Modeling extreme space weather

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Explosions on the sun regularly disrupt the magnetic envelope surrounding Earth, but that envelope, the magnetosphere, largely protects the surface of the planet itself from space weather – with one exception. As a rule, changes in magnetic fields cause electric currents and vice versa, so all that change in the magnetosphere causes electric currents to form on the ground. Called geomagnetically induced currents or GICs, such currents extend some 60 miles underground, electrifying any conductors – power grid lines, or oil pipes, for example – along the way.

A big enough electrical surge from a GIC can knock out the transformers in a power grid. Electric companies can protect the grid from such surges by shutting down or lowering the power load on the system, but this, of course, costs money so they also don't wish to be overly cautious by reducing power output unless it is really necessary. New analysis by scientists at NASA's Goddard Space Flight Center in Greenbelt, Md., published online in Space Weather on February 23, 2012, provides some basic guidelines to help model some of the largest, most damaging GICs.

Video: When explosions on the sun known as coronal mass ejections or CMEs collide with Earth's magnetic fields, the fields change shape and strength. Changing magnetic fields, in turn, can cause electrical currents, known as geomagnetically induced currents to form underground and in Earth's electrical systems. Credit: NASA/GSFC Conceptual Image Lab

Risk analysis and adequate risk protection both rely on numerous factors. Modeling an extreme, devastating GIC is a crucial part of that picture. Referred to as 100-year events, that is, events so extreme they only happen on average once every 100 years, such currents could cause significant damage to Earth's power grids worldwide. But proper preparation and accurate space weather forecasting could mitigate intense damage, the same way that communities can evacuate or protect their homes if given enough advance warning of a hurricane.

"Our main goal here is to provide the initial piece that power engineers need to calculate the risk that such a large 100-year GIC could pose," says Antti Pulkkinen, who is the first author on the paper and who is a solar scientist at Goddard and at Catholic University in Washington, D.C.

To do that, Pulkkinen identified four different factors needed for risk analysis: the conductivity of the ground, the power grid's position on Earth, the frequency of the GIC, and its geographical effects.

The first, ground conductivity refers to how well electricity travels through any patch of Earth. This depends strongly on local geology, what minerals lie in the dirt, and the characteristics of the planet's crust some 60 miles down into the ground. Any given power station will need to take this into consideration when analyzing its own risks.

A second consideration is geographical placement. The magnetic fields in space are driven by different causes in different places, meaning that the very source of the GICs changes at different latitudes on the globe.

"Magnetic fields near the poles, for example, exhibit more violent, larger perturbations that are closer to Earth," says Pulkkinen. "So at high latitudes, one sees larger induced currents."

Next one must consider the frequency of the electrical currents themselves, and how the fluctuations change with time. Transformers don't blow in an instant. It takes time for the heat to build up to dangerous levels, perhaps ten or twenty minutes. So how quickly a GIC transfers energy to the transformer will determine the risk in each case. Generally speaking, short GIC pulses are less damaging than long-lasting large amplitude ones.

The last constraint Pulkkinen and his team say needs to be incorporated into risk analysis is just how large of an area any given model covers. The team found that every scenario is quite complex and, consequently, quite localized. Each modeling scenario is applicable in any direction for a few hundred up to a thousand miles. In the case of large power grids, therefore, scenarios must be developed for individual parcels of the grid and cannot be assumed to be universal across the system.

As the science of space weather grows to its full potential, understanding how events on the sun could affect something as small as a single transformer on Earth will require sketching out the physics with minute attention to detail. This is an important step in producing and fine-tuning those models, says Pulkkinen.

"A comprehensive analysis of the full risk requires a multidisciplinary approach," says Pulkkinen. "No one individual or group can do it themselves. We need a good group of solar and geospace experts, power engineers, and risk analysis experts, all working together in a coherent way."

This work builds on earlier work by Pulkkinen's team that generated the first physics-based GIC forecasting system known as "Solar Shield".

More information: For more on Solar Shield, visit: www.nasa.gov/mission_pages/sun … next-solarstorm.html

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