When the sun attacks power grids: simulation and mitigation of GIC effects

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Geomagnetically induced currents (GICs) are caused by the sun's coronal ejections. They may cause severe power grid instabilities and affect the normal operation of transformers. Some experts are persuaded that GIC could cause a major blackout. Others are less certain. Hence, the need for simulations of the phenomena as a step towards mitigating the risks for the networks.

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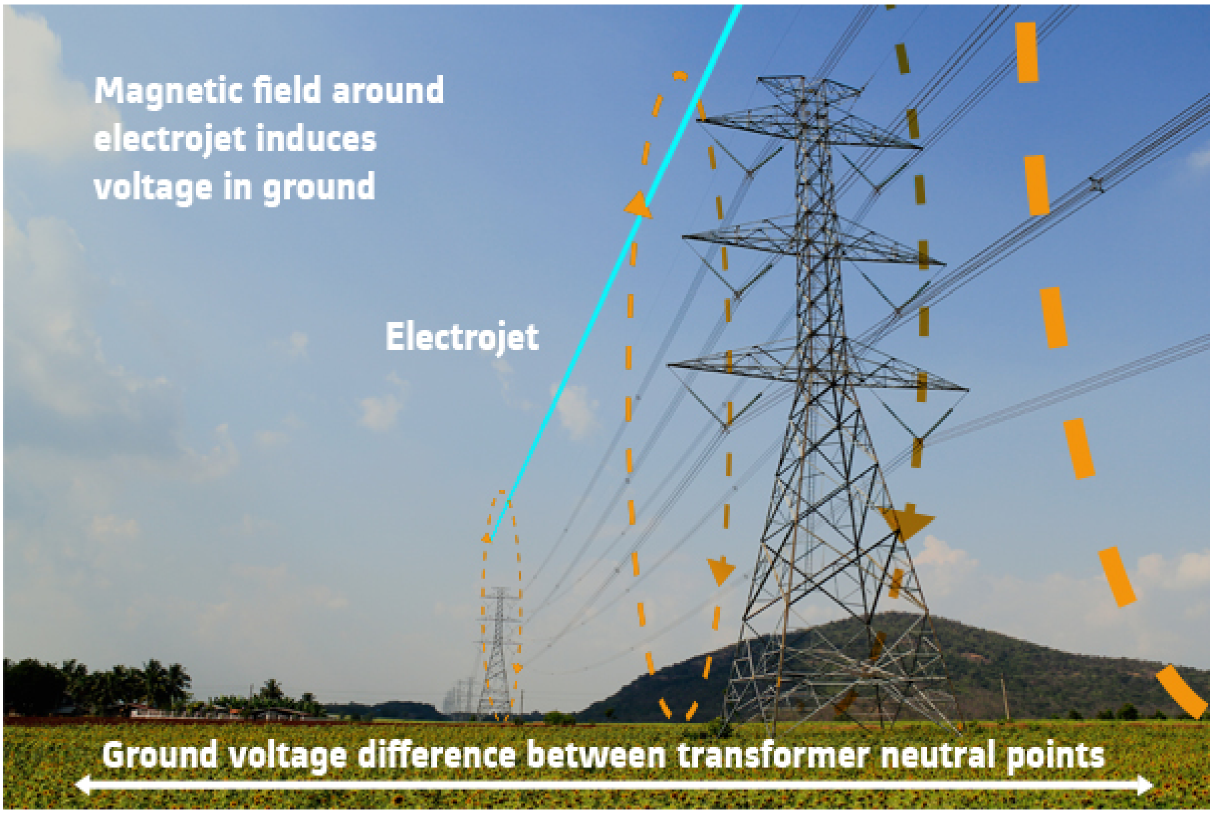
Variations in the sun's activity have a powerful influence on our planet and may even damage its electrical infrastructure. This is particularly the case with coronal mass ejections (CMEs) when the solar corona releases huge quantities of plasma, a phenomenon that can happen up to three times a day at solar maxima. Fortunately, few of these ejections are directed toward the Earth, but when they are, masses of charged particles[1]may create "electrojets" of millions of amperes in the ionosphere. These electrojets induce local potential differences at the Earth's surface, causing geomagnetically induced electrical currents that could affect the normal operation of metallic infrastructure such as oil and gas pipelines, railroads and power transmission grids.

