Solar storms and their impacts on power grids - Recommendations for (re)insurers

Romain LAUNAY, Advisor to the Chairman and CEO, SCOR
Club APREF, 20 May 2014
Solar storms and their impacts on power grids
Recommendations for (re)insurers

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Solar storms: an issue which is hard to grasp for (re)insurers

- ‘Exotic’ nature (vs well-known perils such as hurricanes or earthquakes)

- ‘Emerging’ risk (even though solar storms have arguably existed long before any human being was there to watch)

- Low probability, high severity event. Similar to meteorites?
Solar storms: a credible threat?
## A multi-faceted physical phenomenon

<table>
<thead>
<tr>
<th></th>
<th>Solar flares</th>
<th>Solar energetic particles</th>
<th>Coronal mass ejections (CMEs)</th>
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<tbody>
<tr>
<td><strong>Physical nature</strong></td>
<td>X-rays, extreme UV, gamma rays, radio burst</td>
<td>Energetic protons and ions (typically 10 to 100 MeV, but up to 20 GeV)</td>
<td>Vast clouds of seething gas, charged plasma of low to medium energy particles with imbedded magnetic field</td>
</tr>
<tr>
<td><strong>Time needed to reach the Earth</strong></td>
<td>8 minutes (speed of light)</td>
<td>15 minutes to 24 hours</td>
<td>1 to 4 days</td>
</tr>
<tr>
<td><strong>Duration of the interaction with Earth</strong></td>
<td>Minutes to hours</td>
<td>Several days</td>
<td>One day or two</td>
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Direct impacts on human activities

- The modification of the characteristics of the ionosphere caused by solar storms affects electromagnetic signals going through it. This may result in disruptions to:
  - Radio communications (including GPS signals).
  - Radar systems

- Solar energetic particles and nuclear radiation associated with them may hurt:
  - Solar panel arrays of satellites
  - Electronics
  - Spacecraft and aircraft crew and passengers

- Geomagnetic field distortions may affect systems using compasses, notably:
  - Spacecraft
  - Ships

- Electric currents induced in the ground by CMEs may cause disruptions to:
  - Power grids, potentially resulting in outages
  - Railway signalling systems
  - Oil and gas pipelines
Ground electric fields in the UK may rise to 5 to 10 V per km during solar storms.

Thus the difference of electric potential at the ground between the two endpoints of a 100 km transmission line can typically reach 1 000 V.
From CMEs to GICs (Geomagnetically induced currents)
Impact on power grids

- GICs in electric grids may reach high values (300 A measured in a transformer neutral in Sweden in 2000)

- Possible impact on power grids:
  - Overheating of transformers, damaging them up to the point of failure
  - Increase of the reactive power consumption of transformers => voltage collapse
  - Harmonic currents may cause the tripping of protective systems on the grid => voltage collapse
Real-life examples from past events

- **1859: Carrington event**
  - Auroras turning night to day as far south as Panama
  - Unusable telegraph systems across Europe and North America

- **May 1921**
  - The entire signal and switching system of the New York Central Railroad below 125th street put out of operation

- **March 1989**
  - Loss of electric power to more than 6 million people for 9 hours in Quebec

- **2003 ‘Halloween’ storm**
  - Blackout of less than an hour in Sweden affecting around 50,000 customers
  - Damage to twelve transformers in South Africa necessitating their removal from service
Some of the (many) factors influencing the impact of solar storms on power grids

- Geomagnetic latitude
- Ground conductivity
The picture resulting from the combination of all risk factors is complex
The consequences of a prolonged blackout scenario

- **Erroneous tripping of protective relays leads to collapse of electricity grid**
  - Within seconds, a dramatic fall in electrical energy reliant services
    - Lighting fails
    - Financial services severely degraded
      - Road
      - Rail
      - Air
    - Transport curtailed
    - Few remaining communication services
    - Elevators fail
  - Within minutes to hours, decline in all utility services
    - Water & sanitation services fail
    - Dramatic decline in emergency services
      - No emergency calls or response
        - Increased house fires
        - Manufacturing plants shut
        - Fuel & gas shortages
        - Food spoilage
        - Retail trade halted or curtailed
          - Restaurants
          - Hotel
          - Entertainment
        - Tourism trade severely curtailed
      - Within minutes to days, secondary services decline or disappear
The severe blackout scenarios

- 2004 report from the US National Academy of Sciences:
  - a repeat of the May 1921 solar storm would leave 130 million people without power in the US for an extended period of time, with economic costs skyrocketing to USD 2 trillion for the first four years and recovery taking up to ten years.

