment of 16 large power transformers of 4 different designs with different MVA and kV ratings as well as different core types. This paper presents an overview of the results of this study. The intent of this overview is to compare, and explain, the differences in the magnetic and thermal response of these designs to GIC and how these differences relate to differences in the transformer designs. Main results of the Magnetic Assessment are:

- In 1–phase transformers; core saturation initiation occurs at very low levels of GIC, while in the 3–phase core form transformers with the 3–limb core type; core saturation initiation occurs at GIC levels exceeding 20 Amps / phase. As a result, the VAR demand of the 3–phase transformers is significantly lower by a factor of 6 compared to that of the three 1–phase transformer banks. Also, magnitudes of the current harmonics of the 3–phase transformers are lower by a factor of 3 compared to that of the 1–phase transformers.
- For the same GIC levels, the additional VAR demand is practically equivalent for the two single–phase designs of the same MVA & voltage ratings despite being designed and manufactured by two different manufacturers. Also, the VAR demand, as well as values of the magnitudes of the current harmonics, of the two 3–phase transformers are practically equivalent although one is 2 times the MVA rating of the other.

Main results of the Thermal Assessment Study are:

- Increases of the windings hot spot temperature are very small for all 16 transformers and do not represent any thermal insulation degradation issue for these transformers. This however, does not account for the heating of the tertiary windings caused by circulating currents due to saturation of the core of the 3 – phase bank at three different instances on a cycle. This phenomenon will be the subject of a future paper.
- The main difference in the characteristics of the increases in the flitch plate hot spot temperature is that, in the 3–phase core form transformers, the increase starts after the magnitude of GIC exceeds the value of GIC that causes the initiation of core saturation.
- Considering the time series of GIC, to which the different transformers are expected to be subjected corresponding to NERC's 1 in a 100 years GMD [1], none of these exceeds the 200°C temperature limit recommended by the IEEE GMD Guide [2].

KEYWORDS

Transformers, GIC, GMD, Geomagnetically Induced Currents, Geomagnetic Disturbances

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INTRODUCTION

ABB performed full magnetic and thermal GIC assessment of 16 large Autotransformers of 4 different designs with different MVA & kV ratings as well as different core types. These transformers are installed in a # of Substations at the Altalink Power System. The Table below summarises the list of these transformers. These transformers were identified by a GIC flow modelling of the Altalink system to experience the highest level of GIC. This GIC system assessment utilized an updated earth resistivity model for Alberta developed by Natural Resources Canada and a GIC system model created by Teshmont Consultants [3].

This paper presents an overview of the results of this study. The intent of this overview is to compare, and explain, the differences in the magnetic and thermal response of these designs to GIC and how these differences relate to differences in the transformer designs.

Design #	# of transformers	# of Phases	MVA	HV (kV)	LV (kV)	TV (kV)	Manufacturer
1	2	3	200	245	144	n/a	1
2	3	1	400	525	246	20	2
3	9	1	400	525	252	n/a	3
4	2	3	400	245	144	n/a	1

Table – 1: List of Transformers Analysed

CALCULATED ADDIOTIONAL VAR DEMAND CAUSED BY GIC

Figure 1 presents calculated absolute values of the total 3-phase VAR demand of the 4 designs; which is 3 x VAR demand of the 1-phase transformers and 1 x VAR demand of the 3-phase transformers; when subjected to GIC levels ranging from 0 – 100 Amps / phase.

