IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Space Weather Prediction using NARX Neural Network and Levenberg-Marquardt Algorithm

[1]Ishaan Jaiswal, [2]Er Priyanka,
[1]Student, [2]Assistant Professor,
[1]Bachelor of Technology (Computer Science and Engineering), [2]Bachelor of Technology (Computer Science and Engineering)
[1,2]Shri Ramswaroop Memorial College of Engineering and Management, Faizabad Road, Lucknow, India

Abstract: As we are becoming more and more dependent on electricity to carry on with our day-to-day activities, it has become an important task for us to predict the abrupt and calamitous changes in our space weather that can directly or in-directly hamper with our electricity grids and our satellite systems. The Sun is the major celestial body responsible for changes in the space weather. The Sun, though responsible for life on earth, can also create disastrous impacts on our satellite systems responsible for major communications on earth. It has been seen before that solar activity can prompt space weather changes that could impact technological systems. Hence, it has been of extreme importance to predict these solar activities, before they could reach the earth and cause damages that can disrupt the normal working of the essential equipment responsible for smooth functioning of the economic infrastructure.

***Index Terms* – Machine Learning, Matlab, Neural Networks.**

I. INTORDUCTION

Solar flares, eruptions, CMEs and other storms arising due to changes in the surface temperature and magnetic field of the Sun, can have catastrophic impacts to technological systems around or on the earth. They have been responsible for various failures to our satellites, power supplies, communications and navigation systems in the past. Damage caused to these systems have secondary effects that can easily damage and disrupt indirectly every other system and major infrastructure dependent on them, including telecommunication industry, climatic weather forecasting stations, transport sectors, defense sectors, various emergency response systems and other wireless networks and electronic devices which can lead to significant economic losses. Hence, it has become an important task for us to predict the occurrence of various solar storms and coronal mass ejections as they disrupt our Earth's magnetic field resulting in sudden and alarming changes in the magnetosphere (the region of space surrounding Earth where the dominant magnetic field is the magnetic field of Earth) that results in generation of powerful waves and currents in the Earth's ionosphere (Part of Earth's upper atmosphere, from about 80 to 600 km where ionization of atoms is caused by Extreme Ultraviolet (EUV) and x-ray solar radiation, thus creating a layer of electrons). These currents are replicated in the Earth's conducting surface as geomagnetic induced currents. Since the critical electrical infrastructure is grounded the induced currents can hamper power grids and communication networks.

Solar storms are harmful for various communication systems like radio communications, satellite communications, radars and navigation systems. When the frequencies are below 30MHz, the ionosphere generally acts as a good reflector, allowing communications to distance effectively. Solar extreme ultraviolet and soft xray emissions from solar flares and other solar activities change the density of electrons and causes variations in the functioning of ionosphere responsible for effective communication. An abrupt increase of x-ray radiation from a solar flare causes an increase in ionization of the lower region of the ionosphere producing disturbances of radio signals, sudden phase changes, unnoticed enhancement of signals and fading of short waves. Polar cap absorption (PCA), aurora absorption etc are the effects that are associated with coronal mass ejections (CMEs), can also disrupt radio communications. The prediction will help us take active measures and save the various satellites from damage.

II. PREVIOUS RECORDED EVENTS

There were many such events in the history, some of them are listed below: -

- August 28th to September 2nd, 1859, a massive coronal mass ejection reached earth in eighteen hours. Many sunspots and solar flares were also seen.[1]
- The geomagnetic storm caused by the combination of the solar flare and coronal mass ejection, created strong induced currents in some of the long telegraph wires, in both America and Europe, shocking telegraph operators and causing fires.[1]
- March 13th, 1989, the Hydro-Quebec power grid was collapsed as many protection equipment relays tripped in a continuous sequence of events caused by a severe geomagnetic storm. About 6 million people were left in blackout for 9 hours, resulting in enormous economic loss.[1]
- November, 2003, due to GIS activated storm, an unknown problem was encountered at five major stations, 11 transformers, which eventually collapsed.[3]

- February, 2011, 3 solar flares erupted on the sun which created the strongest electromagnetic shocks that can be felt after even 3 days by spacecrafts and a satellite used to measure radiation, bursts few minutes before they reached the earth.
- Various other damages were reported in the past caused by various solar flares, CMEs, and other solar activities, that resulted in economic losses in various parts of the world like Great Britain, United States of America, France etc.[3]