- 2013 study by AER:
  - a Carrington-level storm would deprive between 20 and 40 million people of electricity in the US, with durations of 16 days to one to two years, with economic costs estimated at $0.6-2.6 trillion.

- Figures presented by Swiss Re in 2012:
  - Economic losses from a Carrington-like event affecting the US and Canada would range between USD 129 bn (best case) and USD 163 bn (worst case).
Milder scenarios

- 2012 study by the UK National Grid:
  - a Carrington-like solar storm, would only result in “temporary localized power interruptions”. Around six super grid transformers in England and Wales and a further seven grid transformers in Scotland could be damaged and could fail.

- February 2012 report from NERC:
  - “NERC recognizes that other studies have indicated a severe GMD event would result in the failure of a large number of EHV transformers. Based on the results of this chapter, the most likely worst-case system impact from a severe GMD event and corresponding GIC flow is voltage instability caused by a significant loss of reactive power support and simultaneous to a dramatic increase in reactive power demand”.

How to evaluate the return period of a Carrington-like solar storm?

- Physical model of solar eruptions
- Ice cores studies
- Extrapolation from smaller events
- Use of historical records of visual observations of aurora borealis
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Long-term measures to reduce the vulnerability of power grids

- Replace transformers with more resilient ones
- Increase spare holdings
- Fit devices in order to block the propagation of DC currents in the grid
- Adjust protection systems against harmonics in order to avoid unnecessary tripping

Modelling tools are essential in order to identify vulnerability hotspots and focus on them

UK Model: ‘Carrington’ = Oct 2003 x8
Operational mitigation strategy of National Grid:
- all circuits returned to service and switched in
- all supergrid transformers connected in order to spread the load
- substations run solid in order to maximise the connectivity of the grid
- extra generation instructed to synchronise
- extra reactive support made available
Industry Advisory
Preparing for Geo-Magnetic Disturbances

NERC and Regional Entities are monitoring the threat to bulk power system reliability caused by damaged equipment from Geo-Magnetic Disturbances. This Advisory provides industry with a set of operational and planning actions to prepare for the effects of severe Geo-Magnetic Disturbances on the bulk power system.

143 FERC ¶ 61,147
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 40
[Docket No. RM12-22-000; Order No. 779]
Reliability Standards for Geomagnetic Disturbances
(Issued May 16, 2013)
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Solar storms are largely absent from insurance policy wording

- Insurance contracts “are unlikely to have been drafted with any degree of consideration for a loss occurrence of the type initiated by extreme solar weather” (AON Benfield, January 2013).

- Consequently:
  - Solar storms would arguably be covered by ‘all risks’ policies
  - Solar storms would arguably not be covered by ‘named perils’ policies, unless they indirectly provoke one of the perils named in the contract (fire, explosions, etc.).
Impact on property covers

- Property insurance policies may be triggered by a major solar storm. In that case they may cover:
  - Physical damage incurred by the insured
    - TSO: USD 10 million per transformer
    - Large corporate: e.g. aluminium melting furnaces
  - Business interruption caused by such damage
  - Business/service interruption caused by physical damage incurred by a supplier/service provider/client
    - Accumulation risk
    - Waiting period hurdle may be easily overcome
    - However, the limit is typically 10% to 15% of the limit applicable to property and BI

- Wider impacts in case of a prolonged blackout:
  - Looting
  - Fires spinning out of control, etc.
Impact on liability covers

- At first glance, ‘Force majeure’: unforeseeable and extraordinary event beyond the reasonable control of anyone.

- However:
  - Plaintiffs may try to show that the risks posed by solar storms to power grids were well known and that mitigation measures were available.
  - They may challenge the idea that solar storms are unpredictable by pointing at existing space weather forecasts. They may point at deficiencies in operational procedures.
  - They may refer to the Advisory issued by NERC in May 2011, even if it is non-binding. In the future, they may refer to binding standards.

- Risks for (re)insurers limited by two factors:
  - small number of generating companies and TSOs in a given area (exposure capped by limit x number of insureds).
  - liability insurance policies for generating companies and TSOs usually only cover liability arising from bodily injury, personal injury and property damage.
Recommendations for (re)insurers: risk management

- Include solar storms in the list of emerging risks to be monitored.

