GEOMAGNETIC STORM RISKS TO ELECTRIC POWER DISTRIBUTION AND SUPPLY SYSTEMS AT MID-LATITUDE LOCATIONS AND THEIR VULNERABILITY FROM SPACE WEATHER

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ABSTRACT

The effects of space weather on power distribution and supply systems are briefly described. Results of studies on the impact of geomagnetic storms of various strengths on electric power supply systems in Azerbaijan (mid latitudes) are provided. Perspectives of study of space weather effects on operational conditions of the regional electric power industry as well vulnerability of electric power systems and possibility of prediction of potential space weather effects for domestic power companies are discussed.

Keywords: space weather, geomagnetic storms, power system, geomagnetically induced currents, transformer

1. INTRODUCTION

The Sun manages all living nature on the Earth and is of practical importance to whole geosphere. Solar and geomagnetic activities, changes in these activities and their manifestations on the Earth, as main constituents of space weather, not only affect the functioning of engineering-technical systems in space and on the ground but also may endanger the biosphere, including human life and all-kind of human activities [1-4]. With technological advances, the needs and reliance on space weather predictions will approach those of terrestrial weather. The public could understand the need to carry out basic research into the Sun, interplanetary medium, magnetosphere, ionosphere and atmosphere in order to protect technological systems such as telecommunications, domestic power supplies and others that affect their daily lives [5].

For a clear understanding of solar and geomagnetic activities' possible effects on technological, biological and ecological systems we have initiated complex investigations on these problems in Azerbaijan [6-20]. Some selected and recently obtained results of the complex study of space weather influence on power distribution and supply systems located in mid latitudes are described in this paper. Relevant data on monitoring of electric power transmissions' failures, covering the period of 1994-2005 is used for investigation of possible influence of space weather events on the Azerbaijani power industry. Particular attention is given to the study of influence of severe geomagnetic storms on power supply systems.

II. SPACE WEATHER INFLUENCE ON ELECTRIC POWER GRIDS AND TRANSFORMERS

"Space Weather" phenomenon, which is one of the important components of the Solar-Terrestrial Physics, is determined by most varied interactions between the Sun, the interplanetary space, and the Earth. The impact of space weather on the geosphere ranges from technical problems on satellites arising from charged particles, through the effects of radiation on humans both in space and in high-altitude aircraft, to problems experienced by ground-based technical system operators during severe geomagnetic storms [1, 2, 5, 21].

The Sun is the main and most important driver of space weather phenomenon. Energetic particles thrown out from the Sun (by solar flares or eruptive ejections) interact with the Earth's magnetic field producing geomagnetic disturbances (storms) and increased ionization in the ionosphere, 100 to 1000 km above the Earth. The most obvious effect of geomagnetic activity (usually solar fast coronal mass ejections (CME) driven storms) is the build up of enhanced ionospheric current system within the equatorward moving auroral oval.

The high energy particles affect satellites causing misoperation or equipment damage that can put the satellite out of operation. Radio waves used for satellite communications or GPS navigation are affected by the increased ionization with disruption of the communication or navigation systems [6]. The magnetic disturbances directly affect operations that use the magnetic field, such as magnetic surveys, directional drilling, or compass use.

The effects of space weather on ground-based technology are mostly due to the varying geomagnetic field during a geomagnetic storm. It has long been understood that ground-based long conductors such as power lines, pipelines, railways, etc. are vulnerable to geomagnetically induced currents (GIC) that are the result of electric currents high in the atmosphere of the Earth (at ionospheric altitudes). GIC are produced during geomagnetic storms and substorms as the magnetosphere interacts with disturbances in the solar wind and are driven by the geo-electric fields produced by the changes in the magnetic field of the Earth.

Geomagnetic disturbances can particularly have serious effects on the electric power systems. Today's electrical power grids are more susceptible to solar-storm disruption than their more localized predecessors because of the large geographical areas they cover and their interconnected and electronically-equipped nature. Those who are interested in details of space weather impacts on power systems are referred to the following papers [21-23, 25-27, 16].

