The U.S. Power Grid - Vulnerability to Solar Storms

An Online Continuing Education Course for Engineers

Course Number: E-4026

Credit: 4 Hours / 4 PDH / 4 CPD

The U.S. Power Grid – Vulnerability to Solar Storms

Lee Layton, P.E.

Introduction

A once-in-a-century solar storm event could induce a power surge into the electric transmission system plunging much of the United States into a blackout that may last several months or even a year or longer. The electric system for as much as one-third of the country could be immediately disrupted with an event equal to the 1921 "New York Railroad" event. However, many experts say that the automatic protections built in the U.S. electric grids would immediately operate on the initiation of a geo-magnetic disturbance (GMD), creating widespread blackouts, but very little damage to the system. In this case, the electric grid could be back in operation in a matter of days. Still the economic impact of a momentary outage is enormous.

Geomagnetic storms — a type of space weather that creates disturbances that affect the planet's magnetic field —have the potential to cause significant damage across the globe with a single event. Severe geomagnetic storms can disrupt the operation of electric power transmission systems and critical infrastructures relying on space-based assets. A geomagnetic storm that degrades the electric power grid would affect not only the energy sector but the transportation, communications, banking, and finance sectors, as well as government services and emergency response capabilities.

Issues with geo-magnetically induced currents (GIC) have been known since the mid-19th century when it was noted that electrical telegraph systems could sometimes run without power during geomagnetic storms, described at the time as operating on the "celestial battery", while at other times they were completely inoperative.

The North American bulk electric power system is perhaps the most critical infrastructure on the continent, for its continued reliable operation supports several other critical infrastructures, including water supply, telecommunications, food and fuel production and distribution, and others. It underpins our government, economy, and society in crucial ways. The U.S. National Academy of Engineering ranked electrification as the greatest engineering achievement of the 20th century, ahead of automobiles, telecommunications, computers, and even healthcare in terms of it positive impact on quality of life.

The extra high voltage (EHV) portion of the grid (345-765 kV) typically experiences the highest GIC flow levels, in part because these lines and connected transformers also have lower resistance per mile than the lower voltage underlying systems and the ground impedance. The loss of these key assets due to large GIC flows on the high voltage system can rapidly widen into geographically widespread disturbances on the power grid.

Power systems may be more vulnerable to the effects of a severe geo-magnetic storm than a few decades ago. Since the 1950s, the number of miles of high-voltage transmission lines has increased by about a factor of ten. Hence, the number of assets that provide a conductive path for GICs has increased dramatically over the last five solar cycles. During the same period, transmission line and transformer designs have increased in voltage from 100-200 kV to 345-765 kV, which has lowered their resistance by a factor of ten and further increased their susceptibility to GMDs. And the conducting paths are lengthening as transmission lines become interconnected (e.g., across national borders).

In the last two decades, construction of new transmission lines has slowed forcing some utilities to operate the bulk power system closer to operating limits more often. This increases the vulnerability to overloads caused by GMDs because the equipment may be operating closer to its nameplate thermal rating when the GIC initiates additional heating. The North American power grid is highly complex; it is comprised of over 200,000 miles of transmission lines, thousands of generating plants, and millions of digital controls (See Figure 1.) Yet, industry has demonstrated a long track record of reliable, secure delivery of power, however, without adequate steps to mitigate their effects, geo-magnetic disturbances (GMDs), may pose a risk to reliability.

