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Impacts of solar storms on energy and communications technologies

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ABSTRACT

The sun brings and gives light and warmth to both the living and non-living on the earth, but it has a temper too. Solar flares, eruptions and other sun storms can have catastrophic impacts to technological systems around or on the earth. They have been known to knock out satellites, power supplies, communications and navigation systems. Damage to these systems can result in secondary effects that can disrupt virtually every major infrastructure dependent on them, including transportation, security and emergency response systems, telecommunications and other wireless networks and electronic equipment which can lead to significant economic losses. This article dissects and analyzes the various threats created by solar storms to electronic communications and electrical systems. Finally, the necessary precautions to be taken to reduce the impacts of the solar threats and hence the associated economic losses are mentioned as the society now becomes more dependent on high tech innovations that are most vulnerable to solar storm activity.

Keywords: Solar storms, electronic communications, power grids, economic losses, magnetic energy, electron density.

INTRODUCTION

The earth is subject to an 11- year of periods of increased solar activity. That is, it undergoes a 22 year cyclical pattern of magnetic poles reversibility, comprising of two 11 years solar cycle phase (Davies, K., 1990). In the first phase magnetic poles reverses their polarity and in the second phase reverses back to original polarity (Harsh .B, and et al, 2012). They are associated with visible sun spots on the surface of the sun which begins with thermonuclear explosion on the sun that swell up and burst open on the sun's surface, releasing radiation and charged particles trapped in the solar wind. The charged particles have a speed of 4 million mph when they reach the earth.

Solar storms can disrupt communication and navigational equipment, damage satellites and even cause blackouts by damaging power plants and electrical grid components.

In 1972, AT and T had to redesign its transatlantic cable power system after a major solar flare that made telephone communication impossible.

Solar storms consist of three major components; solar flares, solar proton events (SPEs) and coronal mass ejections (CMEs).

(i) Solar Flares

Solar flares are the most violent events on the surface of the sun. They occur when the energy stored up in the sun's magnetic field is suddenly released, or converted from magnetic energy into heat energy and motion; approximately 8 minutes after they had occurred, a powerful burst of electromagnetic radiation in the form of x-ray, extreme ultra-violent rays, gamma ray radiation and radio burst arrives at earth. The ultra violent rays heat the upper atmosphere which causes the outer atmospheric shell to expand. The x-rays strip electrons from the atom in the ionosphere producing a sudden increase in the electron density (Marusek, J.A., 2007).

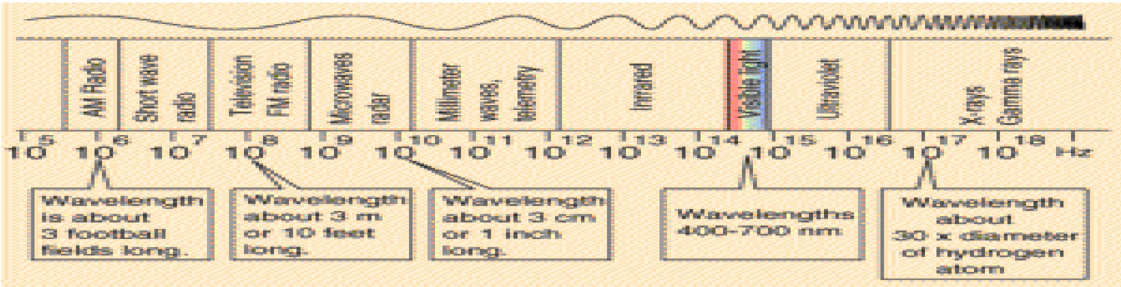


Figure 1: The Electromagnetic Spectrum.

Solar flares are classified according to their brightness in the x-ray wavelength into 3 categories (Marusek, J.A., 2007):

(A) X-class flares that are major events which can trigger worldwide radio blackouts and radiation storms in the upper atmosphere.
(B) M-class flares that are medium-sized which can cause brief radio blackouts in the polar regions and,
(C) C-class flares that are very small and can produce few noticeable effects on earth.

