Electrical Claims and Space Weather

Measuring the visible effects of an invisible force
June 2015

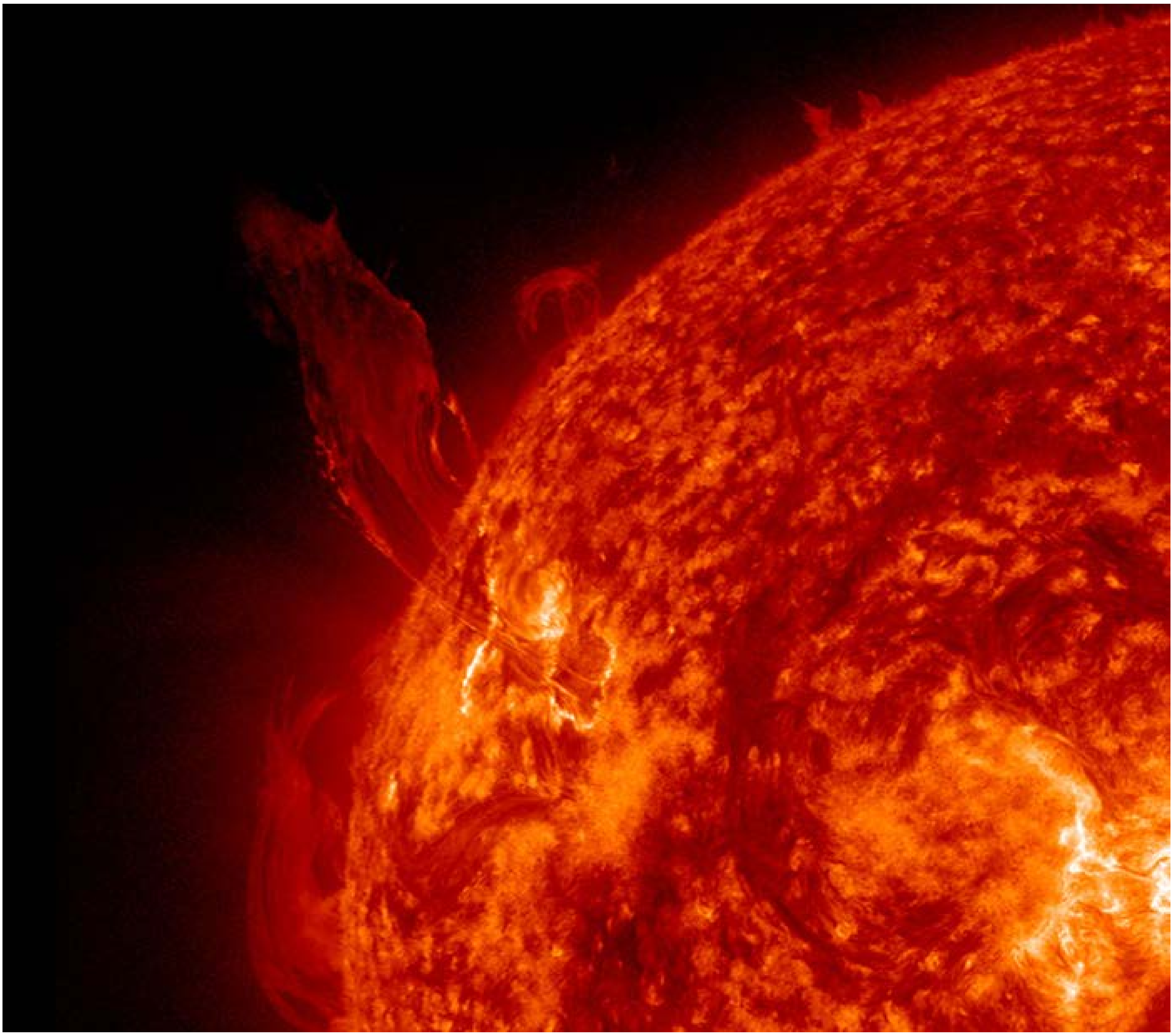

Image Credit: NASA/SDO/Goddard Space Flight Center [1]

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1. Executive Summary

Property and casualty insurance companies are concerned with many types of risks - fire, flood, wind, equipment breakdown and others that affect businesses and homes. One of the primary functions of an insurance company is to protect their customer against losses. An insurance company will seek to protect their customers' insured property by providing guidance on ways to care for and protect that property. This minimizes the overall risk to both the insured and the insurer.

