ABSTRACT

The effects of solar storms, a phenomenon that creates geomagnetic disturbances that impact the upper layers of the Earth's atmosphere and the electric grid, now must be addressed by power engineers. The terrestrial induced currents that result from these space weather events can possibly damage expensive large power transformers and lead to disrupted power supply. The key for staying resilient against such threats is to adopt best practices for transformer monitoring including thermal impact assessments. This article will address the thermal impact assessments in more detail and offer insight into what power companies and utilities need to comply with the new North American Electric Reliability Corporation (NERC) standard TPL-007-1 designed to address the potential impact of geomagnetic disturbances on the power grid.

KEYWORDS

solar storms, geomagnetic disturbances, space weather, grid resiliency, transformer

Solar storms are posing a new threat to the power grid, one that can possibly damage expensive large power transformers and lead to disrupted power supply

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Space weather

Avoiding grid disruption and transformer impact from geomagnetic disturbances

When you think of disruptive weather, snow storms, thunder storms, lightning and high speed winds probably come to mind. Solar storms can also cause problems for the electric power grid and leave millions without power with limited advanced warning. These high impact, low frequency events do not happen often, but when they do, the consequences can potentially be severe.

1. Space weather: What is it and why should we care?

Solar flares can create severe geomagnetic disturbances (GMDs) impacting the upper layers of the Earth's atmosphere inducing currents in long power lines near the Earth's surface. These quasi-dc geomagnetically-induced currents (GIC) that flow through the grounded windings of power transformers introduce a bias onto the ac sinusoidal flux in the transformer core, resulting in asymmetric or half-cycle saturation. This half-cycle saturation, as seen in the example in Figure 1, leads to [1]:

- increased transformer exciting current and reactive power absorption;
- power system or network voltage instability;
- increased transformer vibration and noise level;
- detrimental effects of harmonic currents that result from the half-cycle saturation;
- hot spot heating of the non-current carrying metallic structures within the transformer; and
- hot spot heating of windings due to harmonics and stray flux.

2. NERC TPL – 007 – 1: Regulations to forge against severe GMD events

Protecting the electric system from the impact of GMDs is the focus of the new North American Electric Reliability Corporation (NERC) standard TPL-007-1 [2]. To comply with the new ruling, which took effect on the 1st January 2017, utilities and power companies must conduct assessments of the potential impact of GMD events on their power systems. Where necessary, companies must also take corrective action to protect against instability and system blackouts like the 13th March 1989 occurrence in the Mid-

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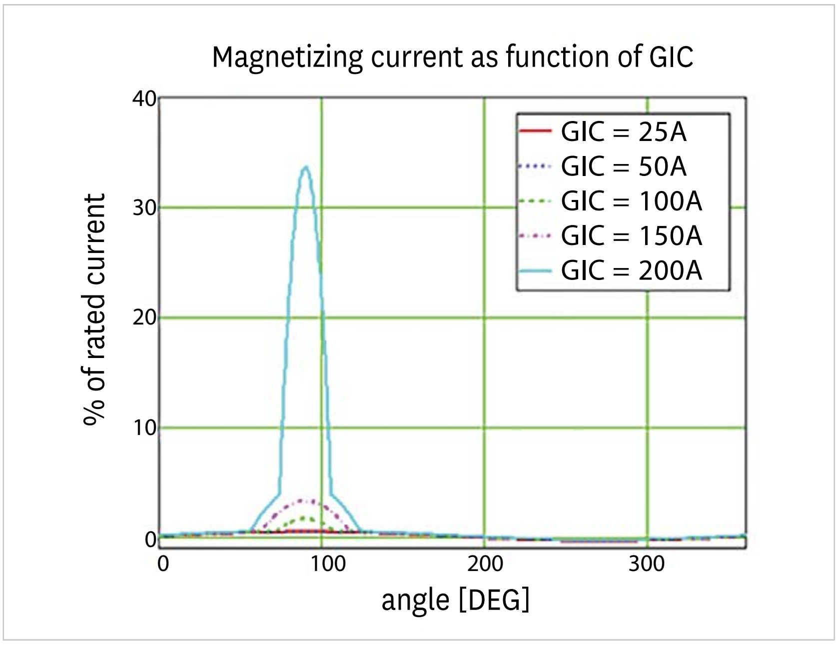

Figure 1. Sample exciting current magnetizing pulse due to GIC events
(Figure courtesy of Trafoexperts)

Utilities and power companies must conduct assessments of the potential impact of GMD events on their power systems

Atlantic region of the United States, which was the largest GIC magnitude recorded in the United States. The required assessments include [2]:

1. GIC disturbance vulnerability assessment: To check the system's vulnerability to the benchmark GMD event (1-in-100-year) without causing a wide area blackout, voltage collapse or transformer damage. Network susceptibility depends on many factors including geomagnetic latitude, ground resistivity, network topology, event duration, loading and equipment design.