III. WHAT ARE SOLAR STORMS?

There are mainly three major components responsible for the emergence of solar storms. They are: -

- **Solar Flares**
  Solar flares are the most violent events occurring on the surface of the sun. They occur due to sudden release of tremendous amount of energy stored up in the sun's magnetic field, as magnetic energy or gets converted into heat energy and motion.[1] Approximately about, 7 to 8 minutes after they occur, a powerful burst of electromagnetic radiation in the form of various electromagnetic radiation like x-ray, extreme ultraviolent rays, gamma ray radiation and radio burst reach the earth. The UV rays heat up the upper atmosphere which causes the outer atmospheric shell to expand. The electron density in the ionosphere is suddenly increased as the x rays strip electrons from the atom.[2]

- **Solar Proton Events (SPE)**
  Solar proton events abbreviated as SPE are cosmic rays mainly comprising of protons and ions having energies in between the range of 100MeV to 10MeV.[2] They are even capable of producing nearly relativistic protons. They produce satellite disorientations, damage to electronic equipment installed in the spacecrafts and the International Space Station. Solar Panel installed to fulfill the electricity requirements in various satellites and spacecraft begin to degrade because of SPEs. They are also hazardous to astronauts as they contain extreme radiation which is also responsible for ozone layer depletion causing cardiac arrest, dementia and cancer.[2]

- **Coronal Mass Ejection (CME)**
  Coronal Mass Ejections (CME) are violent eruptions of magnetized plasma that leave the surface of the Sun with speed as large as 1,000 km/s. Predicting the evolution of a CME as it expands away from the Sun and travels towards Earth is one of the major challenges of Space Weather forecasting[4]. Coronal Mass Ejections are phenomenon when the plasma from the corona (core) of the sun is ejected into space releasing tremendous amount of energy and are accompanied by magnetic flux. This activity results in creation of a solar storm of a high magnitude containing various electromagnetic waves (SUVI, X rays) and magnetic flux. The debris is responsible for damage to communication satellites and degradation to solar panels resulting in decrease in efficiency in telecommunication and broadcasting. Whereas, the magnetic flux induces an emf in the earth due to change in field in the magnetosphere of the earth. This induced emf results in induced currents in the earth. Since all our electrical grids, electronics are grounded to the earth, they get damaged.[2]

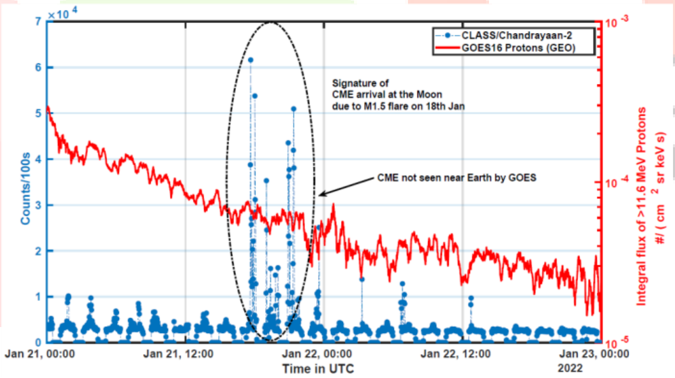


Figure 1: Chandrayaan-2 detected solar proton events due to high intensity solar flares in January 2022.[5]

IV. DISTURBANCE STORM TIME INDEX

The Disturbance Storm Time (Dst) index is a measure of geomagnetic activity used to assess the severity of geomagnetic storms. It is expressed in nano Tesla and is based on the average value of the horizontal component of the Earth's magnetic field measured at four near-equatorial geomagnetic observatories. It measures the growth and recovery of the ring current in the Earth's magnetosphere. The lower these values get, the more energy is stored in Earth's magnetosphere.[6]

Dst (Disturbance Storm Time) equivalent equatorial magnetic disturbance indices are derived from hourly scaling of low-latitude horizontal magnetic variation. They show the effect of the globally symmetrical westward flowing high altitude equatorial ring current, which causes the "main phase" depression worldwide in the H-component field during large magnetic storms. This diskette contains the hourly indices for the period 1 Jan 1957 through 30 Sep 1992, as derived by M. Sugiura and T. Kamei, WDC-C2 for Geomagnetism, Faculty of Science, Kyoto University, Kyoto 606, Japan.[7]

V. TECHNOLOGY USED

I. MATLAB

MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models. MATLAB combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. It includes the Live Editor for creating scripts that combine code, output, and formatted text in an executable notebook.