Over the years insurers have become very familiar with the types of risks and hazards they insure and how to protect the property they cover. They have also learned how much premium to charge to sustain their own business. As science and engineering provide innovations to an ever evolving society, new risks are always emerging. Insurance companies are constantly looking ahead at emerging risks to determine how they will meet new challenges.

Space storms that affect the Earth are by no means new. However, the equipment they can affect and the way this equipment is installed and used today is relatively new and rapidly expanding. What these storms from space can do to this equipment is considered an emerging risk. This risk is being studied by industries, scientists, engineers and political bodies because of the also considerable threat this risk poses to society today.

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2. Introduction

2.1 Facing the storm

Superstorm Sandy was a devastating storm to the US eastern seaboard in 2012. The Philippines are still recovering from the effects of Supertyphoon Haiyan in 2013. The effects of Hurricane Katrina and the massive recent tsunamis striking Japan and Indonesia were disastrous. These were all monstrous events that were broadcast minute by minute, hour by hour, on our televisions and computers. Our communication devices brought vivid images of the devastation caused by these storms into our homes and businesses as we watched the results of the cataclysmic forces that nature can bring to bear on our planet.

2.2 A force of nature

There are other forces that can affect our planet in ways that may not make the news. In a paper published by Zurich Risk Engineering, Don't Get Burnt by Solar Storms: What is Your SPF Level?, [4] Zurich Risk Engineering considered the effects of solar storms as a potential emerging threat. The paper was written ahead of the recent solar maximum peak period.

Its intent was to point out the potential damage that geomagnetically induced currents (GIC) produced by the coronal mass ejections (CME) from solar storms can and have done to our interconnected electrical distribution grid networks.

Many in the scientific and electrical-engineering communities fear that our aging and growing electric infrastructure has become much more vulnerable to the effects of CME and the resulting geomagnetically induced currents.

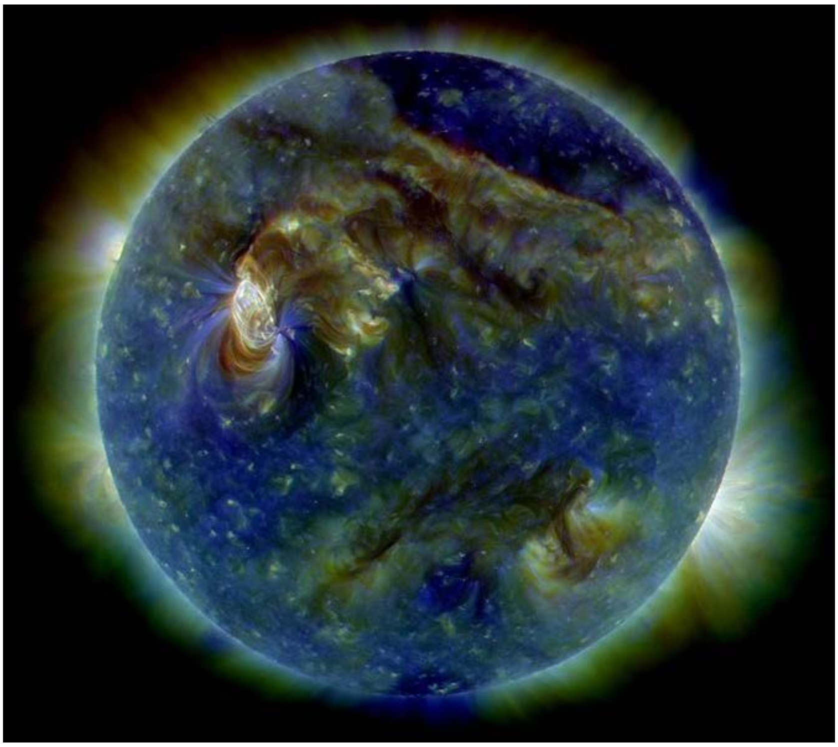
The sun is continuously undergoing nuclear fusion and blows electrified solar gas (plasma) and CME into space. Violent solar storm events occur when the sun's solar magnetic field is strained and suddenly snaps to a new configuration to release massive amounts of energy with intense flashes of light, radiation and CME. Space weather is the term given to violent transfers of matter and energy from the sun to the earth. This type of matter and energy transfer from the sun is often referred to as a "Solar Storm." Although solar storms can occur at any time, their frequency of occurrence and intensity varies on an 11-year cycle (9-14 years cycles) when this activity reaches its maximum activity.