Another classification is based on Hα spectral observations that use intensity as well as emitting surface (Harsh, B and et al., 2012) into f - fair, n - normal and b – brilliant.

Table 1: Classification of Solar Flare Intensity

Class	Peak flux (WM^{-2}) (100-800 Pico meter x-rays near earth)	Class	Peak Flux (WM^{-2}) (100-800 Pico meter x-rays near earth)
M_1	$1x10^{-5}$ WM^{-2}	X_1	$1.0x10^{-4}$ WM^{-2}
M_2	$2x10^{-5}$ WM^{-2}	X_2	$2.0x10^{-4}$ WM^{-2}
M_3	$3x10^{-5}$ WM^{-2}	X_3	$3.0x10^{-4}$ WM^{-2}
M_4	$4x10^{-5}$ WM^{-2}	X_4	$4.0x10^{-4}$ WM^{-2}
M_5	$5x10^{-5}$ WM^{-2}	X_5	$5.0x10^{-4}$ WM^{-2}
M_6	$6x10^{-5}$ WM^{-2}	X_6	$6.0x10^{-4}$ WM^{-2}
M_7	$7x10^{-5}$ WM^{-2}	X_7	$7.0x10^{-4}$ WM^{-2}
M_8	$8x10^{-5}$ WM^{-2}	X_8	$8.0x10^{-4}$ WM^{-2}
M_9	$9x10^{-5}$ WM^{-2}	X_9	$9.0x10^{-4}$ WM^{-2}

Source: Ref.5

(II) Solar Proton Events (SPEs)

Solar proton events are high energy cosmic rays (protons and ions) having energies ranging from 10MeV to 100MeV. Very energetic SPEs are also capable of generating near relativistic protons in the order of 20Gev (Marusek, J.A., 2007).

Table 2: Arrival time of protons based on energy

Energy	Velocity (speed of light)	Arrival time
1 MeV	0.46c	2.9 hours
10 MeV	0.145c	49 minutes
1000 MeV	0.429c	11.1 minutes
1 GeV	0.875c	1.2 minutes

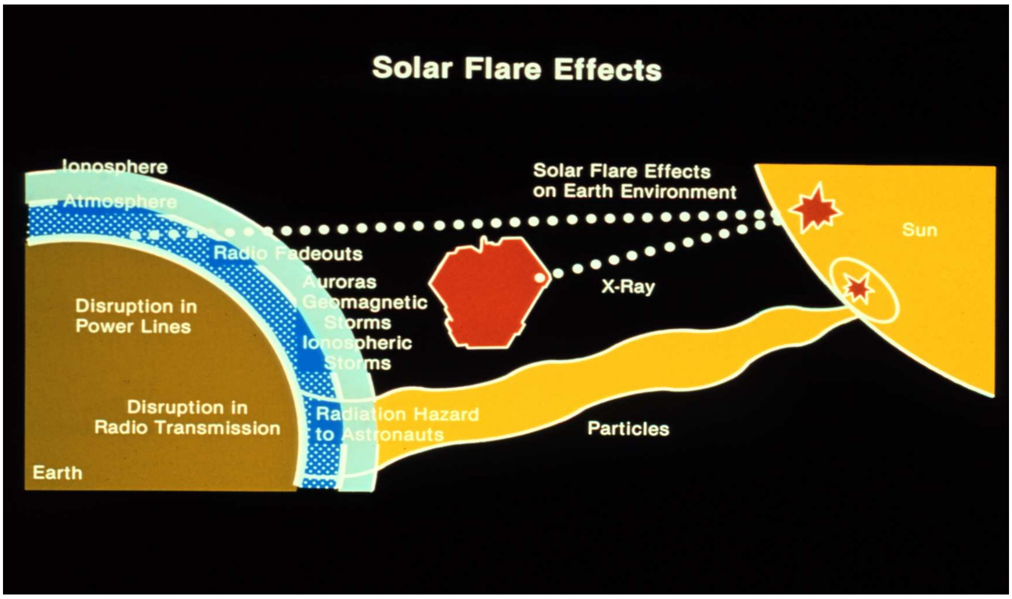
Source: Ref.5

Solar proton events produce satellite disorientation, spacecraft electronics damage, spacecraft solar panel degradation, extreme radiation hazard to astronauts, launch payload failure, high altitude aircraft radiation, shortwave radio fades and disruption in polar regions, ozone layer depletion, cardiac arrest, dementia and cancer (Marusek, J.A., 2007).