II. NARX- Nonlinear autoregressive network with exogenous inputs

The nonlinear autoregressive network with exogenous inputs (NARX) is a recurrent dynamic network, with feedback connections enclosing several layers of the network. The NARX model is based on the linear ARX model, which is commonly used in time-series modeling. The defining equation for the NARX model is

$$y(t) = f(y(t-1), y(t-2), \ldots, y(t-ny), u(t-1), u(t-2), \ldots, u(t-nu))$$

where the next value of the dependent output signal y(t) is regressed on previous values of the output signal and previous values of an independent (exogenous) input signal.

III. Levenberg-Marquardt Algorithm

The Levenberg-Marquardt Algorithm is used to solve non-linear least squares problems. It is also known as damped least-squares (DLS) method. Many software applications use this algorithm to solve generic curve-fitting problems. However, this only find the local minimum as compared to all other algorithms. This was Published by Kenneth Levenberg, while working at the Frankford Army Arsenal in 1944.

IV. Dataset

OMNI data center provide average magnitude of interplanetary magnetic field IMF(nT), negative z-component of IMF Bz (nT), solar wind plasma number density n (cm^{-3}) and the solar wind velocity V (km/s). All the field parameters are in Geocentric Solar Magnetospheric (GSM) coordinate system. They also provide proton temperature T (K), proton density D (cm^{-3}), flow pressure P (nPa), electric field E (mV/m), plasma beta (β), field magnitude average FMA (nT), variance of total IMF σB (nT) etc. The 4 features that were selected as input features were based on their direct correlation with Dst index and how much it gets affected as these parameters change. [8]

The 4 input features that were selected are: Interplanetary Magnetic Field IMF Avg Mag (nT), z component of IMF i.e. Bz (nT), Proton Density (n/cc), Flow Speed (km/s)

V. PROPOSED WORK

A. Importing Dataset

```
[file,path,indx] = uigetfile
filename = [path file]
global Input
Input = importdata(filename)

[file,path,indx] = uigetfile
filename = [path file]
global  Target
Target = importdata(filename)

global X
global T
global Input
global Target
X = tonndata(Input,true,false);
T = tonndata(Target,true,false);
```

B. Choosing Training Function

```
global trainFcn
trainFcn ='trainlm';
```

C. Dividing data into training, validation and test set

```
global net
global inputDelays
global feedbackDelays
global hiddenLayerSize
global trainFcn
inputDelays = 1:2;
feedbackDelays = 1:2;

net = narxnet(inputDelays,feedbackDelays,hiddenLayerSize,'open',trainFcn);
global x
global xi
global ai
global t
global X
global T
[x,xi,ai,t] = preparets(net,X,{},T);
% Setup Division of Data for Training, Validation, Testing
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;
```

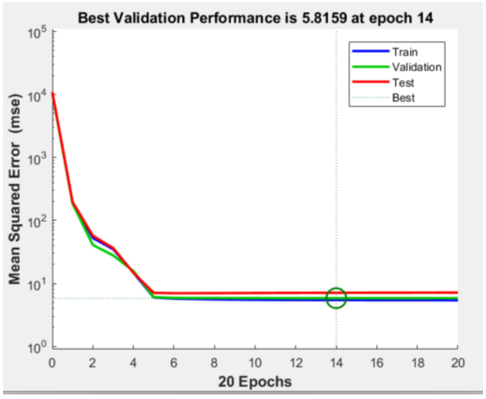
D. Creating a NARX Neural Network

```
global x
global xi
global ai
global t
global net
global tr
global e
global performance
global X
global T

[net,tr] = train(net,x,t,xi,ai);

y = net(x,xi,ai);
e = gsubtract(t,y);
performance = perform(net,t,y)
figure, plotregression(t,y)
netc = closeloop(net);
netc.name = [net.name ' - Closed Loop'];
view(netc)
[xc,xic,aic,tc] = preparets(netc,X,{},T);
yc = netc(xc,xic,aic);
closedLoopPerformance = perform(net,tc,yc)
nets = removedelay(net);
nets.name = [net.name ' - Predict One Step Ahead'];
view(nets)
[xs,xis,ais,ts] = preparets(nets,X,{},T);
ys = nets(xs,xis,ais);
stepAheadPerformance = perform(nets,ts,ys)
```

E. Plot Graph

```
global tr
figure, plotperform(tr)
```

VI. RESULTS



The performance graph shows that we attained a best validation performance of 5.8159 at epoch 14.