The first recorded manifestation of these GICs occurred in 1847, when it was found that they were responsible for the breakdown of an electrical telegraph network. In March 1989, a severe geomagnetic storm caused the collapse of the Hydro-Québec power grid in a matter of seconds, and 6 million people were left without power for hours. Since then, power utilities all over the world have invested in evaluating the GIC risk and developing mitigation strategies.

[1]It takes these particles up to three days to travel from the Sun to the Earth

1 __The GIC issue for power networks

"Geomagnetically induced currents used to be regarded as a cause of transformer failures due to internal heating from stray loss," explains Ray Bardsley, GE Grid Solutions Lead Engineer, Electrical Design. "However, modern thinking is that GICs do not normally cause transformer failures directly; but the effects GIC have on transformers can cause severe network disturbances such as grid instabilities and even blackouts."



How does this happen? "Due to the local voltage differences induced by the electrojets at the Earth's surface, a quasi-direct current (DC)—i.e., a current of very low frequency— may flow along transmission lines, entering and exiting via transformer neutral earthing points that are at slightly different voltages," Ray Bardsley explains. Being quasi-DC, GICs cause the transformer core to have a very high AC magnetization current during a small part of each cycle, creating a high reactive power demand on the system. Moreover, the transformer is led to emit high levels of current harmonics into the system. These effects, caused by the asymmetric half-cycle core saturation, may result in protective relay malfunction. Moreover, the DC amplitude varies during a GIC event as it is transient (GICs occur for a few hours and then go away) and may have some high peak values between lower levels. "Therefore, customers increasingly demand information on GIC risks and expect the assurance that their equipment and grid are well designed and protected against GIC problems," explains Alessandra Sitzia, GE Grid Solutions – Team Leader, Electrical Design.

[2]3D simulations are done in the frequency domain to reduce calculation time.

2 __Numerical simulations are needed

"As testing the effect GICs have on a transformer is difficult to do safely, GE Grid Solutions decided to simulate the process using its SLIM proprietary electromagnetic finite-element simulation software for transformers," Dr. Sitzia adds. To assess the resulting phenomena and associated risks to the network, a combination of 2D time-domain and 3D frequency-domain simulations[2] were performed for three different scenarios—no GIC, GIC at 10 amperes and GIC at 100 amperes—to obtain estimations of some of the transformer behavior such as the core magnetizing current amplitude and harmonics, the revised flux distribution in the transformer tank, localized heating, etc.

3__Adverse effects due to high reactive power and harmonics

Simulation results show that the AC magnetization current during a GIC event becomes asymmetric, with a very large increase of amplitude on one half cycle, but almost nothing on the other half cycle. “This high AC magnetization current demands high reactive power (VAr) from the system,” explains Ray Bardsley. “If the system is unable to supply the demanded VAr then the voltage will fall, and the system trips out as under-voltage protection activates.” Furthermore, the high amplitude AC magnetization pulses inject significant even and odd harmonics into the system, placing severe demands on the network. These harmonics are a “particular problem for shunt capacitor banks providing VAr support to the system, so just when they are needed they might trip out.”

During AC magnetization peaks, the core normally saturates, potentially leading to increased stray flux in some vulnerable items such as core clamping plates, windings and tanks.

Information from these simulations of core behavior under the influence of GIC is fed into full 3D non-linear magnetic field studies to allow the stray loss distribution in the transformer to be calculated for these new conditions. The temperatures on the transformer parts are then calculated using these stray losses as inputs.