High – energy protons in SPEs have been known to produce ultraviolet auroras, invisible to the human eye when they collide with earth's atmosphere producing nitrates by-products that finally settle on the planets surface and can be detectable in the ice cores.

(III) Coronal Mass Ejections (CMEs)
A coronal mass ejection is an ejection of materials from the solar corona. It occurs when a large bubble of plasma escapes the sun's gravitational field and travel through space to the earth at high speeds over the course of several hours. Its arrival time is 2 to 4 hours (Davies, K., 1990). The ejected plasma consists primarily of electrons and protons (in addition to small quantities of heavier elements such as helium, oxygen and iron), plus the entraining coronal magnetic field. CMEs can cause shock waves in the thin plasma of the heliosphere, launching electromagnetic waves and accelerating particles to form showers of ionizing radiation. When CMEs impacts the earth's magnetosphere, it temporarily deforms the earth's magnetic field, changing the direction of compass needles and inducing large electrical ground currents in earth itself, a process called geomagnetic storm.

CMEs impacts can induce magnetic reconnection in earth's magnetotail launching accelerating particles (protons and electrons) towards earth's atmosphere, where they form the aurora.



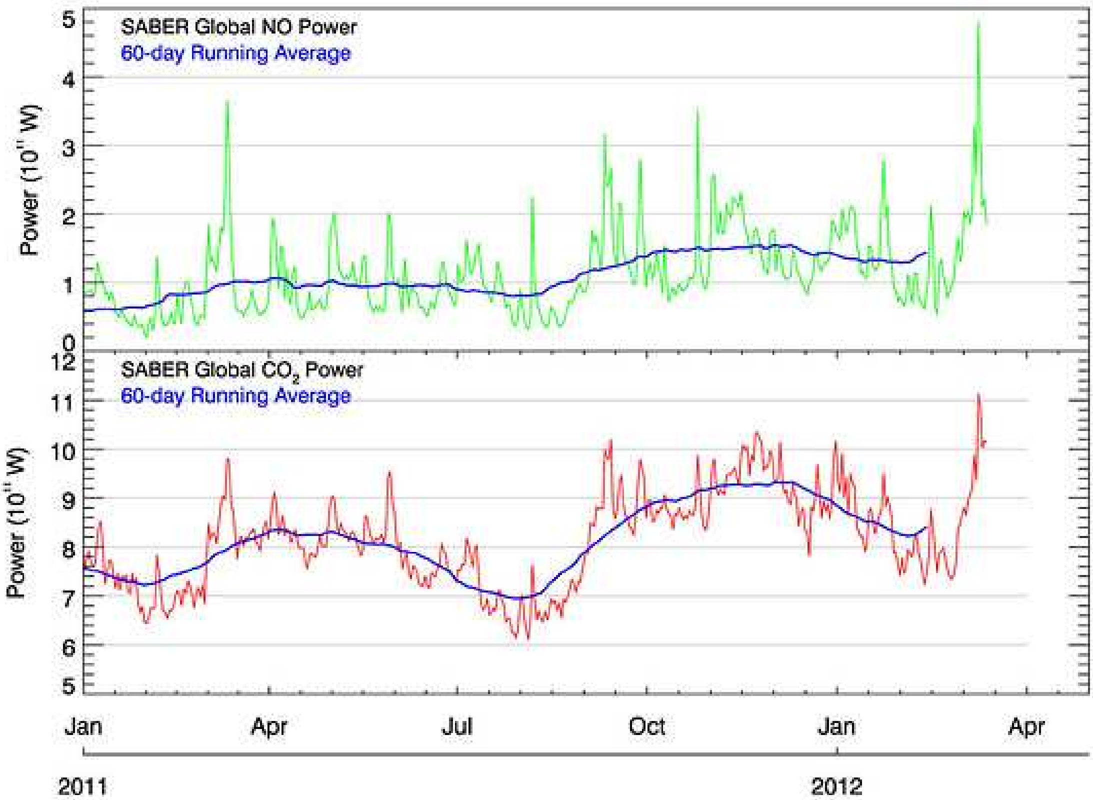


Figure 2: Solar flare effects on earth (Ref.12)