Many in the scientific and electrical-engineering communities fear that our aging and growing electric infrastructure has become much more vulnerable to the effects of CME…

The CME associated with this space weather can have strong embedded magnetic fields. They travel with high velocity and contain atomic particles from the sun, including electrically-charged high-energy atomic particles such as protons and electrons, hydrogen nuclei and large quantities of helium, iron and nickel nuclei. When directed towards the earth, the shock wave of these atomic particles from the CME interacts with earth's magnetic field to generate geomagnetic storms (disturbances) in the earth's magnetic fields. These interactions results in Geomagnetically-Induced Currents (GIC) in many electrical (and mechanical) systems. Spectacular northern and southern lights displays (Aurora Borealis) are the most visible but harmless examples of this phenomenon around the earth's poles. In periods of solar minimums, they are observed in higher latitudes near the North and South Poles but, during periods of solar maximums, they have been observed as far away south as the equatorial regions.

Although all of the effects of solar storms are not fully understood, significant research has occurred over the years to improve our understanding through extensive observations and measurements. The results from this research have also helped to improve scientists' modelling and forecasting abilities, making short and long-term predictions more reliable in the future. It is now believed that GIC in the earth caused by these solar storms can seriously affect the safety and performance of critical infrastructure assets.

Examples include high frequency telecommunication, electrical power grid, space satellites, large pipelines, railway systems, financial systems, GPS navigation and aviation just to name a few. It is believed that an extended interruption to the electrical power grid could cause extreme loss impact at the primary, secondary and tertiary levels including its societal and economic impact.



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Much has been written and there have been and continue to be many discussions and meetings among industry, business and government bodies …

Advance warnings after observation of initial events of the sun's solar flare activities and prompt precautionary actions have recently helped minimize damage to satellites, electric systems and airlines.

There have already been examples of the type of challenges that space weather can present to our modern infrastructure. Some valuable lessons were learned during the Quebec solar event of 1989, when a space storm caused a large-scale blackout in Canada.

A solar superstorm event lasting from October 22 - November 4, 2003 was another event that raised awareness, and started discussions about needed societal change. This solar storm began to reveal the potential threat to our electrical power grids and related infrastructure supported by electricity. According to the Goddard Space Flight Center, at least eight shock waves from powerful CMEs from our sun impacted earth's magnetic field. During this period billions of tons of electrified solar gas (plasma) struck earth's magnetic field. Although the field keeps the solar gas from reaching earth directly, this CME raised radiation levels in space near earth above dangerous levels for nearly two weeks.[3]

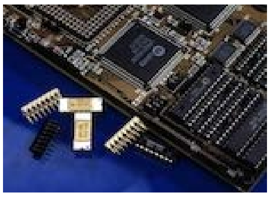
Much has been discussed and written among industry, business and government bodies to discuss the actions that could or should be taken to protect against the potential detrimental effects of this phenomenon.

3. Considering the data

Damage to major electrical equipment in the high-voltage network caused by solar storms in the past has recently raised questions about the potential damage to the more mundane electrical equipment used in our everyday lives that is connected to the 110-volt distribution network; solar storms rattle the earth's magnetic field, and that, in turn, drives currents through the long power lines and their transformers that are not always capable of withstanding the GIC. The resulting power surges can also be damaging to a wide variety of electrical devices and components.

3.1 Question of effect

Do these solar forces have an effect on electrical equipment used all around us? Can this equipment be affected by geomagnetically induced currents?



Do these solar forces have an effect on electrical equipment used all around us - equipment like motors? Communications equipment? Air conditioning equipment? Computers and computer servers? Can this equipment be affected by GIC? How can we tell? How often does the damage occur? If this type of damage is occurring, can it be prevented? And how much is it costing the consumer and insurance companies to repair?