Currents induced in power lines flow to ground through substation transformers. The voltage between the earthing points of two transformers causes GICs which flow through the three-phase transformers to the power cables of high-voltage lines (Fig.1.).

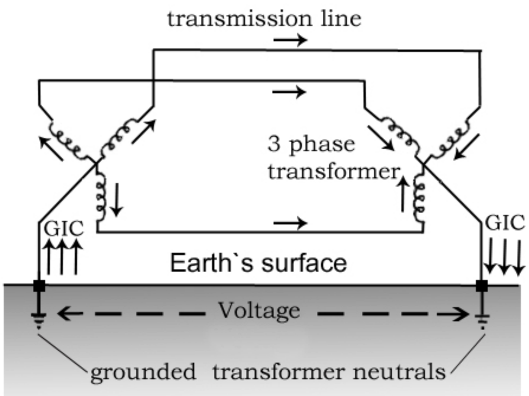

Fig.1. Schematic illustration of the GIC flow through transformers to the power cables.

Because of their low frequency compared to the alternating current (AC) frequency, GICs appear to a transformer as a slowly-varying direct current (DC). GIC flowing through the transformer winding produces extra magnetization which, during the half-cycles when the AC magnetization is in the same direction, can saturate the core of the transformer and can lead to a variety of problems.

In half-cycle saturation the current in the windings can exceed the rated load for the device, and magnetic flux which is normally constrained to the transformer core can leak into adjacent structures. Saturation of the transformer core produces extra eddy currents in the transformer core and structural supports which heat the transformer and damage the device and adjacent structures. Half-cycle saturation caused large exciting current has a fundamental frequency component that lags the supply voltage by 90 degrees and leads to the transformer becoming an unexpected inductive load on the system. The large thermal mass of a high voltage power transformer means that this heating produces a negligible change in the overall transformer temperature. However, localized hot spots can occur and cause damage to the transformer windings. Increased heating can cause transformers to burn out.

Saturation results in a very spiky AC waveform with full of increased (extra) harmonic levels in the transformer that can lead to operation of capacitor-bank protective devices and can produce unwanted relay operations, suddenly tripping out power lines, can cause misoperation of other equipment on the system and lead to problems ranging from trip-outs of individual lines to collapse of the whole system. Capacitor banks are an important device for maintaining voltage support, and the combination of a high inductive load and loss of capacitors makes voltage support difficult.

The stability of the whole system can also be affected as compensators switch out of service. For example, such a sequence of events led to the Quebec (Canada) blackout of March 13, 1989, during a Great Geomagnetic Storm, which left the whole province without power for over 9 hours.

III. GEOMAGNETIC STORM IMPACTS ON ELECTRIC POWER DISTRIBUTION AND SUPPLY SYSTEMS AT MID-LATITUDES

Geomagnetic activity mainly consists of geomagnetic storms, substorms and aurora. Geographically, most auroras are located within oval-shaped regions around both geomagnetic poles of the Earth. The ovals are displaced relatively to the magnetic poles such that they extend further towards equator at the midnight sector. During a storm, auroral ovals become greatly disturbed, broadening and expanding equatorwards, particularly on the nightside. This brings the aurora to the middle and low latitudes. Another important condition is the auroral electrojet. When geomagnetic activity has any practical importance to human technology and life, etc., we talk about space weather.

American Space Environment Center (SEC) in Boulder established special scales for the intensity of space weather. The National Oceanic and Atmospheric Administration's (NOAA) Space Weather Scales were introduced as a way to evaluate space weather conditions and their possible effects on humans and systems [24]. The scales describe the environmental disturbances for three event categories: 1) solar radiation storms, 2) radio blackouts, and 3) geomagnetic storms (from G1 (weak) to G5 (severe)).