- Map your exposure / Build extreme scenarios

- Prepare for the fact that in the future supervisors may ask reinsurance companies to consider a one in 200-year solar storm as part of Solvency 2-compliant internal models / Engage in a dialogue with modelling firms.

- Monitor new results coming out of ongoing research.
Recommandations for (re)insurers: underwriting (1)

- When underwriting insurance policies covering generating companies or TSOs in countries above a certain geomagnetic latitude:
  - Check that they have taken measures to reduce their vulnerability to solar storms.
  - Check whether they have developed modelling tools.
  - Check that they receive and check space weather forecasts.
  - Check that they have operational procedures in place in case a major solar storm should approach the Earth.
  - In the US, as soon as NERC Reliability Standards are applicable, make sure that coverage is subject to the respect of these standards by operators.
Recommandations for (re)insurers: underwriting (2)

- When underwriting property insurance covers for manufacturers with high potential physical damage in case of a prolonged power blackout, encourage them to receive space weather forecasts and set up operational procedures.
- Monitor and manage the accumulation risk linked to service interruption extensions.
- When assessing the risk of cascade triggering of CBI covers along supply chains, take prolonged blackout scenarios into account.
- Review insurance policy wording. In particular:
  - clarify the ‘physical damage’ requirement clause, especially with reference to a scenario where the grid would collapse without incurring any physical damage in the strict sense.
  - clarify the notion of ‘supplier’ in service interruption extensions.
### Recommendations for (re)insurers: Governmental affairs

- Draw the attention of governments to the importance of maintaining current forecasting capabilities.

- Draw the attention of governments to the importance of funding research.

- Promote awareness of solar storms by non-US governments and power grid regulators of countries above a certain geomagnetic latitude. Promote the inclusion of risks from solar storms in grid reliability standards.
Bibliography:

- Aon Benfield (January 2013). Geomagnetic storms.
- LLoyd's, & AER. (2013). Solar storm Risk to the north American electric grid.
- NERC (February 2012). Effects of Geomagnetic Disturbances on the Bulk Power System.
- Royal Academy of Engineering (February 2013). Extreme space weather: impacts on engineered systems and infrastructure.
Solar storms and their impacts on Satellites

Club APREF
May 20, 2014

Didier PARSOIRE
Chief Underwriting Officer, Space – SCOR Global P&C
## Solar Weather: Various phenomena

<table>
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<tr>
<th>Phenomenon</th>
<th>Typical solar event</th>
<th>Description</th>
<th>Impact on</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomagnetic Storms</td>
<td>CME, solar wind</td>
<td>Disturbances in the geomagnetic field caused by gusts in the solar wind that blows by Earth.</td>
<td>Power systems, Spacecraft operations, Satellite navigation, low-frequency radio navigation</td>
<td>G1 (Minor) to G5 (Extreme)</td>
</tr>
<tr>
<td>Solar Radiation Storms</td>
<td>CME, Solar flares</td>
<td>Elevated levels of radiation that occur when the numbers of energetic particles increase.</td>
<td>Biological (high exposure for astronauts, crew and passengers of high-flying aircraft) Satellite operations and HF communication</td>
<td>S1 (Minor) to S5 (Extreme)</td>
</tr>
<tr>
<td>Radio Blackout</td>
<td>Solar flares</td>
<td>Disturbances of the ionosphere caused by X-ray emissions from the Sun.</td>
<td>HF communications, Low-frequency navigation signals</td>
<td>R1 (Minor) to R5 (Extreme)</td>
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## Solar Storms & Hazards on Satellites & Space activities

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<tr>
<th>solar event</th>
<th>Manifestation</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronal Mass Ejection (CME)</td>
<td>Low energy Electrons (KeV)</td>
<td>Electrostatic Discharge (ESD) outside of Spacecraft</td>
</tr>
<tr>
<td>or Solar wind</td>
<td></td>
<td>Arcing of Solar Array</td>
</tr>
<tr>
<td>Solar flares</td>
<td>High proton &amp; ion fluxes</td>
<td>Upset of Spacecraft operations (&quot;phantom&quot; commands)</td>
</tr>
<tr>
<td></td>
<td>Long period of High Flux penetrating high energy</td>
<td>Solar Array performance</td>
</tr>
<tr>
<td></td>
<td>electrons (MeV - GeV)</td>
<td>Degradation (3-5% in a day)</td>
</tr>
<tr>
<td></td>
<td>Elevated levels of radiation</td>
<td>Fogging of optical sensors</td>
</tr>
<tr>
<td></td>
<td>Disturbances of the ionosphere caused by X-ray</td>
<td>Charging and internal ESD</td>
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<tr>
<td></td>
<td>emissions from the Sun.</td>
<td>Damage to electronics</td>
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<td></td>
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<td>Insulation failure</td>
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<td></td>
<td></td>
<td>Biological impact to Astronauts, especially during Extra-vehicular</td>
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<tr>
<td></td>
<td></td>
<td>Activities (EVA)</td>
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<tr>
<td></td>
<td></td>
<td>Erroneous GPS signals for navigation and other GPS-related services</td>
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</table>