4__No significant heating

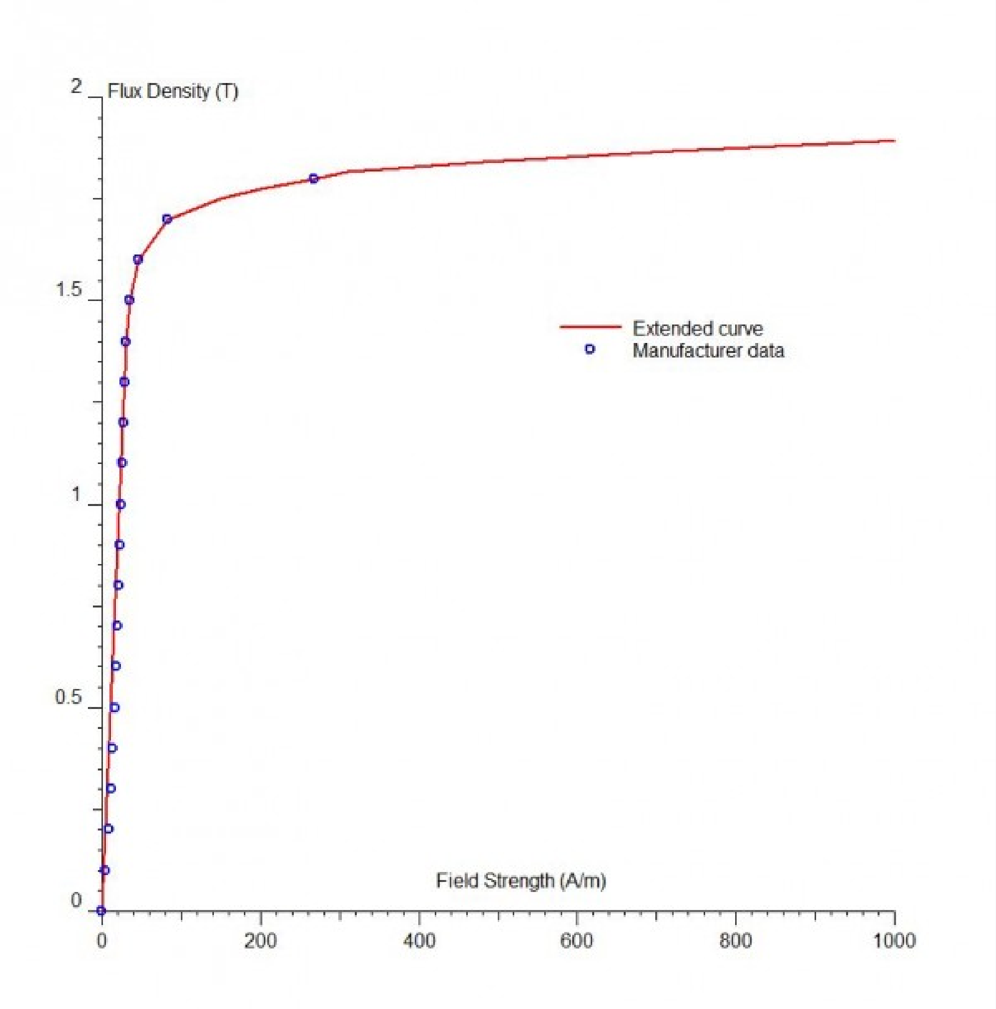
"The calculated temperatures due to stray loss are not significantly affected by the presence of GIC," says Ray Bardsley. "Because saturation occurs for a very short duration during each cycle, the heating effect is not as great as would be expected from full core saturation—only one-sixth to one-tenth of the level from full saturation," he points out. Nonetheless, special stray flux protection measures such as copper rejection sheets and non-magnetic steel components can be installed.

5__ Mitigation design strategy

Since GICs need to be taken into consideration, the optimum strategy is to try to design a three-phase transformer with no return limbs, which is inherently less susceptible to the effects of DC bias. Where this is not practical (for example due to manufacturing, transportation limitations, or a requirement for single phase transformers) then a special GIC engineering study has to be undertaken, with the help of GE's SLIM software.

What if steel property data are not available?

The main effect of GIC is to vastly increase the magnetizing current in one half of each AC cycle. This means that the transformer core steel is driven to higher flux density values for that half cycle, values that may exceed those measurable by standard means by the steel manufacturer. Therefore it is necessary to adopt a mathematical extension of the steel's magnetization curve to allow the accurate simulation of the core. A significant amount of research has been done in this area to develop algorithms that extend the curve to match the observed behavior in experimental cores. Two such algorithms have been introduced in the GE Grid Solutions SLIM software and an implementation of the “Law of Approach” is illustrated in the figure below.



Magnetization curve for typical transformer steel, showing mathematical extension.

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