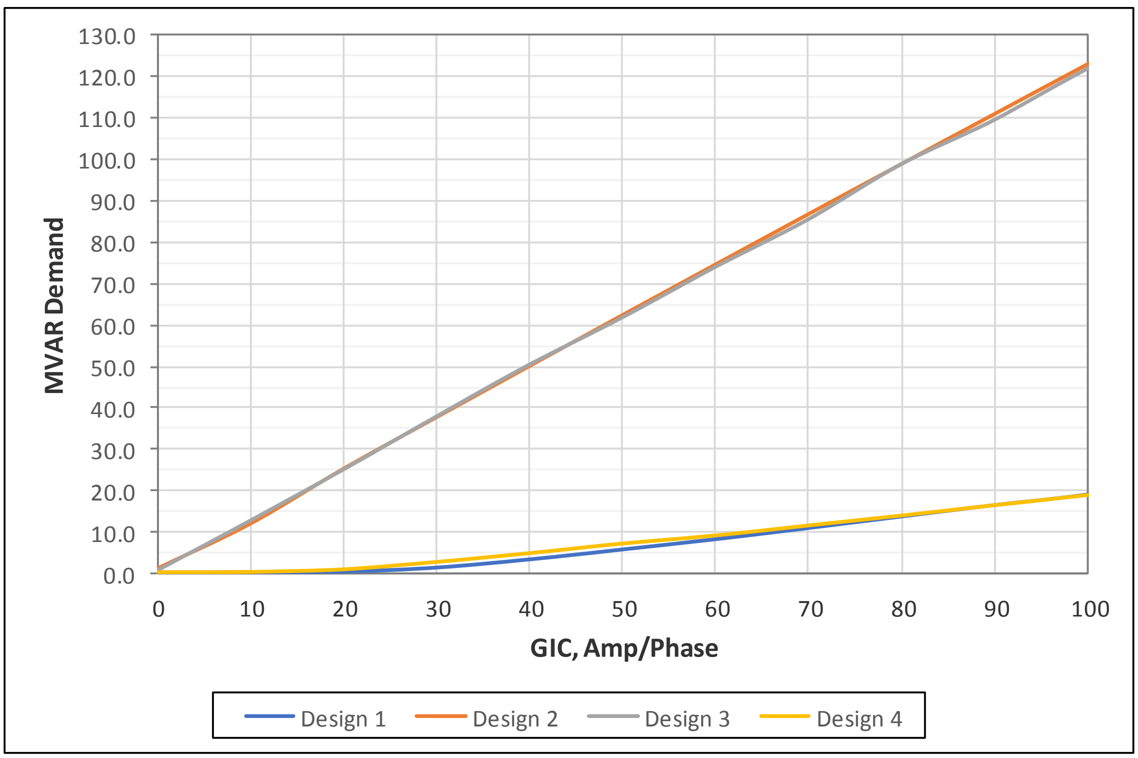


Figure 1: Calculated absolute values of additional VAR Demand for the 3-phase banks

The figure demonstrates the following:

- There is a significant difference between the characteristics, as well as the magnitudes, of the VAR demand in the 1-phase core form transformers (Designs # 2 & 3) vs. the 3-phase core form transformers with the 3-limb core type (Designs 1 & 4).
- Core saturation initiation in the 1-phase transformers is caused by very low levels of GIC while it is caused by much higher levels of GIC (referred to as Ics) in 3-phase core form transformers with the 3-limb core type.
- The VAR demand of the 1-phase transformers (Designs #2 & #3) is linearly proportional to the magnitude of GIC; while in the 3-phase transformers, the VAR demand is negligible up to a GIC level equal to Ics then it becomes linearly proportional to the magnitude of GIC above the value of Ics for the design.
- The magnitude of Ics in the 3-phase core form transformers, with the 3-limb core, is typically smaller for smaller transformers and larger for larger transformers. However, it is also a strong function of the rated flux density in the core as well as other design parameters of the transformer. The value of Ics is in the 25 Amps / phase range for design # 1 while it is slightly lower (20 Amps / phase) for the larger transformers of design # 4.
- The VAR demand is practically equivalent for designs 2 & 3 in spite of the fact that they were designed and manufactured by two different manufacturers. However, these 2 designs have the same MVA & voltage ratings as well as the same core type.
- VAR demand of the 1-phase transformers is significantly higher than that of the 3-phase transformers banks by almost a factor of 6.
- VAR demand of the two 3-phase transformers are practically equivalent although one transformer has 2 times the MVA rating of the other. This is related to the fact that while the 200 MVA transformers have smaller magnetic path length, the 400 MVA transformers have a larger core cross section area resulting in equivalent magnetic reluctances and, therefore, equivalent magnitudes of the magnetizing current.

