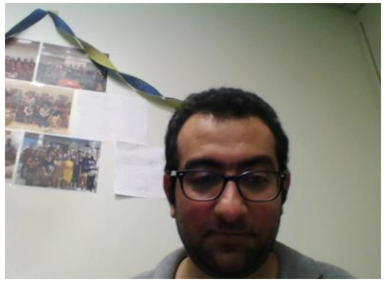

Temperature-Triggered Failure Hazard Mitigation of Transformers Subject to Geomagnetic Disturbances

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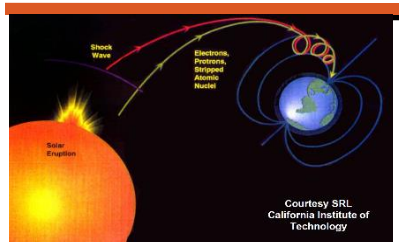


ABSTRACT

Geomagnetic disturbance (GMD) engenders significant threats to the power system infrastructures, potentially resulting in the bulk high-voltage power transformers half-cycle saturation, excessive system reactive power losses, and transformer over-heating, among others.

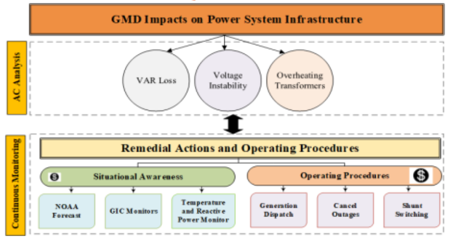
This research focuses on the mitigation of temperature-triggered transformer's hazard of failure following a GMD disturbance. The main contributions of the paper are: a) deriving temperature models of transformers during a GMD hotspot and under full load conditions; b) quantifying the loss of life and failure risk of transformers triggered by a GMD disturbance; c) mitigating the transformer's hazard of failure through reducing the loading of the transformer. The above approach is tested in the Texas 2000-bus synthetic case, and the results verify the effectiveness of the algorithm.

To implement the mitigation techniques on failure hazard of transformers, groups of critical transformers across the system are identified based on the GIC injection variation and their corresponding temperature rise. In so doing, we prioritize the vulnerable transformers within the critical cluster of transformers, i.e., those with highest failure probability and system-wide consequences.

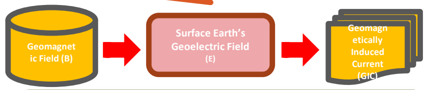
2003 U.S. /CA GMD-CAUSED BLACKOUT

Affected 10 million people in Ontario and 45 million people in eight U.S. states.

GMD AWARENESS AND MITIGATION PROCEDURES

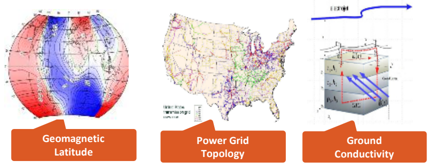


GIC MODELING AND ITS CHARACTRISTICS



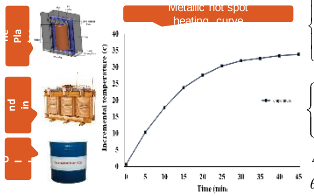
$$I_{dc} = I(n,m) = \frac{V(n,m)}{R_{Eff}} = \frac{E_N\, L_N(n,m) + E_E\, L_E(n,m)}{R_{Eff}}$$

KEY PARAMETERS FOR GIC CHARACTRIZATION



- High-latitude areas are more susceptible to the GIC hazards.
- GICs magnitude are more vulnerable while they are flowing through high-voltage lines.

TRANSFORMER THERMAL MODEL



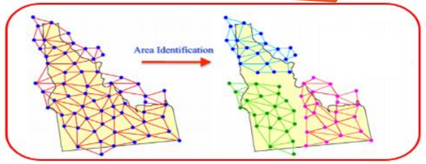
$$\begin{cases} \Delta\theta(t) = \frac{\theta_{ss}}{I_{dc}^{pu}}\left(1-\sum_{i=1}^{n} c_i e^{\frac{-t}{\tau_i}}\right) \\ \theta_{ss} = \Delta\theta_F - \Delta\theta_i \end{cases}$$

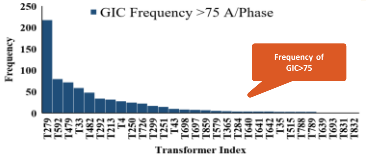
$$\begin{cases} \lim_{t\to\infty} \Delta\theta(t) = \theta_{ss} \\ \Delta\theta(t) = 0 \quad \forall t < 0 \end{cases}$$

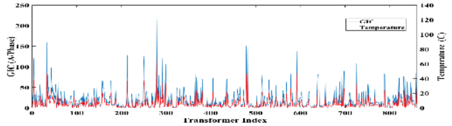
$$\Delta\theta_{HS}(t) = GIC(t) * h(t)$$

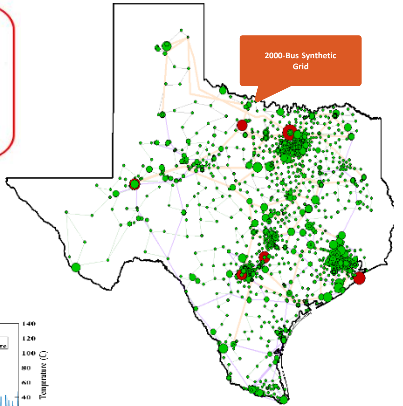
$$\theta_{Final}(t) = \theta_{HS} + \theta_{oil} + \theta_{Ambient}$$

IDENTIFICATION OF MOST VULNERABLE TRANSFORMERS









MITIGATION PROCEDURES ON THE MOST VULNERABLE TRANSFORMERS

Algorithm: Hazard Calculation

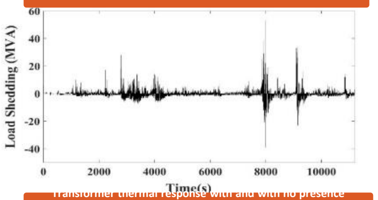
1: Solve GIC flow
2: Calculate the transformer's GIC-caused temperature rise ($\theta_{HS}(I)$) and the hotspot temperature under loading condition ($\Delta\theta_{H,full\_load}$)
3: Identify the overheated transformers
4: Calculate the loss of life of transformers and hazard of failure ($H(\theta_{HS}, I)$)

Hazard Mitigation Procedure

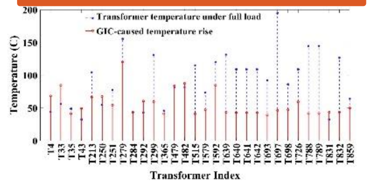
5: Set the desired threshold for hazard rate as H_{Th}
6: Initialize the transformer load rate, line power flow, load shed step size, simulation time, etc.
7: while $H > H_{Th}$ & (Load- load shed >0)
8: Reduce the $Load(\theta, I)$ by step size
9: Perform recursive step 2 ($\theta_{HS}(I)$) & step 4 ($H(\theta_{HS}, I)$)
10: end procedure

- ❑ The hazard rate is a function of temperature, which itself is a function of current, one way to reduce the hazard rate is to shed the load of high-risk transformers.

Time-series load shedding for failure mitigation of T279.



Transformer thermal response with and with no presence of GIC.



- ❑ Decreasing the loading of transformers reduces the transformer's temperature under full loading conditions and mitigates the hazard rate value of the transformer within a safe range.

REFERENCE

[1] P. Dehghanian and T. Overbye, "Temperature-Triggered Failure Hazard Mitigation of Transformers Subject to Geomagnetic Disturbances," 2021 IEEE Texas Power and Energy Conference, TX.