Present day challenges in understanding the geomagnetic hazard to national power grids

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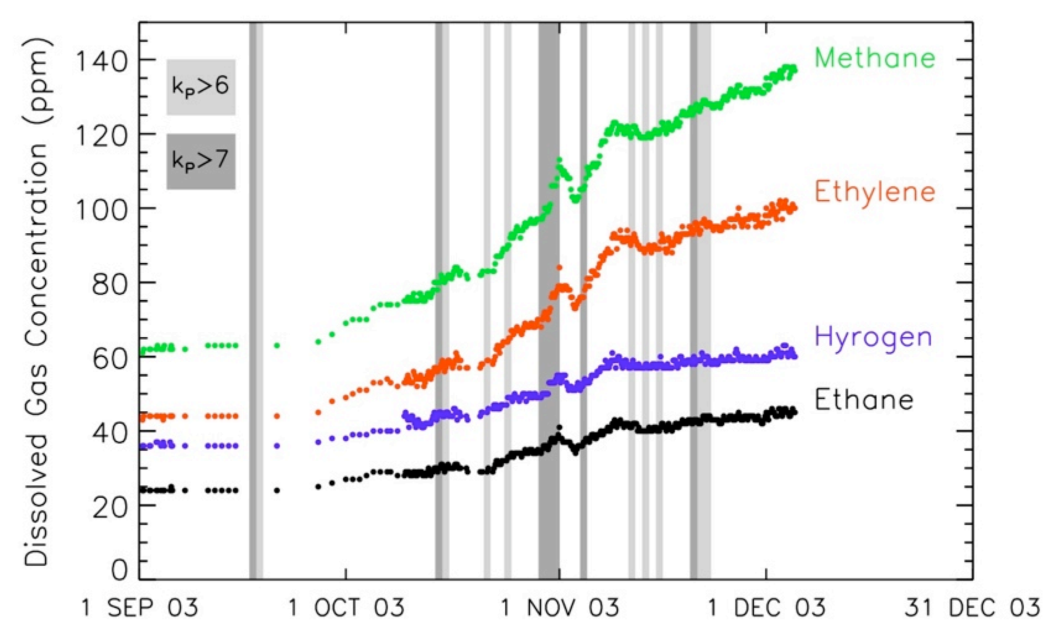
Abstract

Solar activity gives rise to changes in the near- Earth space environment, often referred to as space weather, that can adversely affect technologies on and above the surface of the Earth. For example, the impact of a coronal mass ejection on the Earth's protective magnetosphere can lead to a geomagnetic storm, boosting existing magnetospheric currents. These current systems cause large magnetic variations that induce electric fields in the solid Earth. These fields, in turn, generate geomagnetically induced currents (GICs) that flow in conducting pipes and wires, in ways influenced by the electrical properties of each network. Consequently, power grids and pipeline networks at all latitudes are at risk from the natural hazard of GICs. As solar activity begins to increase from the deepest solar minimum in a century, we consider the current understanding of this hazard, as it affects major power systems in Europe and Africa. We also summarise what can be said with some certainty about the hazard and what research is yet required to address outstanding questions and develop useful tools for geomagnetic hazard mitigation.