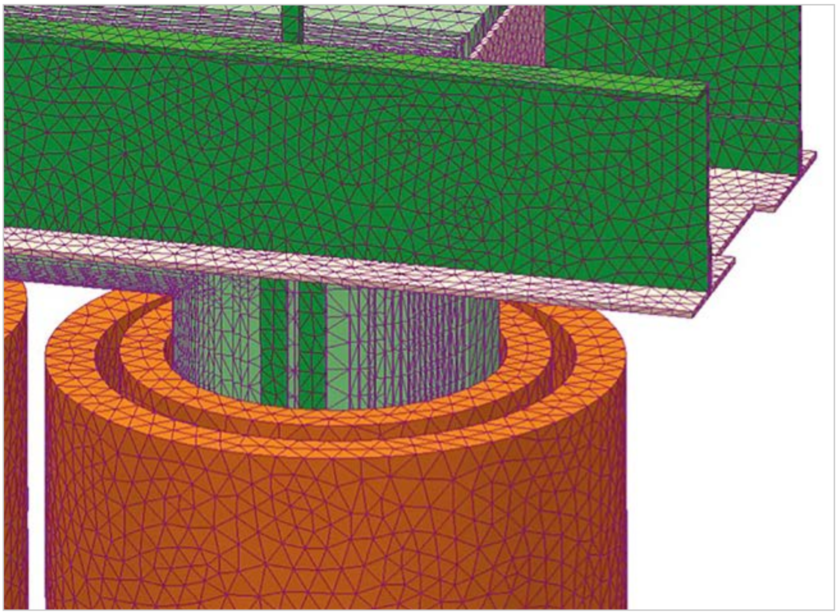

Figure 2. Finite Element Model of transformer clamp and flitch plate
(Figure courtesy of Trafoexperts)

2. Transformer thermal impact assessment: Typical GIC ranges vary significantly depending on the network, with 75 amps being the industry threshold compromise based on the benchmark event. If the calculated GIC is greater than 75 amps, a thermal impact assessment is required to ensure that all wye-grounded transformers connected to long transmission lines, usually above 200 kV, can withstand thermal transient effects associated with a benchmark GMD event. Long transmission networks are needed to develop sufficient induced voltages to cause these quasi-DC currents to flow in transmission lines and through earth grounded neutrals of high voltage transformers.

Based on the benchmark GMD event, a transformer thermal impact assessment should contain the following calculations [2]:

- transformer magnetizing current for the specified GIC current profile,
- peak magnetizing current as a function of the GIC level,
- reactive power consumed by the transformer as a function of the GIC level,
- harmonic components of magnetizing current due to GIC,
- increase in the core clamp, tie plate and winding hotspot temperatures,
- transformer thermal capability curves for base and peak GIC levels.

3. NERC TPL - 007 - 1 compliance timelines

All apply to planning coordinators and transmission planners unless otherwise noted [1].

- **22 September 2016** – FERC Approved Date
- **1 July 2017** – Identify roles and responsibilities within the utility
- **1 July 2018** – Network planners needs to have completed their GIC network planning models
- **1 January 2019** – Network planners need to have provided GIC flow information regarding which transformers are subject to the GIC Disturbance Benchmark Event
- **1 January 2021** – GIC thermal impact assessments complete (Role: generation owners, transmission owners)
- **1 January 2022** – Develop corrective actions plan

4. Solutions: Coordinating efforts to prepare for the emerging phenomenon

Adequately preparing for GMD events is essential to avoid service disruptions that could leave millions without power and result in significant financial losses. There are several steps utilities and power companies can take:

1. Understand where your network may be vulnerable. First, your utility's network planning department or your regional transmission organization will perform GIC flow studies to determine which transformers may be subject to the GMD benchmark event. The time and magnitude, or signature, of the event is critical to determining the thermal capability of a transformer design to withstand it. Planners will need to provide GIC currents and durations at the transformer neutral for engineering study purposes.