Finally, could this be further evidence as to the type of catastrophic damage that a major solar storm could cause to the much larger electrical equipment used in in power grids? These would seem to all be good questions but difficult to answer without data previously unavailable to researchers who have been considering the bigger picture.

3.2 Organizing and assessing

Like other large property and casualty insurers, Zurich Insurance routinely analyzes statistics of insurance in North America. These are claims associated with commercial uses of all insured equipment including electrical and electronic equipment, and consider both the equipment and any resulting loss of productivity. Is there a way to compare the number of electrical losses to periods of increased solar or geomagnetically active periods in the areas where electrical losses occurred?

After attending the 2012 Electrical Infrastructure Summit in Washington DC and hearing a presentation given by Lockheed Martin, a joint project was suggested by Zurich Risk Engineering.

This project would seek to compare when and how many electrical losses occur with the amount of geomagnetic activity that occurs during active solar periods; an analysis would be performed to determine if electrical losses increased during space storms. Zurich Insurance possesses claims data with usable information dated from 1987 to the present; Lockheed Martin has expertise in analyzing when geomagnetically active periods occurred and the relative strength of solar activity over that time frame.

The research produced some new ideas:

- What effects are solar explosions having on equipment when the storms are not so strong that they cause blackouts but they are strong enough to produce GIC?
- Do space storms affect other types of electrical or electronic equipment besides large transformers and satellites?
- If they do affect other types of equipment, how can it be determined?

These questions were addressed in a joint study entitled, Assessing the Impact of Space Weather on the Electric Power Grid Based on Insurance Claims for Industrial Power Equipment [5] published in the journal *Space Weather* in August, 2014.

3.3 Affected equipment

In the noted study, a statistical analysis of over 11,000 insurance claims submitted from 2000 through 2010 for equipment losses and related business interruptions was performed.

These claims were for losses reported in North American commercial organizations and were associated with damage to, or malfunction of, electrical and electronic equipment. The statistics reflect that typical claim rates are reported at higher frequencies on days when geomagnetic activity is elevated.

See the following chart for an example of what the data show.

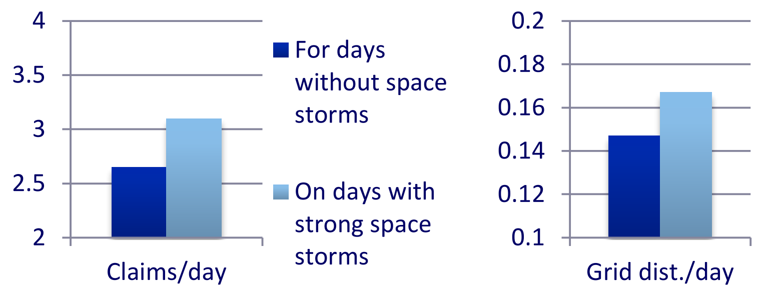


Figure 1. Insurance claims per day for electrical and electronic equipment to Zurich NA (left) [5] and the number of grid disturbances per day (right) [10]. Red bars show the average number of all claims and grid disturbances on the top 10% of most geomagnetically active days, while the blue bars show the numbers for nearby geomagnetically inactive days.

This type of comparison looks to minimize the effects of influences other than space weather – such as ordinary weather, changes in the power-grid, and change in society's use of power – thereby enabling the determination of the impacts of space weather alone.

Claims for damage due to electrical causes increased by approximately 20% for the top 5% of the most geomagnetically active days (i.e. days that have the highest energy levels measured due to impact from space weather). These claims increased by about 10% for the top third of most geomagnetically active days overall.

The study goes on to indicate that the dependence of claims rates for electrical equipment for geomagnetic activity are the same as that of past major disturbances in the US high-voltage electric power grid. When all of the available numbers were presented, there is not only a risk to the more advanced parts of national electrical grids and satellites but the effects of space weather appear to have some direct bearing on electrical equipment that we have all around us including computer servers, telecommunications equipment, generators, motors and many other types of electrical equipment.

The study concluded that there is a significant increase in claim frequencies when there is an increase in geomagnetic activity; an increase that is comparable in magnitude to the increase in occurrence of frequencies of space weather-related phenomenon.