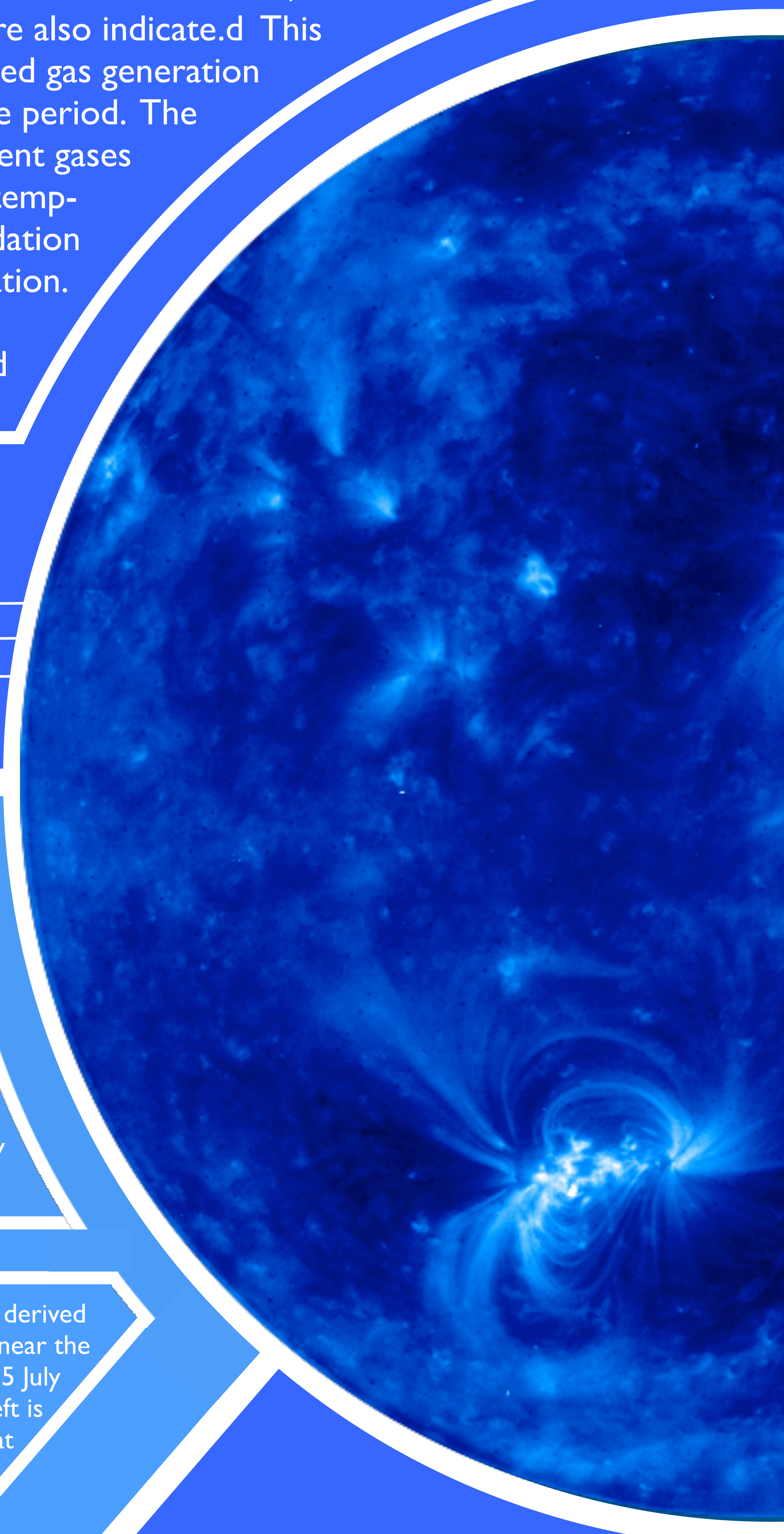
Ten things we DO know about GICs

1. Solar storms (i.e. CMEs) that lead to high levels of GICs are statistically more likely during periods close to solar maximum and in the descending phase of the solar cycle, but they do also occur at all other times in the solar activity cycle.
2. The magnetospheric and ionospheric currents that drive GICs are different at different latitudes.
3. The dominant cause of GICs in power grids is the time rate of change of the Earth's magnetic field.
4. Interpolating the magnetic field from spatially distributed geomagnetic observations improves the prediction accuracy of GICs at any given point, even at mid-latitudes (e.g. Bernhardi et al., S. Afr. J. Sci., 2008). This is in comparison with pre- dictions made from data from a single magnetic observatory, taken to be representative of the 'regional' situation.
5. GICs are larger in countries and regions where the geology is generally more resistive (discussed, e.g., in Pirjola and Viljanen, URSI Symposium on Environmental and Space Electro-Magnetics,1991).
6. A multi-layered and laterally varying ground conductivity model gives better prediction of GICs, than the simpler assumption of an homogeneous Earth (e.g. Ngwira et al., Space Weather, 2008; Thomson et al., Space Weather, 2005).
7. GICs have been demonstrated to affect power systems at all latitudes.
8. GICs can affect many power transformers simultaneously at multiple points across regional and continental scale networks.
9. Series capacitors in transmission lines may interrupt GIC flow in power networks, but are expensive. However, some strategies involving capacitors may increase GIC and reactive power demands (e.g. Erinmez et al., J. Atmos. Sol.-Terr. Phys.2002).
10. It is possible from transformer dissolved gas analysis to identify GIC-initiated damage before complete trans- former failure occurs. This is especially true if the rate of gassing simultaneously increases in widely separated transformers across a network.

Failure in a large South African generator transformer three weeks after the Halloween storm of October 2003. The disruption of the winding and insulation by the arcing fault at the time of final failure is clear. The arcing fault also destroys evidence that might lead to a better understanding of the progression of damage after initiation by the geomagnetic current event.