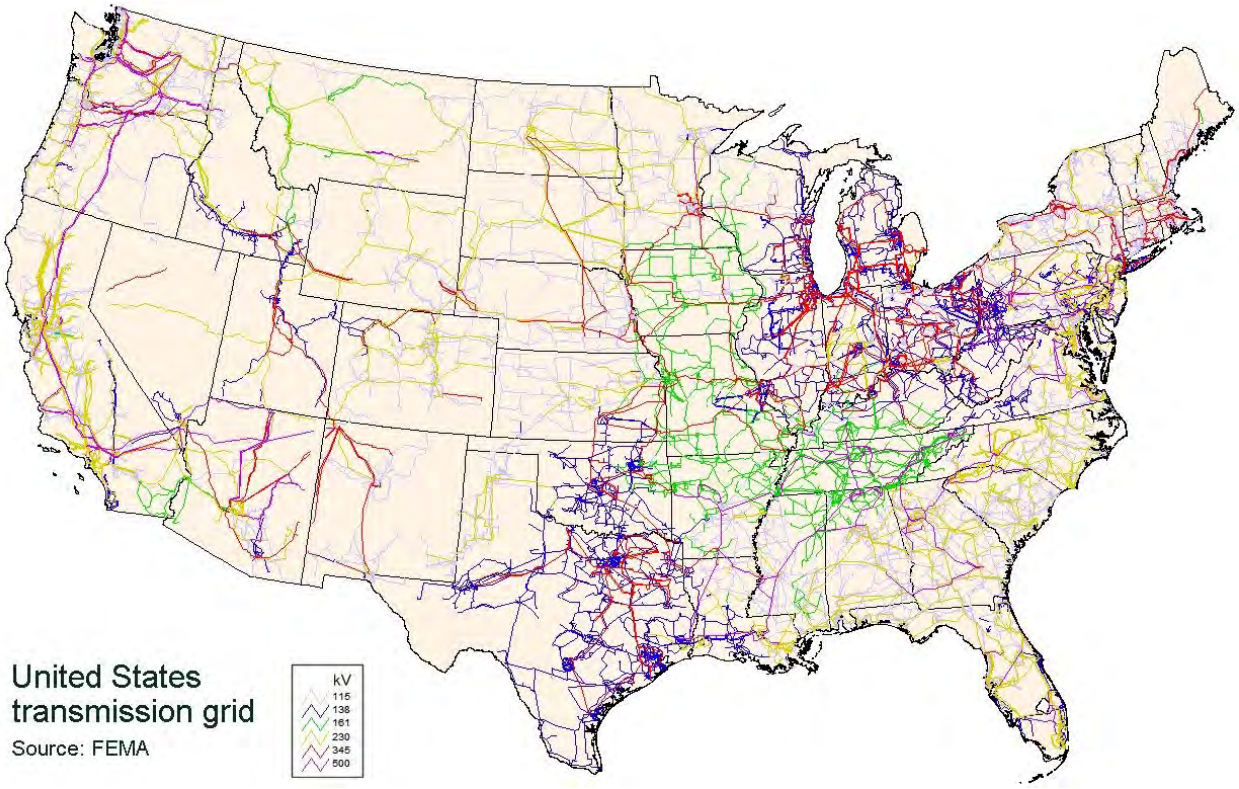

Figure 1

GMDs start with the sun. Solar coronal holes and coronal mass ejections (CMEs) are the two main categories of solar activity that drive solar magnetic disturbances on the Earth. CMEs involve the ejection of a large mass of charged solar energetic particles that escape from the sun's halo (corona), in a matter of days, or sometimes just a few hours (see Figure 2.)

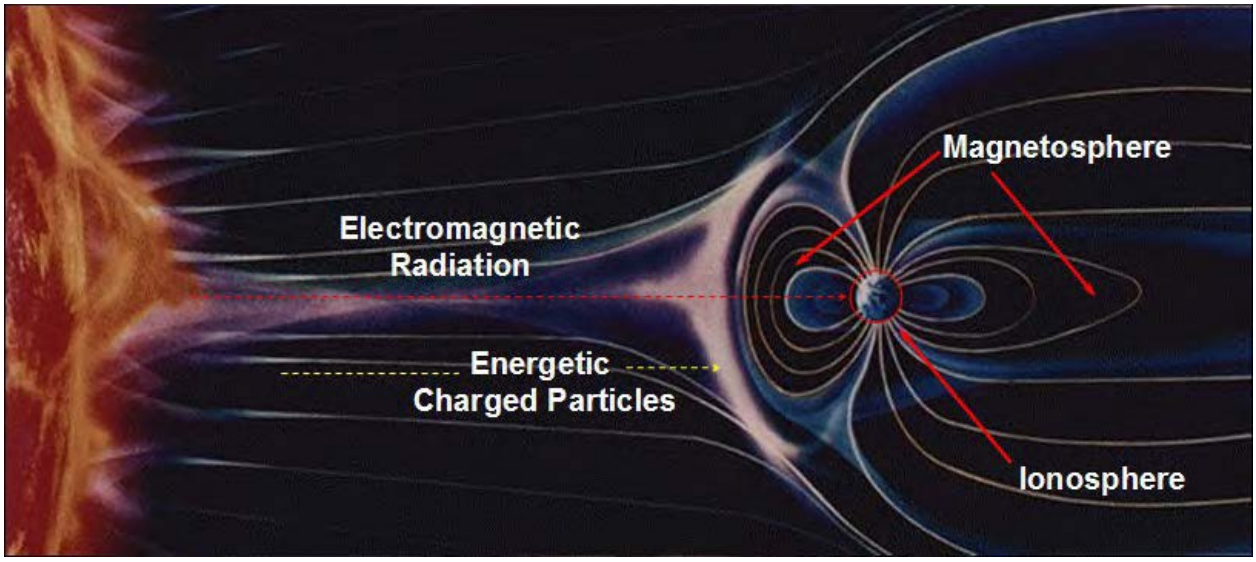

Figure 2 **Source: National Weather Service**

Solar storms, which emanate from the sun as coronal mass ejections (CMEs), can produce an impulsive disturbance to the Earth's geo-magnetic field over wide geographic regions.