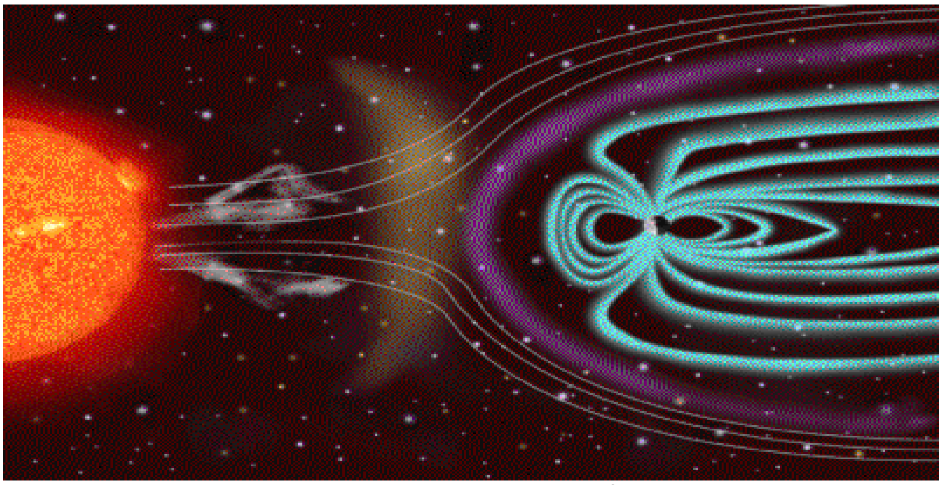


Figure 3: coronal mass ejection (Ref.10)

2.0 RECORDED EVENTS

It has been established that solar activity can prompt space weather changes that have impacted technological systems.

● From August 28th until September 2, 1859, numerous sunspots and solar flares were observed on the sun, the largest flare occurring on 1st September. A massive coronal mass ejection headed directly at earth due to solar flare and made it within eighteen hours.

● On September 1-2, the largest recorded geomagnetic storm occurred, as recorded by Colaba observatory near Bombay, India. There are records in Boston that the light was so bright that even at 1:00am it was possible to read a newspaper without any other source of light.
● The combination of the solar flare and coronal mass ejection caused a geomagnetic storm that created strong enough currents in certain long telegraph wires, in both United States and Europe, where induced emf was experienced shocking telegraph operators and causing fires
● On March 13th, 1989 a severe geomagnetic storm caused the collapse of Hydro-Québec power grid as equipment protection relays tripped in a cascading sequence of events. Six million people were left without power for nine hours, with significant economic loss. The storm even caused auroras in Texas.
Geomagnetic storms and their impacts on power grids have been widely studied. Its impacts on North American power grids occur at disturbance of around 500nT/minutes. Whereas the magnitude of effect in 1972 was greater than 200nT/minutes. The disturbances on 14th may, 1921 is considered as largest storm of the previous century (Harsh, B and et al., 2012).
● In August 1989, another storm affected microchips, leading to a half of all trading on Toronto's stock market.
Since 1989, power companies in North America, the UK, Northern Europe and elsewhere evaluated the risks of geomagnetically induced currents (GICs) and development mitigation strategies.
● On 15th July, 2000, the ring current and ground level disturbances were observed.
● On 6th November, 2001, GIS flows in the network were observed in Japan.
● In November, 2003, five major stations, 15 transformers, encountered an unknown storm which led to the collapse due to GIS activated storm (Harsh and et al., 2012).
●On February 26, 2008 the magnetic fields erupted inside the magnetotail, releasing about 1015J of energy. The blast launched two gigantic clouds of protons and electrons, one toward the earth and one away from earth. The earth-directed cloud crashed into the planet below, sparking vivid auroras in Canada and Alaska (NBC NEWS.Com).
●On February 9-12,2011sunspot 1153 grew more active crackling with C- and M- class solar flares (www.globaldatavault.com).
●In 2011, the Space Weather Prediction Centre (SWPC) in Boulder, Colo reported how three solar flares erupted on the sun and the strongest electromagnetic shocks were being felt after 3 days by the ACE spacecraft, a satellite that measures radiation bursts a few minutes before they stroke the earth(NBC NEWS.Com).

