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As Sun Storms Ramp Up, Electric Grid Braces for Impact

Electric transformer failures, like this dramatic one, are a risk if solar storms create extra electrical currents in the Earth's magnetosphere. Below, a loop of plasma erupts from the sun on March 19, captured by NASA's Solar Dynamics Observatory spacecraft.

Photograph by TJK/Alamy

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This story is part of a special series that explores energy issues. For more, visit The Great Energy Challenge.

Storms are brewing about 93 million miles (150 million kilometers) away, and if one of them reaches Earth, it could knock out communications, scramble GPS, and leave thousands without power for weeks to months.

The tempest is what's known as a solar storm, a flurry of charged particles that erupts from the sun. Under the right conditions, solar storms can create extra electrical currents in Earth's magnetosphere—the region around the planet controlled by our magnetic field.

The electrical power grid is particularly vulnerable to these extra currents, which can infiltrate high-voltage transmission lines, causing transformers to overheat and possibly burn out.

"The concern is if the electric grid lost a number of transformers during a single storm, replacing them would be difficult and time-consuming," said Rich Lordan, senior technical executive for power delivery and utilization at the Electric Power Research Institute (EPRI).

"These power transformers are very big devices, and the lead time to get a replacement can be two months—*if* there's a spare one stored nearby. If a utility has to order a new one from the manufacturer, it could take six months to up to two years to deliver."

The danger is becoming more critical, as the sun is approaching what's known as solar maximum—the high point in our star's roughly 11-year cycle of activity. Scientists anticipate stronger storms around solar max, in 2013.

Using the latest sun-watching satellites and computer models, scientists have been trying to improve solar storm predictions. At the same time, electricity operators are developing plans for how to respond to solar storm warnings and determine what the consequences for the grid might be in a worst-case scenario.

"Geomagnetic storms are low-probability, high-impact events," Lordan said. "When assessing the risk to the grid, one has to ask, What's the level of storm intensity that the grid system should be prepared for?

"Based on the data and the scenarios we can reasonably expect, I believe the power-delivery system can operate through a solar storm."

Listening for the Solar Whistle

Earth is being constantly bombarded by charged particles from the sun, which emits material in all directions. This is known as the solar wind. But sometimes the sun ramps up magnetic activity on its surface, triggering huge flares of plasma.

(Related: "Solar Flare Sparks Biggest Eruption Ever Seen on Sun")

Such "solar flares are like the whistle on a freight train," said Joe Kunches, a space scientist for the National Oceanic and Atmospheric Administration's Space Weather Prediction Center (SWPC). The big impacts come from coronal mass ejections (CMEs), cloud-like bundles of plasma that are sent racing off the sun's upper atmosphere, or corona, during periods of intense surface activity.

That's not to say every CME is a harbinger of doom—the clouds are highly directional and can miss Earth entirely or strike only glancing blows.

"The sun doesn't give a hoot about us," Kunches said. "It erupts and produces lots of energy, and sometimes we get a direct hit and sometimes we don't."

(Related: "Huge Solar Storm Triggers Unusual Auroras")

However, said Antti Pulkkinen, a sun researcher with NASA Goddard Space Flight Center, "if these clouds do move toward Earth's near-space environment . . . they can carry billions of tons of matter moving at 2,000 kilometers [1,242 miles] a second."

When the cloud reaches our magnetosphere, its charged particles become electromagnetically coupled to Earth's magnetic field, generating large electrical currents millions of amperes strong, Pulkkinen said. The sprawling electrical grid on Earth's surface then acts like an antenna, allowing these currents to flow into transmission lines.

"These storms are by their basic nature global," Pulkkinen added. But the risks to electrical grids are greatest at higher latitudes, since the largest electric currents are funneled toward Earth around the Poles.

For instance, in 1989 the transmission system for Canada's Hydro Quebec electricity provider collapsed during a solar storm, leaving millions of people without power for nine hours or more. And the "Halloween storms" of 2003 triggered blackouts in the city of Malmö, Sweden, and likely caused transformer failures in South Africa.

"Because they are located closer to the magnetic North Pole, Canadian utilities are deeply involved in monitoring geomagnetically induced currents, modeling impacts for vulnerability, and refining their operational protocols," EPRI's Lordan said.

European utilities and the South African electricity provider ESKOM also are preparing for the upcoming solar maximum, in part with advice and data from NASA.

(Related: "What If the Biggest Solar Storm on Record Happened Today?")

The AC/DC Problem

Technically, geomagnetically induced currents aren't that strong compared with the currents that normally flow between power plants and electricity consumers. For electricity to travel long distances, it needs to be transformed to high voltage and back again, to limit energy loss due to resistance in the transmission wires.

Trouble arises because the extra currents from solar storms are direct current (DC) flows, and the electricity transmission system is used to handling alternating current (AC) flows, said EPRI's Lordan.

(Related: "Upgrading the Electric Grid With Flywheels and Air")

The extra DC flows saturate transformers, which start to overheat, causing their insulation to break down and their parts to experience accelerated aging. Above a certain temperature, a transformer will fail.

At the same time, the saturated transformer starts to consume what's known as reactive power.

