

## Screening Criterion for Transformer Thermal Impact Assessment

Project 2013-03 (Geomagnetic Disturbance Mitigation)

TPL-007-1 Transmission System Planned Performance for Geomagnetic Disturbance Events

### Summary

Proposed standard TPL-007-1 – Transmission System Planned Performance for Geomagnetic Disturbance Events requires applicable entities to conduct assessments of the potential impact of benchmark GMD events on their systems. The standard requires transformer thermal impact assessments to be performed on power transformers with high side, wye-grounded windings with terminal voltage greater than 200 kV. Transformers are exempt from the thermal impact assessment requirement if the maximum effective geomagnetically-induced current (GIC) in the transformer is less than 15 Amperes per phase as determined by a GIC analysis of the system. Based on published power transformer measurement data as described below, an effective GIC of 15 Amperes per phase is a conservative screening criterion. A list of reference materials is included herein.

### Justification

Heating of the winding and other structural parts can occur in power transformers during a GMD event. These thermal impacts are dependent on the thermal time constants of the transformer. The following analysis of tested transformers [See References 1-4] assumes a long-duration 15 Amperes per phase neutral current in the transformer, which is a conservative assumption.

From IEEE Std. C57.91 2001 [5], the suggested long-time emergency loading metallic hot spot temperature is 160°C as shown in **Table 1**. The top oil temperature limit for the same operating conditions is 110 (ambient + full load). This suggests that a 50°C temperature increase for three hours for metallic part hot spot heating is a conservative and safe incremental temperature. The highest incremental asymptotic hot spot temperatures measured in [1-4] are shown in Figures 1 to 4.

TABLE 1: Excerpt from Maximum Temperature Limits Suggested in IEEE C57-91 2001

	Normal life expectancy loading	Planned loading beyond nameplate rating	Long-time emergency loading	Short-time emergency loading
Insulated conductor hottest-spot temperature °C	120	130	140	180
Other metallic hot-spot temperature (in contact and not in contact with insulation), °C	140	150	160	200
Top-oil temperature °C	105	110	110	110

**Figure 1** corresponds to the thermal asymptotic response of the tie plate of a 500/16.5 kV 400 MVA single-phase Static Var Compensator (SVC) coupling transformer [1]. The asymptotic behavior for GIC values above 5 Amperes per phase has been linearly extrapolated. Although such extrapolation is probably very conservative for GIC values above 40 Amperes per phase it is consistent with the thermal behavior of metallic hot spots demonstrated in other measurements (e.g., [2], [3]). The incremental asymptotic temperature for 15 Amperes per phase is 46.8 °C.

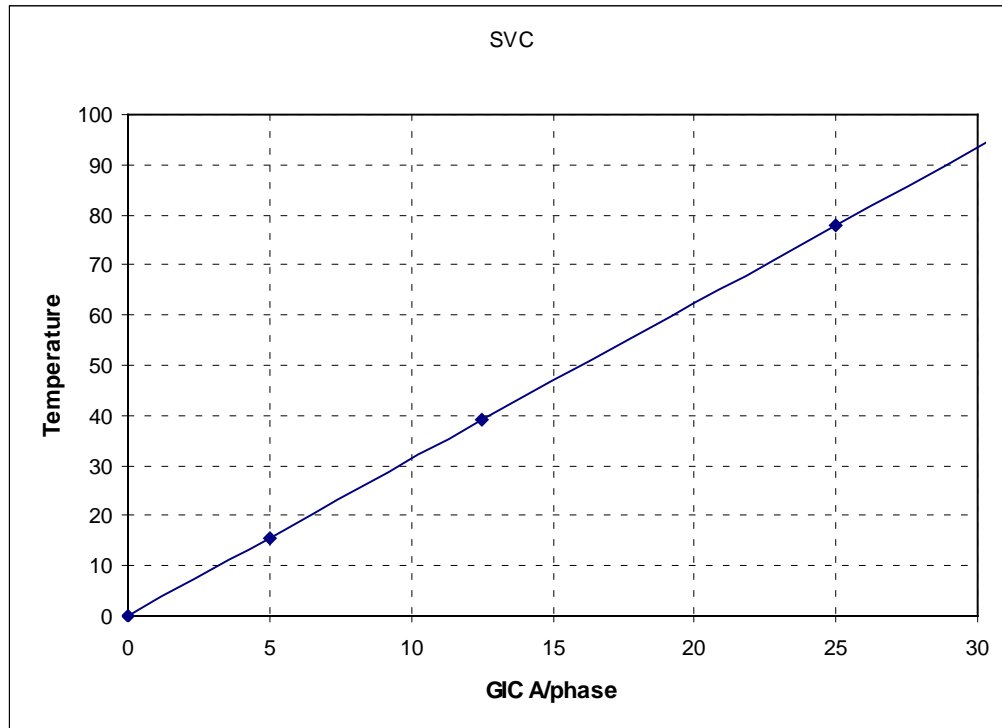


Figure 1: Asymptotic thermal response of the tie plate of a 500 kV 400 MVA single-phase SVC coupling transformer.