3.0 STORMS EFFECTS ON:

3.1 POWER GRIDS

When magnetic fields move in the vicinity of a conductor such as a wire, a geomagnetically induced current is produced in the conductor. This happens on a ground scale during geomagnetic storms (the same mechanism also influences telephone/telegraph lines) on all transmission lines. Power companies which operate long transmission lines (many kilometers in length) are thus subject to damage by this effect. The (nearly direct) currents induced in these lines from geomagnetic storms are harmful to electrical transmission equipment, especially generators and transformer-since they induce core saturation, constraining their performance (as well as tripping various safety devices),and causes coils and cores to heat up. This heat can disable or destroy them, even inducing a chain reaction that can blow transformers throughout the system.

The susceptibility of electrical power grid to disruption and damage from solar storms is a function of latitude, strength of the geomagnetic storm, earth ground conductivity, orientation of the power line length of the transmission line, power grid construction.

The following geomagnetic storms amongst others damaged the electrical power grid:
●August 2, 1972-A solar storm caused a 230,000 Volt transformer located at the British Columbia Hydro and Power Authority to explode (Odenwald, S., 2000).
●December 19, 1980-A very expensive 735KV transformer failed 8 days after the Great Red Aurora at St.James Bay, Canada.
●April 13, 1981-A replacement of 735KV transformer at St.James Bay, Canada also failed the failing year during another geomagnetic storm.
●In 1989, the Salem Pressurized Water Reactor, PWR in New Jersey was affected. The solar storm induced a large current into the PJM 500-KV transmission system which damaged the Salem unit 1step up transformer, resulting in a large melted mass of copper and copper shot (Oscar W., 2012).

●October 30, 2003-A power grid in southern Sweden located in Malmo experienced a 20-50 minute electrical blackout affecting 50,000 customers. The same storm damaged over 15 transformers beyond repair in South Africa.
Electricity is essential to our industry, communication, transportation, commerce, water supply, healthcare, education and other social welfare. An electrical blackout will affect many modern facilities. The world commerce today is very reliance on computers and telecommunications. Loss of this infrastructure will take a heavy toll.

3.2 OIL AND GAS PIPELINES
Oil and gas are major types of fossil fuels that can be converted through thermal processes to electrical power generation.

Geomagnetic induced currents affect oil and gas pipelines. In pipelines, GIC and the associated pipe–to-soil voltages can increase the rate of corrosion in pipelines especially in high latitude regions that can eventually lead to pipeline integrity failures and major fuel leaks (Marusek, J.A., 2007).

Solar storms may had encourage the gas pipeline rupture and explosion on the 4th June 1989 that demolished part of trans-Siberian railway, that engulfed two passenger trains in flame killing half a thousand people (Oscar Wilde, 2012).

Also, the induced currents can also affect the flow meters that transit the flow rate of oil/gas in the pipeline producing false readings. The length of the pipeline adds to its vulnerability due to the increased potential for corrosion (Marusek, J.A., 2007).

3.3 ELECTRONIC COMMUNICATIONS
Solar storms can affect radio communications, satellite communications, radars and navigation systems. On frequencies below 30MHz, the ionosphere generally acts as an efficient reflector, allowing communications to distance. Solar extreme ultraviolet and soft x-ray emissions from solar flares change the electron density and gradients in the ionosphere reflections. A sudden increase of x-ray radiation from a solar flare causes substantial ionization in the lower region of the ionosphere producing ionospheric disturbances of radio signals, sudden phase anomalies, sudden enhancement of signals and short wave fade. Solar flares also produce a wide spectrum of radio noise (Cohen N and et al., 1994).
Polar cap absorption (PCA), aurora absorption, multipatting and non-great circle propagation effects are associated with coronal mass ejections (CMEs) that can disrupt radio communications.