HARMONIC CONTENT OF THE MAGNETIZING CURRENT

The pulse nature of the magnetizing current under GIC current corresponds to a large content of high order harmonic currents. Figure 2 below presents calculated RMS magnitudes of the 2^{nd} harmonic content of the magnetizing current for the 4 designs when the transformers are subjected to 0 - 100 Amps / phase of GIC. Figure 3 presents the corresponding magnitudes of the 4th harmonics content of the magnetizing current.

The figures demonstrate the following:

- Designs #2 and #3 show practically equivalent magnitudes of the 2nd current harmonics with Design #2 having slightly higher magnitudes than design #3. The difference is much greater for the 4th harmonic current as demonstrated in Figure 4.
- Designs #1 and # 4 have equivalent magnitudes of the 2nd and 4th harmonic currents in the same way as observed earlier for the VAR demand which is determined by the fundamental component of the magnetizing current.
- Absolute values of magnitudes of the 2nd and 4th harmonic of the 1-phase transformers are significantly higher than those of 3-phase transformers; by almost a factor of 3.
- Magnitudes of the 2nd harmonic currents are higher than those of the 4th harmonic, by a factor of 2 for all designs.
- While magnitudes of the 2nd harmonic increase linearly with GIC; the increase in magnitudes of the 4th harmonic is much slower and in fact magnitudes of the 4th harmonic start to even decrease at higher GIC levels.