3.4 Data effectiveness

These costs are related to real numbers occurring in real time for real equipment. The question from an insurance perspective is can steps be taken to help lower those numbers …

For this study, Senior Vice President of Zurich Machinery Breakdown, Cass Kuhlke, Zurich North America, estimates that Zurich's market share for the study period was about 8% in North America for policies covering commercially-used electrical and electronic equipment and business interruptions related to failures(5). The full sample of Zurich claims for the study used 11,242 entries that were related to electric or electronic failures over the study period 2000 to 2010.

If Zurich Insurance insured 8% of the Equipment Breakdown market during this time period, then there may have been some 140,000 electrical claims in North America that could have been examined in a similar study if all insurance companies could provide similar data. If claims increase by 20% on the most geomagnetically active days and increase by about 10% for the top third of most geomagnetically active days overall, we can only surmise how much this may be costing industry and insurers overall in an 11 year period. The amount would have to be considerable.

The Zurich Insurance-Lockheed Martin joint study explains fully how the claims data was compared to geomagnetic current data during this time period to arrive at the above conclusions. This study could lead to other questions:

- Is 8% of the market a fair representation of the entire market?
- Can we derive overall costs from this data?
- Does the damage occur due to geomagnetically induced current or from previous damage and geomagnetically induced current?

The increased damage during times of increased solar activity cannot just be ignored. These are costs related to real numbers occurring in real time for real equipment. Can steps be taken to prevent the losses or damage from occurring?

4. Dollars and data

There were specific costs associated with the claims figures from the Zurich Insurance-Lockheed Martin Study. Zurich Insurance and its affiliated companies paid out millions of dollars in claims over this 11-year period. Likewise, the owners of the equipment paid out funds in the form of insurance deductibles, amounts they had to pay towards equipment repairs prior to insurance remunerations. The costs associated with the non-reimbursed impacts of space storms appear to be very much larger than the insured assets.

4.1 Extrapolating the data

First, let us look at the insurance impact alone. The initial study could only consider claims for property damage and business interruption because the amounts of deductibles that customers paid towards the total amounts were not available for the calucations made. However, we can make some educated deductions along the following lines.

We can estimate that the average deductible for these types of property and casualty losses is 10% of the payment being made by the insurance company. During this time period, Zurich paid out approximately USD 175 million for the electrical losses used in the case study.

Using our assumption that deductibles over the period averaged 10% per loss this would bring the total amount of deductibles paid over the period to about USD 17.5 million. That would bring the total payout by Zurich and its insureds to USD 192.5 million for the period.

We also felt it would be interesting to note the average cost of these claims to the insurance company. Using the initial total number of unfiltered claims in the case study of 11,242, the average amount spent per electrical claim is USD 17,123 each.

When we examine the 8,151 “filtered” claims related to purely electrical issues only (excluding, for example, lightning, theft, flooding, fires, etc.), the amount paid out by Zurich and its insureds totals about USD 151.7 million. The average amount per claim increases to about USD 18,611 each. The types of claims reported range from damage to thermostats, phones and small motors to large motors, generators and transformers. All types of equipment are included in the survey.

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4.2 Claim payouts

Assuming Zurich held 8% of the US market during the period and our customers incurred USD 151.7 million for electrical claims associated with solar storms, it is then estimated that total losses incurred would have been about USD 1.9 billion for the entire US market over the ten year period.

The aforementioned case study concludes that the overall fraction of all insurance claims statistically associated with the effects of geomagnetic activity is 4%. This would indicate a total payout in the US only over that time period for "normal" electrical equipment related to GIC to be about USD 7.6 million annually to all insurance companies and industries.

But this does not include the costs associated with business interruptions and lost time caused by the damaged equipment. Information is available, however, that allows us to make an estimate of the overall impact.

… we are potentially looking at an average impact on the order of US$10 Billion per year each for both the US and European economies!

4.3 Overall cost to the national economy

Until now, we looked at costs only to pay for damage to equipment that was insured by one insurance company in one region of the globe and some of the business interruption costs associated with that damage when covered by an insurance policy. These costs, however, do not begin to cover the amount of anticipated losses that occur during major power outages or that would occur with a complete breakdown of the US power grid. For an idea of those types of losses, we would turn to a review of the EPRI-funded study of power-quality impacts on the US economy "The Cost of Power Disturbances to industrial & Digital Economy Companies" [(6)] and an equivalent one for the European Union countries(9).