Effects on satellite services range from temporary outage to partial or total failure.
Mitigation Measures

- At the difference of ground systems, satellites are expected to experience severe environment in space and are designed accordingly
- Mitigation by Design
  - Faraday Cage against electrical charge
  - Radiation hardened components
  - Electrical barriers
  - Equipment Redundancy
  - Majority vote
- Mitigation through Operations
  - Early warning (few hours to few days) provided by NOAA / ESA
  - Turn-off non-critical systems onboard satellite
  - Reorient Solar panels to minimize solar flux impact
Low Peak doesn’t mean low Risk

- Solar cycle 24 peak (2013) much lower than prior one
- Solar peak is more a measure of frequency than severity of events
- Particles / Radiation emissions are not necessarily phased on peak
Solar storm impact on Satellites / Space-based operations: Consequences on human activities

- Disruptions of satellite communication services
  - Telecommunication services
  - TV and Radio broadcasting
  - Direct-to-home TV

- Disruption or alteration of Navigation signals (GPS)
  - Aircraft navigation including precision landings
  - Road/maritime navigation services
  - Oil & gas: offshore platforms positioning
  - Financial transactions relying on GPS signals for time-stamping

- Radiations
  - Health of Astronauts
Risk Assessment

- Satellites & Space operations are a relatively new activity with limited experience on extreme solar events

- Carrington Event
  A repeat of the 1859 event could produce a potential economic loss of USD 44 billion for lost satellite transponder revenues plus about USD 24 billion for the replacement of geosynchronous satellites (oldenwald et al., 2006)
Space Insurance & solar storms

- **Space Policies**
  - “Launch plus one year” Policies: cover launch, commissioning and initial In-orbit operations
  - “In-orbit life” Policies: renewable 12 months policies covering operations over the satellite lifetime (typically 15 years)
  - Due to the nature of space operations (no repair, potential catastrophic failures), cover is a true “all risks” Policy covering damage, physical loss, failure, faulty design, loss of performance, etc.
  - Solar storms are in the realm of expected events for a satellite and as such are not excluded

- **In-orbit experience**
  Solar storm origin always difficult to prove – A few examples:
  - 1994: Intelsat K, Anik E1 & Anik E2 all experienced failure on same day.
  - 1996: Anik E1 power loss (USD 142m claim)
  - 1997: Telstar 401 (USD 132m claim)

- **Lloyd’s RDS scenarios (2013 revision – under evaluation in 2014)**
  1) **Solar energetic Event** (assumed to be a 1-in-100 years event)
     - large solar flare impacting solar arrays performance of all live insured satellites
     - Calculated as 5% of aggregate value of all GEO satellites
     - Current insured value in orbit ca. USD 24,5 Billion => scenario value: ca. USD 1.2 Billion
  2) **Space weather design deficiency** (assumed to be a 1-in-50 years event)
     - Add four largest lines for a given satellite type among predetermined satellite types
     - Estimated market cost for this scenario: ca. USD 1.7 billion
Conclusion

- Satellite operations are a relatively new activity with limited return of experience as regard severe solar events.

- Satellites are designed to sustain severe space environment, including solar storms up to a certain degree.

- Given their greater reliance on satellites, terrestrial activities and our way of life would be significantly impacted by any severe disruption of satellite systems.

- Insurance is covering losses due to Solar storms with no limitation.

- Cat Exposure assessment is currently done through rather simple aggregation scenarios (no stochastic model) - According to these scenarios, an extreme event would largely exceed the Space Market annual premium.

- Increased awareness of solar events impact on ground risks should allow to improve modeling, benefiting to the space insurance market as well.