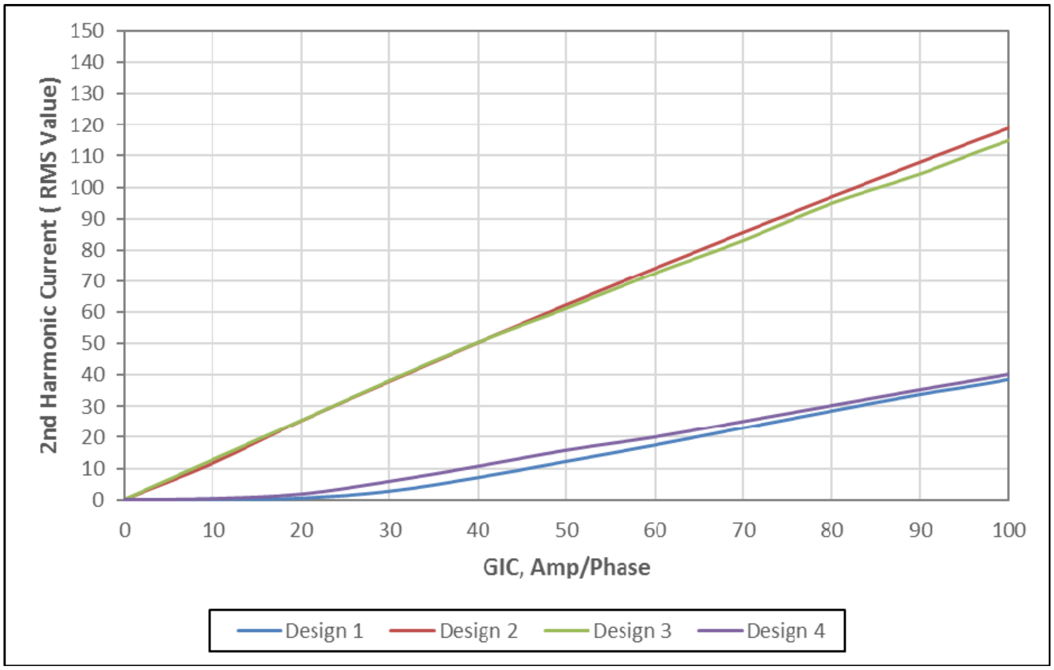


Figure 2: Calculated absolute magnitudes of 2nd harmonic current due to GIC

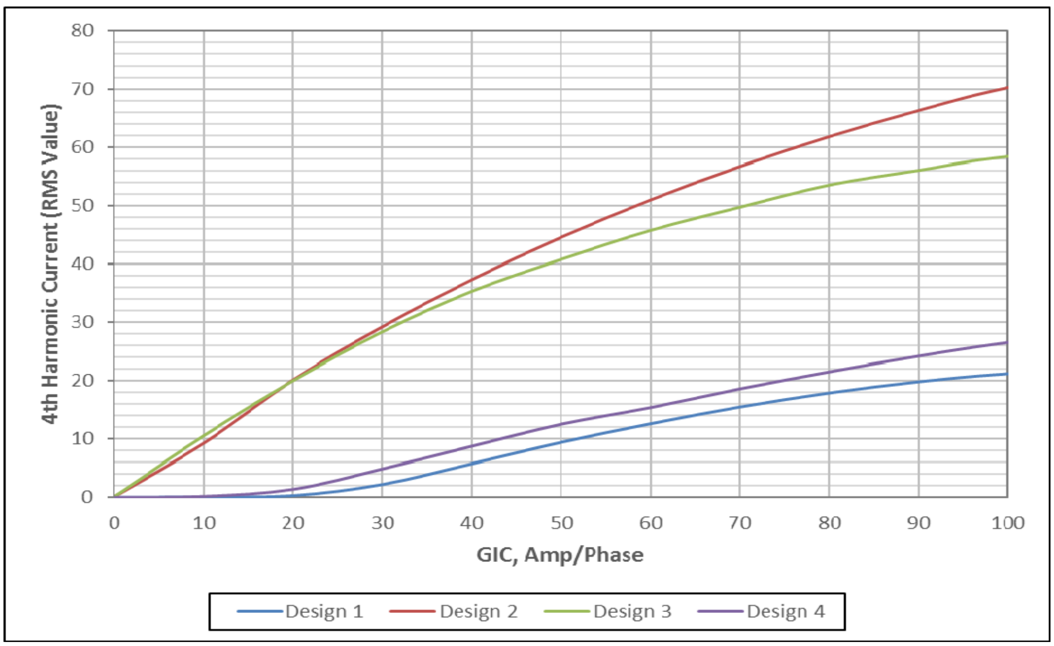
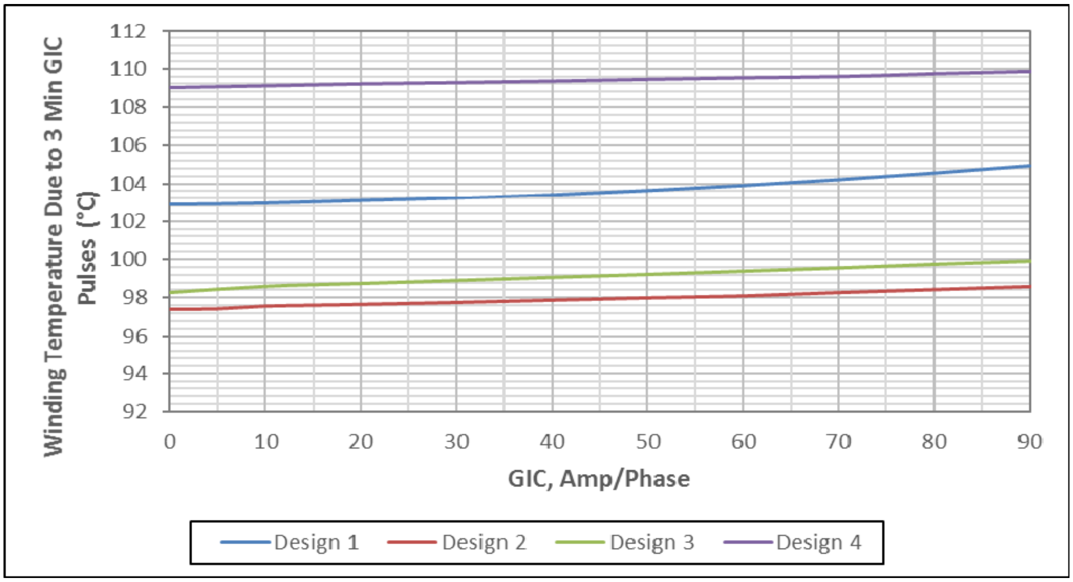