These studies suggest that the real cost to society of electrical problems associated with space storms by far exceeds what we see in the Zurich Insurance-Lockheed Martin "snapshot of time" claims payouts results. It is hard to quantify that impact with certainty, but we can make estimates based on studies of the impacts of all power quality variations on the economy, and then taking the percentage attributable to space weather assuming that these are not substantially different in their impacts from all other issues that affect electic power supply.

One such study [(6)] for the US asked companies around the country to estimate the impacts of all power outages and power quality issues (that include voltage sags, frequency drifts, transient perturbations, and harmonics besides that standard 60 Hz voltage cycle) on their business. The estimate would include not only equipment damage, but also loss of productivity, loss of materials, problems with resumption of production, or any other impact. The study then estimated the overall impact based on the thousand respondents that participated in their survey. When correcting for inflation from 2000 to the present, the overall economic impact from power perturbations was as large as USD140 billion per year to USD230 billion per year. Another (much smaller) study [(9)] for 25 members states of the European Union estimated an economic impact (converted to dollars and corrected for inflation from 2007 to the present) upwards of USD200 billion per year.

If we consider again the results of the Zurich Insurance-Lockheed Martin Study and conclude, conservatively, that space weather is associated with some 4% of all of these impacts, we are potentially looking at an average impact on the order of USD10 billion per year each for both the overall US and European economies!

These numbers are rather uncertain because they are determined by relatively small surveys of industry and assume that space weather impacts are on average comparable to the impacts of any other issue with the continuity of stable power supplies. But we learn three important things from this:

1. Overall economic impacts of space weather on only electric power supply are worth paying attention to,
2. The existence of such impacts lets us begin to study what might happen if the Sun generated even larger storms,
3. The loss of insured hardware is only a very small fraction of the overall losses to industry through the interruption of their regular operations.

There is a considerable cost to protect against the effect of geomagnetically induced currents or electro-magnetic pulses.

5. Using the data

After examining the hazard and risks associated with solar storms, the data used to examine the risk, the effectiveness of that data, the type of equipment affected and the dollar amounts that could be at stake, the question becomes, what do we do with this information? Can it help make a difference in how our society prepares for such an event?

5.1 Assumed costs versus probable costs

Over ten years, USD 1.9 billion may not sound like much to the property and casualty insurance industry, when compared to all claims paid during that time, but there are other factors to consider. These are the probable known costs through insured property. The total damage being caused to businesses is much higher through uninsured or unclaimed damage, business interruptions and productivity losses. Why suffer these types of losses when actions can be taken to reduce them? There are ways to protect equipment against this type of harmful electrical current.

Our study only considered claims in one small sector of one company – Equipment Breakdown for Zurich Insurance covers 8% of the equipment breakdown market. It is suspected that there are untold thousands of claims under other business segments, primarily property insurance coverage, that are listed as fire or explosion that could have very well been caused by damage related to overheating due to the effects of GIC.

That is one of the difficulties of studying the effects of damage from space weather – much of the damage occurs over time and is cumulative.

Damage from space weather is also occurring concurrent with the normal "runtime" damage that occurs when operating any type of mechanical/electrical equipment over a period of time. When the equipment finally does break down, it can be very difficult to determine if the initiating cause of breakdown was from GIC from space weather or just overheating from long use, poor maintenance or some other mechanical issue.

Finally, bringing the scientific community and industry together on this matter is proving to be somewhat problematic.

Scientists have the evidence and the facts; indeed, even history appears to agree that our planet will eventually be subjected to a possibly crippling solar event sometime in the relatively near future.

5.2 Waiting, watching, thinking

The "Big One" has not occurred in modern times – not yet. An entire Canadian provincial electrical grid was knocked offline in 1989 for fourteen hours but they recovered quickly and no major property damage was experienced. There was several million dollars in business income lost and many frayed nerves but the province persevered and learned much.

South Africa lost 14 of its 400 kV transformers over a two-week period during a drawn-out solar event in 2003 – a major inconvenience to an entire country for a few days and parts of the country for months but they did manage to endure and recover from that episode as well.