"When you look at power in the system, there's real power—like that in incandescent light bulbs—and then there's 'imaginary' power called reactive power, measured in vars," Lordan said.

Reactive power is produced when the current and voltage are out of phase. This type of power flow needs to be carefully managed to keep the voltage steady in transmission lines.

During a solar storm, however, any saturated transformers draw on more reactive power than what normal control equipment can handle. This can lead to voltage collapse, when it's no longer possible to push the needed power through transmission wires.

Even without a full collapse, fluctuating voltage in the transmission system can cause the grid to become unstable, which can impact transformers, relays, capacitors, and even the generators at power plants.

A Satellite Shield

In 2007 NASA Goddard began a collaborative effort with EPRI called the Solar Shield Project, which uses monitoring data from several sun observatories to run state-of-the-art computer simulations and make solar storm predictions.

Solar Shield first collects a constant stream of data from satellites such as the Solar and Heliophysics Observatory (SOHO) and the Solar Terrestrial Relations Observatory (STEREO).

(Related Video: "Solar Eruptions Captured in 3-D")

"When an operator sees an eruption on the sun, he or she will derive the three-dimensional parameters of that eruption, such as size, speed, and direction," NASA's Pulkkinen said. The resulting model can provide one- to two-day warnings of incoming solar storms to EPRI, which then disseminates the alert to participating utilities across the North American power industry.

"If operators know a couple days beforehand that there's a good likelihood of a storm, they can postpone maintenance of critical lines," Pulkkinen said. This step maximizes the amount of the grid available, reducing strain if localized portions fail.

"Operators can also bring in more reserve power to the system to make it as stable as possible," he said. If particular transformers start showing signs of trouble, operators can reduce their load or disconnect them.

If the storm is expected to be severe enough, "the most dramatic action is to close down the entire grid," Pulkkinen said. "If the system is turned off, the extra DC currents alone won't harm the transformers."

But such a move would be "the last mitigation measure in the toolbox," he said, because switching the system off intentionally would result in temporary blackouts.

"The industry's goal is to provide safe, reliable, and cost-effective power," EPRI's Lordan said. "Utilities would be watching the system closely and would attempt to operate through the storm."

"If the utility system did go down because of a voltage collapse, utilities would have to wait for the storm to pass and then activate procedures to bring the system back up," Lordan said.

"If transformers are lost, the system can operate around a certain number of failed units. But if it's hundreds of transformers, then the industry would quickly get together and move the spares where they are most needed."

The European Union is working on a similar solar-storm alert project called SPACECAST, which is projected to be operational by March 2012.

Trying to Avoid Surprises

As with other natural disasters, the ability to react to a solar storm depends first on the accuracy of monitoring and prediction efforts, which in turn need to be based on real-world physics.

But unlike hurricane predictions, for instance, "we have a tougher nut to crack, because the space weather system is so vast," NOAA's Kunches said. "If you were to make the sun the size of a basketball, Earth by comparison would be like a pinhead. Then you put the basketball at one end of a full-size court and the pinhead at the other end."

In addition, space weather forecasters don't yet have all the pieces of information needed to say for sure whether an incoming storm is going to be the type that will create geomagnetically induced currents.

"The strength of a CME is a function of the polarity of the embedded magnetic field in the plasma," Kunches said. "Polarity dictates whether the storm will be short-lived, very strong, etcetera, and stronger storms are more likely to induce geomagnetic currents. But we don't have that information until the storm is very near Earth."

What's more, even with a host of sun-watching instruments and monitoring centers, sometimes the sun simply "throws us a curveball," he said.

Between SOHO, STEREO, and NOAA's GOES satellites, "we're looking like crazy back at the sun, and we still get one out of ten or twenty surprise CMEs that just don't show up very well in the imagery," Kunches said.

Not only do the satellite-watchers miss some events, they also run the risk of false positives. The forecasters were recently duped just a few weeks ago, on June 21. "All our instruments saw what appeared to be an Earth-directed CME as plain as the nose on your face, so we put out a warning," Kunches recalled. "And it turns out nothing happened."

New Era in Space-Weather Forecasts

Answers may come from recently launched satellites such as NASA's Solar Dynamics Observatory (SDO), which is now watching the sun around the clock in high resolution, taking pictures every tenth of a second in multiple wavelengths.

"One of the goals of SDO is to provide us with the keys to unlock the physics of solar eruptions," NASA's Pulkkinen said. "The SDO team can't predict when the eruptions will happen, but it can observe them and help us predict from there."

Overall, he added, "from a space-weather forecasting viewpoint, we're living in a very exciting time. This is the first time in history we're able to make one- to two-day predictions. It's the first time we have the observation capacity via satellites, and the first time we have full-scale models and the computational power to run those models."

(Related: "Sun Headed Into Hibernation, Solar Studies Predict")

According to NOAA's Kunches, perhaps the most vital aspect today in space weather forecasting and mitigation is well-coordinated communication.

"It's important to be as well-educated about the sun as possible," he said. "There's a recognition in the emergency management community and other levels of government that, as best we can, we need to communicate about space weather.

"If something does happen, even if we didn't predict it very well, the idea is that we can get the word out quickly, and people will know what to do."