2. Check transformer factory acceptance test records for evidence of power transformer capabilities under GIC. There are no other previous existing standards on GIC. Over the past several years, many utilities have updated their transformer purchase specifications to include GIC capability studies as part of their procurement process. They will need to confirm that original equipment manufacturer (OEM) studies done to date were performed for the right GIC current levels and durations.

3. Where transformer GIC capabilities evidence is not available, conduct a thermal impact assessment. The effects of asymmetric or half-cycle saturation on large power transformers are relatively well understood but difficult to quantify. This requires an engineering study to establish power transformer capabilities under GIC disturbances per IEEE C57.163-2015 [3].

Doble's approach is to perform the transformer thermal impact based on GIC signature levels as defined from the client's system analysis. These rectangular-shaped GIC signatures are more conservative than actual GIC signatures but greatly simplify the calculations of transformer magnetic and thermal response to GIC. The evaluation, however, can be customized to extend to any required number of events or any specified event signatures based on the following four steps:

The key for staying resilient against GIC threats is to adopt best practices for transformer monitoring including thermal impact assessments

- Compute the core flux bias and flux density distribution based on the defined GIC current by finite element simulations.
- Determine the magnetizing current wave shape associated with each GIC signature.
- Determine how losses and temperature change in the affected transformer components between base load condition and the GIC saturated condition. This is achieved with additional finite element simulations, as depicted in Figures 2 and 3, assuming properly transposed winding conductors.
- Produce the thermal capability curves in accordance with IEEE Std. C57.163 – 2015.

The majority of required data can be extracted from design review documentation for more modern units (those less than 20 years old). For older units, those that have been operating for more than 20 years, much of the required data can be extracted from test reports and outline drawings. The remainder can be estimated using engineering judgment of experienced transformer design engineers as allowed in IEEE Std. C57.163 – 2015.

5. Key takeaway: Being prepared pays off

The threat of GMDs has become a critical issue by the new NERC ruling. By taking proper GMD mitigation steps, power companies will not only meet regulatory requirements, but also eliminate the uncertainty associated with GMD events, avoiding potentially severe power grid disturbances.

Conclusions

The effects of solar storms can be mitigated with the right strategy and approach. By addressing vulnerabilities through mechanisms such as thermal impact assessments and GIC disturbance vulnerability assessments, power companies can reduce their exposure to these types of high impact, low frequency events and comply with the impending NERC TPL -007-1 regulatory deadlines.

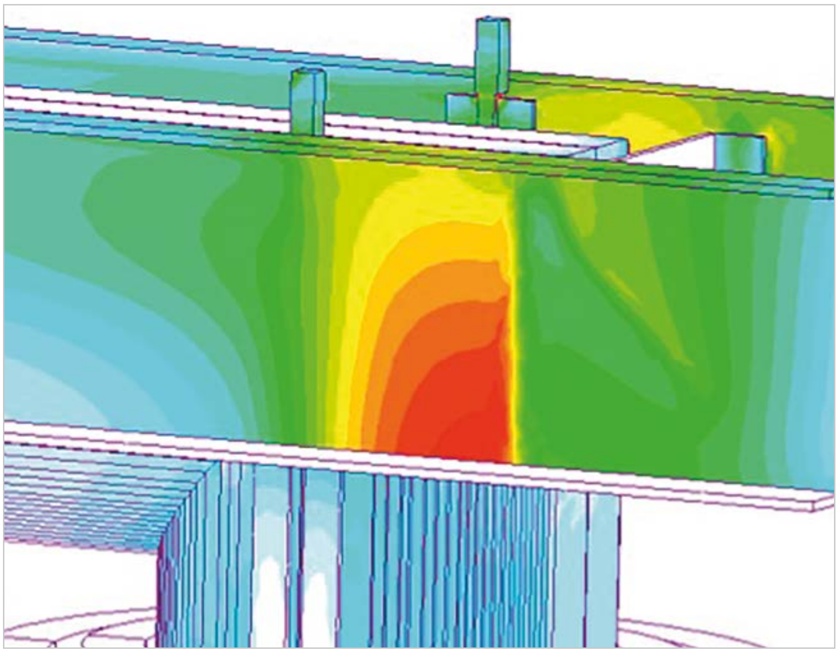

Figure 3. Magnitude of magnetic flux density distribution under GIC event *(Figure courtesy of Trafoexperts)*

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