Nothing like the worst known historical case – the Carrington Event of 1859 – has occurred and caused damage to our modern-day electrical infrastructure. However, many scientists believe an event like this one could dwarf the more recent moderate solar events and cause catastrophic damage to whatever part of the globe is directly affected.

The issue in trying to decide to take steps to protect our electrical equipment from this type of hazard appears to be overall cost. There is a considerable cost to protect against the effect of GIC or electromagnetic pulses. Protective devices such as surge suppression protection has been developed and tested that can protect all types of electrical equipment against these types of damaging electrical currents but there can be substantial costs to retrofitting existing equipment with the devices they need for protection.

Adding the protection during manufacturing also adds cost to the construction of the equipment. If one manufacturer adds the device and has to raise the price to maintain profit levels while another manufacturer decides to not add the device and continue to sell the equipment at the original price, inequities develop in the market and unprotected devices will most likely continue to be installed.

If an insurance company decided to recommend to their customers that the protective devices be installed to protect their investment on critical equipment or raise the premiums on that equipment, many customers may simply move to other insurance companies that did not recommend such a requirement. This can occur when such protective equipment is not mandated by construction codes or laws.

As described in a 2013 AON Benfield report on geomagnetic storms (AON Benfield, January 2013)[(7)], it would be very difficult for insurance companies to try to price this type of risk for several reasons:

- Most risk professionals do not have a complete understanding of the technical complexities of this hazard and the vulnerability of the components of equipment to geomagnetically induced currents
- There is no industry-wide definition of an industry-wide loss occurrence from extreme space weather that has caused a large scale economic and social disruption and recovery issue on insurance policies
- The majority of direct and contingent business interruption contracts still depend on the loss of use of property due to physical damage
- The material damage and replacement costs from the solar event would be a small component of the total losses with the nature of the larger losses being potentially much more exotic due to the cause of damage

… solar storms are a natural reoccurring activity of our solar system's sun and this planet will be affected in some manner.

6. Decisions

6.1 Where to begin

It would appear then that all stakeholders are at an impasse – industry, government, science, insurance and society in general. Each group is aware that the hazard exists; solar storms occur routinely and cyclically. Each group knows that strong solar storms can cause damage to our electrical equipment and, as shown by the recent Zurich Insurance-Lockheed Martin Study, the damage occurs to all kinds of electrical equipment, not just large transformers and power grids.

We know that a very strong storm directly affects the earth about once every 150 to 200 years so our planet may be due for the next one; a storm strong enough to allow people to be able to see the Aurora Borealis near the equator like they did in 1859; a storm strong enough to set equipment attached to electrical lines on fire much like what happened to telegraph lines in use at the time.

It is fairly certain that this type of event will happen again; not maybe, not might, but will; solar storms are a natural reoccurring activity of our solar system's sun and this planet will be affected in some manner.

Recovery from another Carrington-type event could take a very long time.

Step-down Transformer (Photo by Zurich RE Pat Dunphy – 20131022)

The primary stakeholders in this discussion know that the equipment a modern society depends on can be protected from the effects of this phenomenon. The US grid can be protected by the installation of surge suppressors in strategic equipment. These same groups also know that it would cost taxpayers and industry a great deal of money to make these changes.

The way to mandate that protective equipment be installed would be to pass laws that institute rules to require those changes. The only way to see such laws passed, however, would be to have enough people understand the consequences of not passing them, what the potential costs can be if such a superstorm occurs and the at-risk equipment and systems are not protected.

Many of these stakeholders know how long it takes to replace a 500 kV transformer – the kind you find in our electric power grid. It can take up to 12 to 18 months to replace one of these large transformers because they are no longer built in large quantities in the United States. Is it even possible to imagine trying to replace 200 of these transformers after a major solar storm event? This issue alone might make it possible to contemplate why such an event could dwarf an event like Superstorm Sandy or Hurricane Katrina. When we now consider how much damage is believed to have been caused or is being caused by normal solar cycles, it may be almost impossible to imagine the amount of damage that could occur to all of the types of electrical equipment in use in our everyday lives. Recovery from another Carrington-type event could take a very long time.