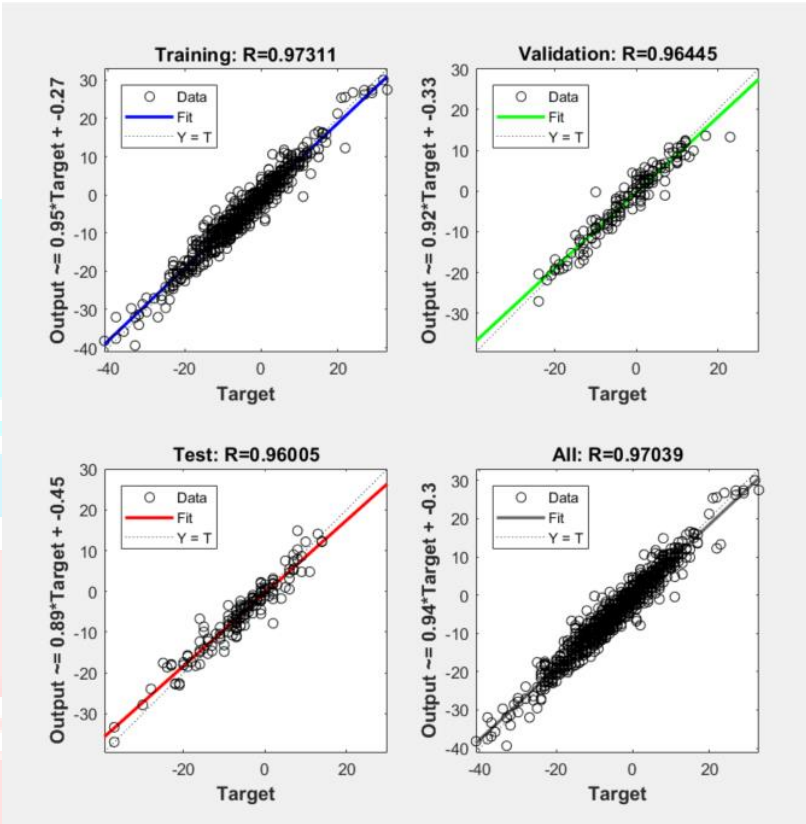


Figure 2: Regression plot when 4 features are given as input

It is observed that the R value of the test when we have 4 features is 0.96005. Regression R Values measure the correlation between outputs and targets. An R value of 1 means a close relationship, 0 a random relationship. Thus, our model exhibits a very strong correlation between predicted and actual values.

VII. CONCLUSION

Hence, it has been of extreme importance to predict these solar activities, before they could reach the earth and cause damages that can disrupt the normal working of the essential equipment responsible for smooth functioning of the economic infrastructure.

VIII. ACKNOWLEDGEMENT

I would like to thank our guide Er. Priyanka for helping me throughout this research and for the continuous guidance during the development of this project.

REFERENCES

[1] Mathew J. Owens, Mike Lockwood, Luke A. Barnard, Chris J. Scott, Carl Haines, and Allan Macneil "Extreme Space-Weather Events and the Solar Cycle", Springer, published on 20th, May, 2021.

[2] Ashok Kumar Singh, Asheesh Bhargawa, Devendraa Siingh, and Ram Pal Singh "Physics of Space Weather Phenomena: A Review", MPDI journal of geosciences, published on 8th July 2021.

[3] Omatola and Okeme, "Impacts of solar storms on energy and communications technologies", Archives of Applied Science Research, 2012.

[4] E. Camporeale "The Challenge of Machine Learning in Space Weather: 2 Nowcasting and Forecasting"

[5] https://www.isro.gov.in/chandrayaan2-latest-updates

[6] https://www.spaceweatherlive.com

[7] https://www.ngdc.noaa.gov

[8] J.-G. Wu and H. Lundstedt, "Prediction of geomagnetic storms from solar wind data using elman recurrent neural networks," Geophysical Research Letters, vol. 23, no. 4, pp. 319–322, 1996.