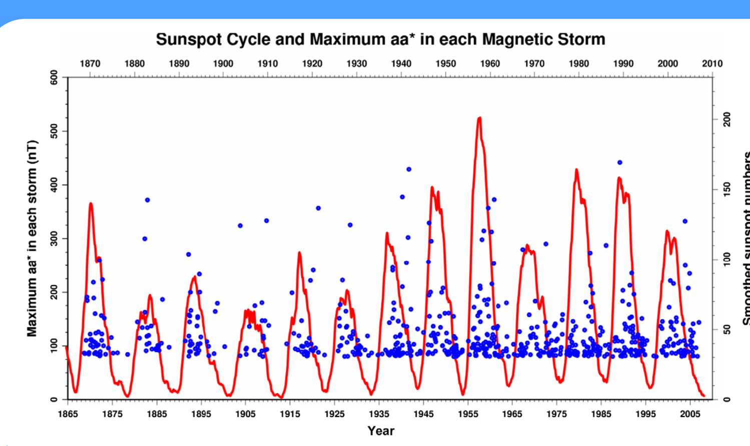


Results of dissolved gas analysis for a transformer in South Africa during the geomagnetically active period in late 2003. Intervals of K_P 6 and 7 level activity are also indicate.d This shows continued gas generation throughout the period. The ratios of different gases indicates low temp- erature degradation of paper insulation. Similar trends were observed at other sites.

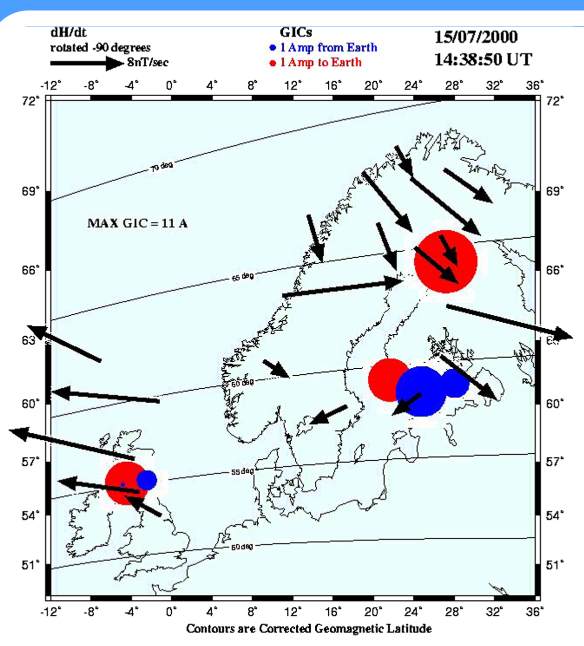


Ten things we DON'T know about GICs

1. What are the solar and interplanetary events and signatures that are most 'geoeffective' in terms of GIC causation?
2. What are the characteristics of extreme geomagnetic storms that pose the highest risk to power systems?
3. In predicting GICs, what is the contribution of each of the different components of the geomagnetic field and other parameters such as the ionospheric total electron content and the interplanetary magnetic field (e.g. Pulkkinen et al., Space Weather, 2006)?
4. What are the definitive spatial/temporal scales of the magnetospheric and ionospheric currents that drive significant GICs in grids?
5. What is an adequate number/distribution of magnetometers to model GICs?
6. Which information, given on what timescale, is most useful for any given power utility/authority to manage its GIC risk?
7. In modelling GICs in a power grid, what is an appropriate level of detail required of Earth conductivity (as a 3D model or otherwise)?
8. What are the characteristics of power transformers that determine their susceptibility to GICs and therefore determine the extent of damage sustained under different levels of GICs?
9. What are the transformer failure mechanisms subsequent to damage initiated by GICs?
10. Where should scientists go to access industry archives, particularly archives of any GIC measurements obtained concurrently with network data (i.e. network configuration and connections, DC resistances of transmission lines and transformers and station earthing resistances)?



Large storms identified by peaks in the 24h running average (aa*) of the 3h geo- magnetic aa index against time since 1868. Monthly smoothed sunspot number is also shown. An 80nT threshold has been used to better identify the largest individual storms.



The complexity of ionospheric current vectors derived from UK and Scandinavian magnetometer data near the time of the storm commencement during the 15 July 2000 magnetic storm. The scale vector at top left is 8 nT/s. Coloured spots denote measured GIC at in national power grids at the time (red shows GIC flowing to the Earth) and in one gas pipeline in Finland. Spot size is propor- tional to measured GIC. The largest current at this time was ~11 A. Data are courtesy of the Finnish Met. Institute, Lancaster University, the British Geological Survey, Scottish Power PLC and Gasum Oy.

Conclusions

Compared with the 'do knows' in our list, our 'don't knows' may be more contentious within the scientific community. It may be debated which items are most important at the present time, understanding that other issues might yet become more relevant. However, by making progress on our current 'don't knows' we expect advances in the community's ability to monitor, model and predict the impacts of space weather and GICs on power grids.

Solar cycle 24 is just beginning and we can expect that the space weather hazard to ground-based technologies will increase, just as it did during the up-turn of previous cycles. Wider discussion of these issues is required, not just within the international space weather community, but also within industry and wider society.

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