Figure 3: Calculated absolute magnitudes of 4th harmonic current due to GIC

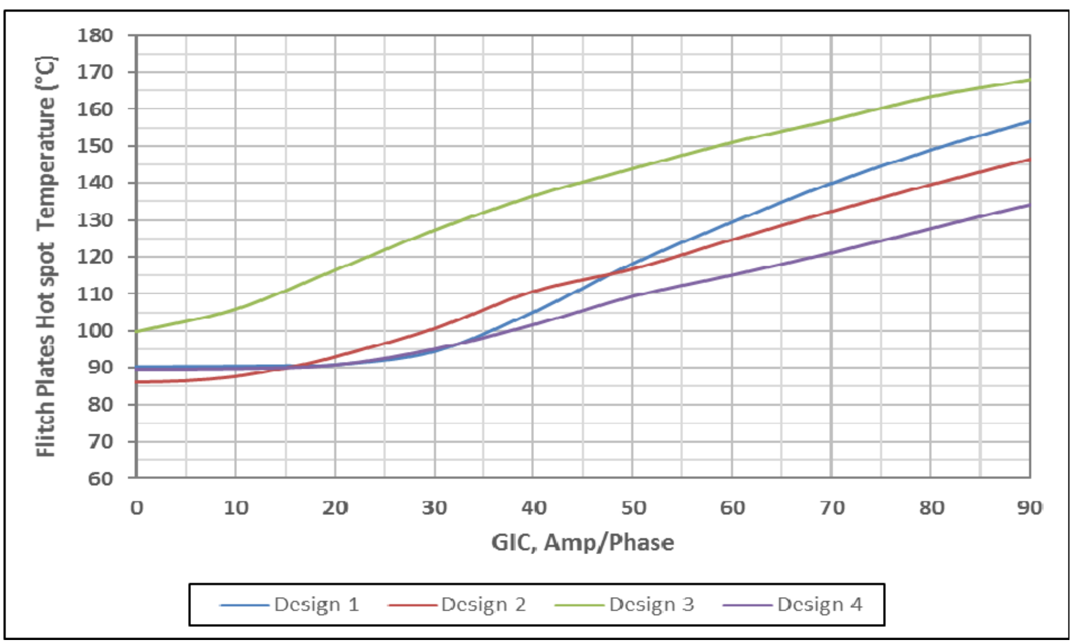
GIC THERMAL CAPABILITY

Calculated hot spot temperatures of windings and flitch-plates caused by a 3-minute duration GIC pulse are shown in Figure 4 below for a GIC range of up to 90 Amps / phase. The 90 Amps value is what AltaLink system studies showed to be the highest level of GIC any transformer in the fleet will be subjected to under the NERC GIC Benchmark event [1].

Figure 4 (a) shows very small increases of the windings hot spot temperature even at 90 Amps / phase GIC for all designs. Designs #1 and #4 have higher final winding hot spot temperatures than designs #2 & #3. This is because of the higher values of the initial full load hot spot temperatures for these designs compared to those for Designs #2 and #3. Figure 4 (b) demonstrates that the increase in the flitch plate hot spot temperature due to GIC is determined not only by the MVA rating and core type of the transformer but rather by a number of other important design parameters. The main difference in the characteristics of the increase in the flitch plate hot spot temperature is that in 3-phase core form transformers with the 3-limb core, the increase in the temperatures starts after the magnitude of GIC exceeds the value of Ics (GIC that causes the core to saturate). For designs #1 and 4, this occurs for GIC levels of about 25 Amps / phase. Figure 4 (b) also demonstrates that no flitch-plate hot spot temperature of any of the 4 designs exceeds the temperature limit recommended of 200 °C recommended by IEEE "Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances", C57.163 – 2015, for transformers subjected to GIC [2].



(a) Windings



(b) Flitch plates

Figure 4: Calculated Hot Spot temperatures due to a 3-minute GIC pulse

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