The effects of solar storms on radio communications through ionospheric reflectivity and scintillation include (NSSA, 2007, Barnes, P.R and et al., 1991):
● HF radio communication (3-30MHz)
» Increased absorption.
» Depressed maximum usable frequencies (MUF).
» Increased fading and flutter
» Effect short–wave propagation through sunlit side of earth.
» Effect ground-to-air, ship-to-shore and amateur radio communications
» Increased lowest usable frequency (LUF)
●VHF propagation (30 – 300MHz)
» Effect pagers and cellular phones
» Susceptibility to fadeout of the high and low band in mobile voice communications for dispatching utility company line crews
● Satellite communications (200MHz to several GHz)
» Increased scattering of satellite-to-ground ultra high frequency (UHF) transmissions or scintillation can seriously interfere with direct satellite communications links
» Radio frequency interfere (RFI)
» Loss of phase lock
» Severe distortion of data transmissions from geosynchronous satellites
» Erroneous positioning information from single frequency GPS
» Drastic loss in spacecraft electrical power due to inability to reposition craft.
»Faraday rotation of the plane of polarization effect on satellites that employ linear polarization up to 1GHz
● Radar surveillance systems

» Azimuth angle errors
» Range errors
»Radar energy scatter due to auroral interference
» Elevation angle errors
● Navigation systems
» position errors
» Scintillation of GPS signals
» Inaccuracy due to the introduction of small delays from GPS satellite signals
» fadeout of signals

4.0 PREVENTIVE MEASURES
Having analyzed the treats that can be caused by solar storms upon the improved technologies being enjoyed today, it is necessary to highlights measures to mitigate them. These precautionary measures include but not exhaustive of the following:
● Use of series capacitors to block the flow of GIC in transmission lines or neutral – blocking capacitors in transformer neutrals.
● Putting sunscreen on all technology.
●Replacement of copper wires with optical fibers by telecommunications operators
● Installation of solar storm warming system (solar monitor) that can offer up to date information on solar activity, including images, flares locations, flare predictions.
● Use of shorter transmission cables as they are less vulnerable to damage.
● Long term preventive measures also exist to protect against coronal mass ejections, including digging transmission cables into the soil, placing lighting rods on transmission wires, reducing operating voltages of transformers and using cables that are shorter than 10 kilometers. It might also be possible to develop and deploy large resistors that would add another level of protection to large transformers.
●Incorporating solar storm hardening into satellite design.
●By receiving geomagnetic storm alerts and warning (e.g. by the space weather prediction center, via space weather satellites), power companies can minimize damage to power transmission equipment by momentarily disconnecting transformers or by inducing temporarily blackouts.

CONCLUSION

Economics around the world have become increasingly vulnerable to the ever-changing nature of the sun. Solar storms can disrupt power grids, interfere with high frequency airline and military communications, disrupt global positioning system (GPS) signals, interrupt civilian communications, and blanket the earth's upper atmosphere with hazardous materials. There are many warnings from concerned scientists saying that electromagnetic space storms from the sun may wipe out telephone lines and television signals, cripple aircraft navigation systems, and leave cities without power supplies. The question now is what can be done? The ability to carefully observe and monitor conditions on the sun and characterize in details the nature of solar outbursts would allow forecasters to predict that would make radio wave and energy providers and space users to adjust to the predictions in order to avoid serious breakdown of infrastructures and hence huge economic losses. Therefore, with effective alerts and warnings, hazards to technology can be adjusted, power grids can be modified and polar flights can be rerouted. For a brighter future, scientists and forecasters could work closely with government and research partners (Universities) to develop prediction models and other tools to improve services to the space weather community to provide timely, accurate information and forecasts to help keep our advanced-technology global economy moving forward.

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