The storms are global phenomena; a single severe storm can adversely impact systems on multiple continents. The disturbance in the Earth's geo-magnetic field can cause geo-magnetically induced currents (GICs) in the ground and electrical network. Once they are introduced into the bulk power system's transmission and generation facilities, these ground-induced currents can saturate and may damage some equipment, which can be difficult to immediately replace, such as high voltage transformers, which require long lead times to construct.

A severe geomagnetic storm is defined as any event with a disturbance storm time of less than -500 nanoTeslas. No recorded geomagnetic storm since 1932 has exceeded -760 nT.

These quasi-DC currents can enter and exit the power system at transformer grounds disrupting the normal operation of the power system and can, in some cases, damage equipment. Because of their proximity to the Earth's magnetic north pole, higher latitudes typically experience greater

effects of GMDs. However, a severe storm can affect equipment and systems even at lower latitudes.

Over the past decade, natural hazards have caused catastrophic consequences across the globe. Tsunamis, hurricanes, flooding, earthquakes, and volcanic eruptions have led to hundreds of thousands of fatalities and billions of dollars in economic costs. Significant geomagnetic storms happen less frequently, but have the potential to cause considerable damage across the globe with a single event. In the past, geomagnetic storms have disrupted space-based assets as well as terrestrial assets such as electric power transmission networks. Extra-high-voltage transformers and transmission lines may be particularly vulnerable to geo-magnetically induced currents caused by the disturbance of Earth's geomagnetic field. The simultaneous loss of large numbers of these assets could cause a voltage collapse and lead to cascading power outages, resulting in significant economic costs to the Nation. An extreme geomagnetic storm is a low-probability, high-consequence event that could pose a systemic risk to the Nation.

Historical Geomagnetic Events

Great solar storms occur approximately once per decade. Table 1 lists the major solar storms over the past 150 years. The largest solar storm ever recorded occurred in September, 1859 and is known as the "Carrington Event".

Table 1
Major Solar Storms

Event	Year	Strength
Carrington Event	1859	-1,750nT
New York Railroad Event	1921	-1,060nT
Quebec Event	1989	-589nT
Bastille Day Event	2000	-301nT
Halloween Event	2003	-383nT

The events shown in Table 1 are discussed in more detail below.

Carrington Event – 1859

On September 1 – 2, 1859, the largest recorded geomagnetic storm occurred. From August 28 until September 2, 1859, numerous sunspots and solar flares were observed on the Sun, the

largest flare occurring on September 1st. This is referred to as the 1859 solar super storm or the Carrington Event. It can be assumed that a massive Coronal mass ejection (CME), associated with the flare, was launched from the Sun and reached the Earth within eighteen hours — a trip that normally takes three to four days. It is estimated that the *Dst* would have been approximately -1,750nT. Scientists reached this conclusion by analyzing anomalous nitrate concentrations in polar ice core samples and estimating the fluency of protons, which are an indicator of the amount of solar energetic particles that reach the Earth. This event was named after British amateur astronomer Richard Carrington, who observed a white flare light the day before the onset of the storm – an observation independently confirmed in London, England.

Dst is an abbreviation for the Disturb… m Time index that …ength of the magnetic …g the horizontal …e geomagnetic field.

These were manifestations of two intense magnetic storms that occurred, driving magnetometer readings off their scale and disrupting telegraph… worldwide. Unfortunately… enable a direct estimation … specifically, large GICs w… dramatic effects on telegra… …udes or geo-magnetically induced volta…

Aurorae were seen as far so… …ena that are usually only seen near the p… …intensity recur at an average rate of approxima… …orms have occurred in 1921 and 1960, v…

The New York Railroad Ever…

The highest magnitude GMD … …he storm disabled all telegraph service … …in major portions of the western U.S. T… …marine cables would need to be brought to the surface for re… …of this severity has tested the power grid since then – not even the 1989 storm. The 1921 storm may have been ten times stronger than the 1989 storm that collapsed the Hydro Québec system. However, sophisticated monitoring equipment, widely deployed today, was not available at the time of the storm, making exact replication of the storm signal impossible. The minimum Dst is estimated to have been around -1,060nT.

Quebec Event - 1989

To date the most severe power system disturbance resulting from a geomagnetic storm occurred during the 1989 Quebec event which was a storm level K-9 event. This is the most well-known recent GMD experience in North America and it led to the collapse of the Hydro Québec system