6.2 The debate

There are many facts known about the effects of space weather and discussions continue. The known facts are discussed and theories debated in industry and manufacturing offices, at utility offices and power plants, by scientists and engineers and even in the Halls of Congress in the US and the House of Commons in the UK. Many scientists and engineers discuss ways to monitor the sun and measure the solar cycles so they can detect the strength of the solar waves and resulting coronal mass ejections that could possibly hit the earth. Insurance companies debate whether this type of damage would be a covered loss or not.

If it was excluded from policies, how could it be proven the damage came from GIC when the damage looks like any other kind of electrical system damage?

7. Conclusion

We live in an interconnected world.

Photo authorized by Smithfield Foods, Inc. - 20100409

We live in an interconnected world. It now appears that our power grids are not the only equipment at risk here during solar-driven space storms; much of the electrical equipment we use in our everyday lives appears to be at some risk of damage from a major solar event. Regardless of what part of the planet is most affected by the next major solar event, those effects will most likely be felt around the globe in one way or another. If we understand the technical aspects of this threat and interconnected vulnerabilities in various industry segments, such as power distribution, electric utilities, oil and gas pipelines in the energy sector and technology exposures, then this issue could become a top risk management priority. It could also become a national defense and homeland readiness issue due to the damage such a storm could inflict on a country's electrical infrastructure and society.

The world doesn't have to wait for the worst to happen. Studies by other insurance companies have been published, scientists and politicians from around the planet have been sounding an alarm in their respective countries and studies like the one recently published by Lockheed Martin and Zurich Insurance continue to add more information to the ever increasing evidence of this threat. What comes next?

Is it possible to follow up on all of these studies and warnings with a joint effort? Can there be an assessment of our nations' leaders' awareness of this threat, readiness, prioritization of their mitigation strategies and action plans? This would require continuing the high-level dialog with a variety of stakeholders and participation in workshops and other forums.

Studies of protective equipment must be continued with testing on installed equipment to occur that proves the theories our engineers and scientists tell us about. The world can prepare for another Carrington event because the technology and the know-how are available. Perhaps insurance companies can provide some incentives for those that take on the burden of these tests in a partnership-type arrangement since we are protecting both of our interests.

We have knowledge and it appears we have been warned. The question is – do we have the will to follow through on that knowledge?

> Regardless of what part of the planet is most affected by the next major solar event, those effects will most likely be felt around the globe in one way or another.

8. Glossary

Carrington Event: A powerful geomagnetic solar storm in 1859 during solar cycle 10. A set of solar coronal mass ejections interacted with Earth's magnetosphere and induced one of the largest geomagnetic storms on record. The associated "white light flare" in the solar photosphere was observed and recorded independently by English astronomers Richard C. Carrington and Richard Hodgson.

Coronal Mass Ejection (CME): Large eruption of magnetized plasma from the Sun's outer atmosphere, or corona, that propagates outward into interplanetary space. The CME is one of the main transient features of the Sun. Although it is known to be formed by explosive reconfigurations of solar magnetic fields through the process of magnetic reconnection, its exact formation mechanism is not yet understood.

Geomagnetically Induced Current (GIC): A manifestation at ground level of space weather. During space weather events, electric currents in the magnetosphere and ionosphere experience large variations, which manifest also in the Earth's magnetic field. These variations induce currents (GIC) in conductors operated on the surface of Earth. Electric transmission grids and buried pipelines are common examples of such conductor systems. GIC can cause problems, such as increased corrosion of pipeline steel and damaged high-voltage power transformers. GIC are one possible consequence of geomagnetic storms, which may also affect geophysical exploration surveys and oil and gas drilling operations.

Electromagnetic Pulse (EMP): A broadband, high-intensity, short-duration burst of electromagnetic energy. Such a pulse may originate from the electromagnetic radiation from a nuclear explosion caused by Compton-recoil electrons and photoelectrons from photons scattered in the materials of the nuclear device or in a surrounding medium. The resulting electric and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges. May also be caused by nonnuclear means such as from the CME produced during a solar space storm

Power Grid: A system of high-voltage cables and transformers by which electrical power is distributed throughout a region

Solar Storm: a sudden temporary outburst of energy from a small area of the sun's surface —manifesting as either a solar flare or coronal mass ejection, or often both.

9. References

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