**Figure 2** corresponds to the thermal asymptotic response of tie plate of a 735 kV 370 MVA single-phase core-type autotransformer [2]. The asymptotic response depicted in **Figure 2** is a combination of measurements and calculated values. In this case, 12.5 Amperes per phase caused an increase of 36 °C while 25 Amperes per phase caused an increase of 89 °C. Interpolation between these two points gives an increase of 47 °C at 15 Amperes per phase. The highest current injected into this transformer is reported as 75 Amperes per phase for 1 hour. The transformer was energized from the 735 kV terminals and weak-source uncertainties normally seen in factory floor tests [4] would have been low in these tests.

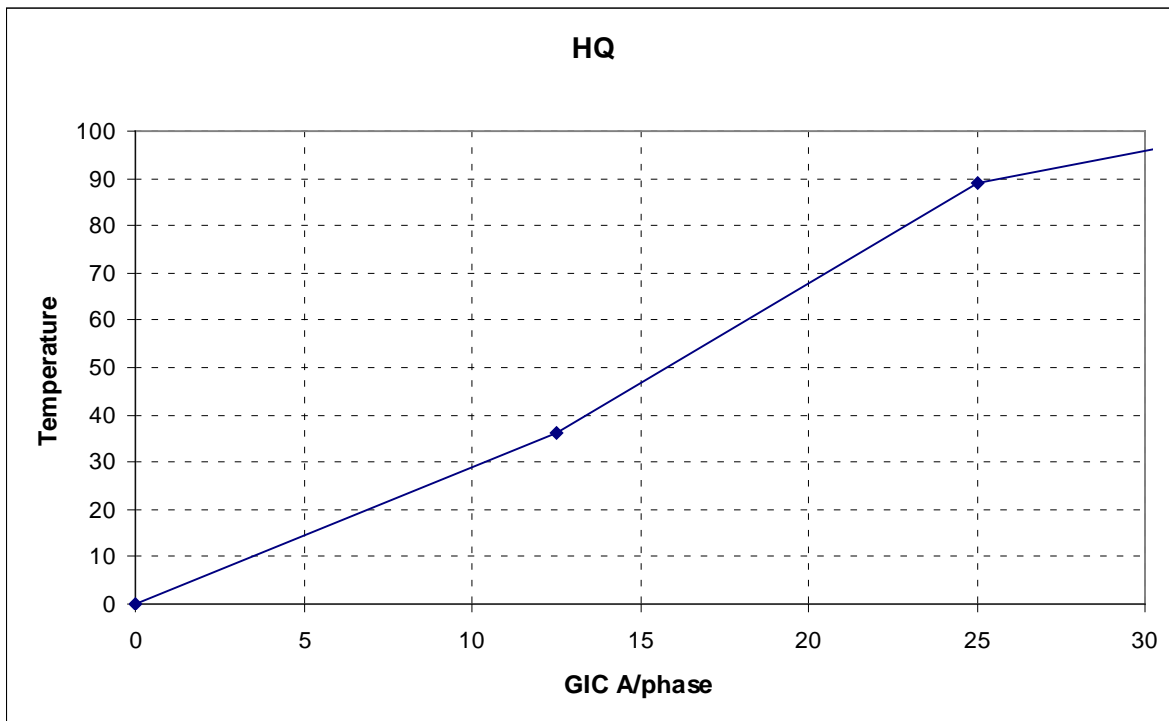


Figure 2: Asymptotic thermal response of the tie plate of a 735 kV 370 MVA single-phase core-type autotransformer.

**Figure 3** corresponds to the thermal asymptotic response of the top and bottom clamps of a 400 kV 400 MVA five-leg core-type fully-wound transformer [3]. Hot spot temperature of 34 °C for 15 Amperes per phase occurred at the Flitch plate. Highest current injected into this transformer is reported as 66.67 Amperes per phase for approximately 10 minutes. The transformer was energized from the 400 kV terminals and weak-source uncertainties would have been low.

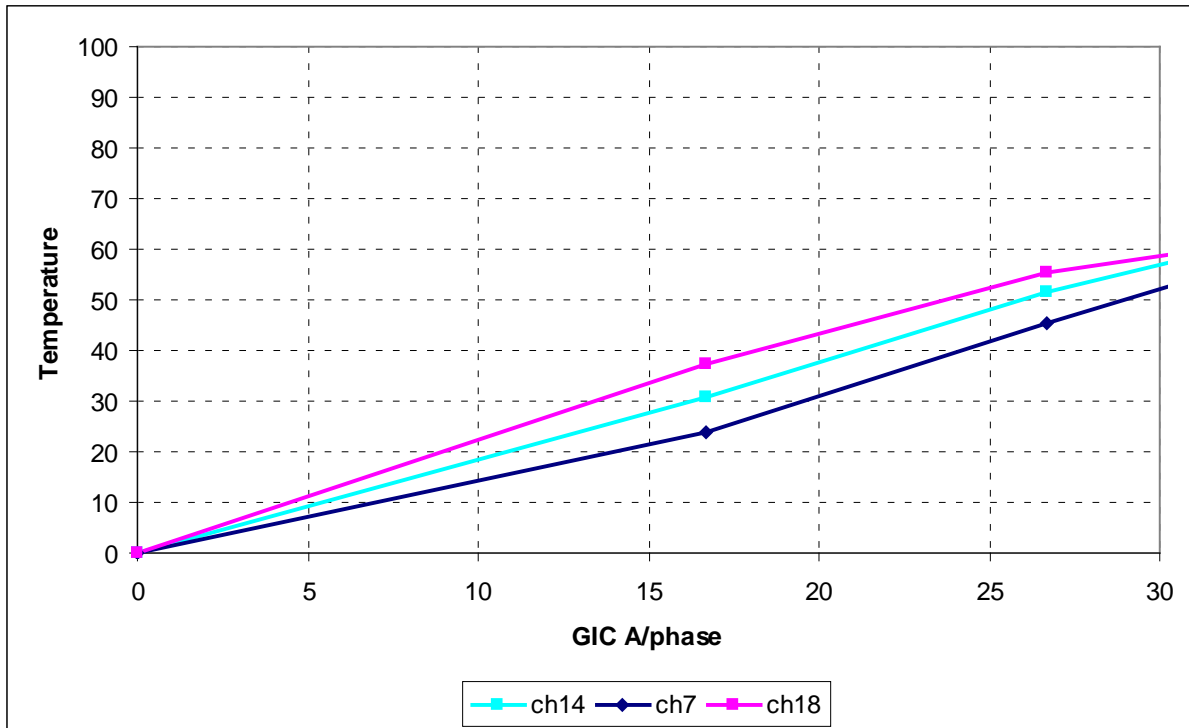


Figure 3: Asymptotic thermal responses of the bottom and top yoke clamps (ch14 and ch7), and Flitch plate (ch18) of a 400 kV 400 MVA five-leg core-type fully-wound transformer.

**Figure 4** shows tests carried out in a factory floor of a fully instrumented 400 kV 400 MVA single-phase core-type autotransformer. Tie-plate hot spot temperature of 46 °C for 15 Amperes per phase was measured. The weak ac supply is an issue in these tests and the actual asymptotic response for lower values of GIC above 10 A/phase is probably higher than measured. However at these relatively low GIC values, saturation of structural parts is not a dominant issue.

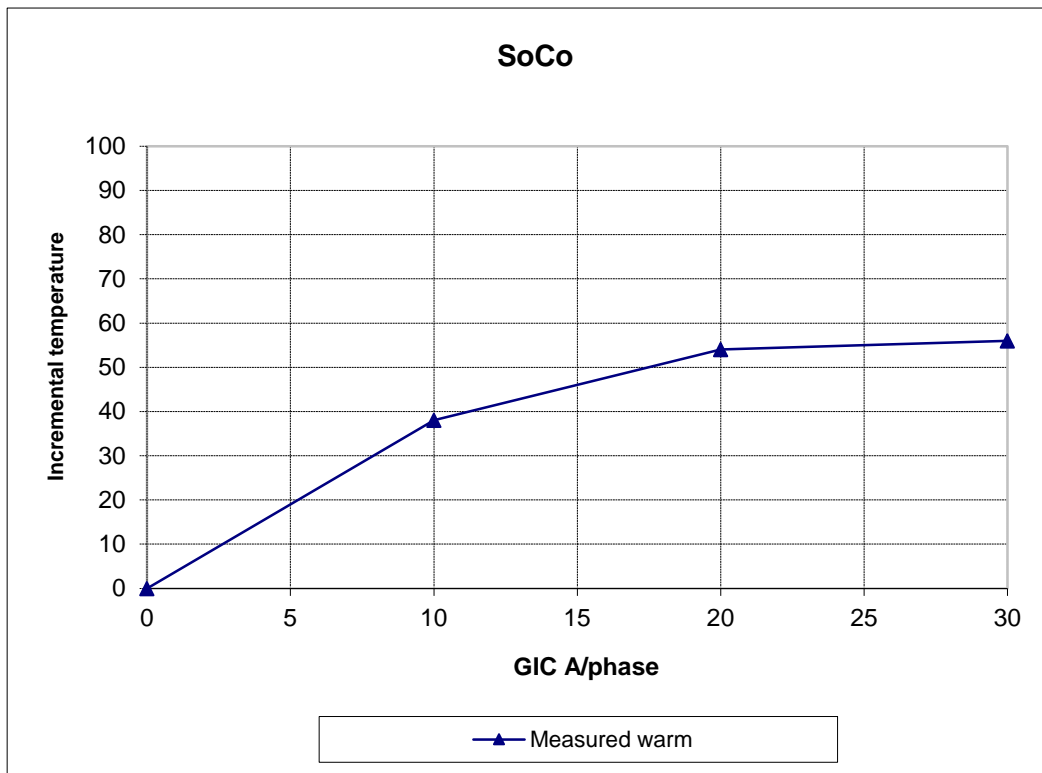


Figure 4: Asymptotic thermal responses of the tie plate of a 400 kV 400 MVA single-phase core-type autotransformer.

In all of the test results presented, an effective GIC value of 15 Amperes per phase resulted in a temperature increase of less than 50°C. These results strongly support use of 15 Amperes per phase as a conservative criterion for determining which applicable transformers require assessment using more detailed methods like those described in the Transformer Thermal Impact Assessment white paper [6]. Furthermore there is significant margin in the assumption of an injected dc current of 15 Amperes per phase for three hours (as opposed to GIC time series information). This conservative approach provides ample margin to account for any uncertainty resulting from the limited number of tested transformers.

## References

- [1] Marti, L., Rezaei-Zare, A., Narang, A. , "Simulation of Transformer Hotspot Heating due to Geomagnetically Induced Currents," *IEEE Transactions on Power Delivery*, , vol.28, no.1, pp.320-327, Jan. 2013
- [2] Picher, R.; Bolduc, L.; Pham, V.Q., "Study of the Acceptable DC Current Limit in Core-Form Power Transformer," *Power Engineering Review, IEEE* , vol.17, no.1, pp.50,51, January 1997
- [3] Lahtinen, Matti. Jarmo Elovaara. "GIC occurrences and GIC test for 400 kV system transformer". *IEEE Transactions on Power Delivery*, Vol. 17, No. 2. April 2002.
- [4] NERC GMD TF Presentation, Atlanta, Nov. 2013 [http://www.nerc.com/comm/pc/Geomagnetic%20Disturbance%20Task%20Force%20GMDTF%202013/GMDTF%20Transformer%20Session.pdf?Mobile=1&Source=%2Fcomm%2Fpc%2F\\_layouts%2Fmobile%2Fdispform.aspx%3FList%3Da84e3238-8456-4456-9ca7-fe46bebd7392%26View%3De8c6afc7-3ec9-4e4c-89d7-ef43bd2911d9%26ID%3D39%26CurrentPage%3D1](http://www.nerc.com/comm/pc/Geomagnetic%20Disturbance%20Task%20Force%20GMDTF%202013/GMDTF%20Transformer%20Session.pdf?Mobile=1&Source=%2Fcomm%2Fpc%2F_layouts%2Fmobile%2Fdispform.aspx%3FList%3Da84e3238-8456-4456-9ca7-fe46bebd7392%26View%3De8c6afc7-3ec9-4e4c-89d7-ef43bd2911d9%26ID%3D39%26CurrentPage%3D1)
- [5] "IEEE Guide for loading mineral-oil-immersed transformers and step-voltage regulators." IEEE Std C57.91-2011 (Revision of IEEE Std C57.91-1995).
- [6] Transformer Thermal Impact Assessment white paper. Developed by the Project 2013-03 (Geomagnetic Disturbance) standard drafting team. Available at: <http://www.nerc.com/pa/Stand/Pages/Project-2013-03-Geomagnetic-Disturbance-Mitigation.aspx>