The location of the aurora usually changes geomagnetic latitude as the intensity of the geomagnetic storm changes. As a storm becomes more intense, the edge of the auroral boundary typically moves to lower geographical latitudes. Under geomagnetic storm G2 conditions the aurora will have expanded, but only a G3 storm begins to move the aurora down to lower latitudes to the point where mid-latitude affects are possible. It must be taken into account that lines of geomagnetic latitude do not map exactly with the geographic latitude. If geographic mid-latitudes are close to the magnetic pole, then they are more affected.

Space weather effects on electric power transmission grids and transformers are widely investigated mainly for high-latitude geographical locations where these impacts take place due to large impulsive geomagnetic disturbances driven by auroral electrojet intensifications (see, for example, [23, 25]), but there are signs that space weather can have significant risks to ground-based systems at low-latitude and mid-latitude locations, which were reported, side by side with our investigations [15-20], recently in [26]. Therefore, in this paper, the possible impact of geomagnetic disturbances on power supply systems was studied for one of mid-latitude locations (Azerbaijan).

The CMEs from the Sun, with velocities up to 2000 km/s, give raise to shock-waves in the solar wind. The related pressure pulses, when impinging the Earth's magnetosphere, both compress it and increase the magnetopause current. This leads into a few tens of nano-Tesla (nT) intensifications in the low-latitude ground-based magnetic field intensity, lasting typically for some tens of minutes. These signatures are called Sudden Storm Commencements (SSC) or Sudden Impulses (SI), depending whether a magnetospheric storm is initiated or not. The yearly number of SSCs shows the 11-year solar cycle dependency.

Geomagnetic storm processes, such as magnetospheric shocks or high-speed magnetospheric compressions associated with SSC and SI, ring current intensifications can produce widespread disturbances to the geomagnetic field that extend to low and middle latitudes, causing GIC concerns and risks for the power industry at any latitude, even equatorial locations [26, 27]. SSC is characterized with low-amplitude B field disturbances. The magnitude of the geomagnetic field disturbance is not large, but it can have a very high rate-of-change even at very low latitudes. Ring-current intensifications also have been shown to produce large magnitude and long-duration observations of ground-induced currents in power grids at low-latitude locations and especially in cases of extensive power grid development.

Sustained disturbance conditions at low-latitude and equatorial latitude locations that are likely linked to ring current intensifications may be the source of sustained GIC at these locations and the cause of large power transformer failures.

As some of the space weather events and their effects can be devastating (like those that had place in 13-14 March 1989 or in October-November 2003), it is very important to get more and better knowledge about solar and geomagnetic storms' potential effects on technological systems.

We have investigated possible impact of geomagnetic storms of various strengths on fast developing electric power industry of Azerbaijan and its operational reliability, on the base of reliable and accurate technical-engineering data on electric power transmission and supply systems' failures made by the Dispatcher Office of the Joint Stock Company "AZERENERJI" (Azerbaijan State Energy Company) and "BARMEK-AZERBAIJAN Electrical Network LTD" with time span of 1994-2005. A particular attention was paid to the effects of so-called solar extreme events, namely those of in July 2000 and October-November 2003 as well as in September-October 2001, April 2002, November 2004, January 2005, etc., which gave unique chances for conducting of these researches. For example, the October-November 2003 solar extreme events were some of the largest in Solar Cycle 23.

Detailed and accurate daily notes and relevant controlling measurements on request within collaborative scientific project allowed creating the data on power supply system behavior (failures, breakdowns, voltage oscillations, etc.) for time period of 1994-2005 (this time span is very close to 11-year solar activity cycle with minimum and maximum allowing to study possible gradual changes). Early or real-time warnings were conducted at Shamakhy Astrophysical Observatory (ShAO) for domestic power industry operators and relevant research institutes (f. e., Research Institute of Energetic, Institute of Physics under ANAS). Power system behavior during the days of high risk was studied separately and digital database was carefully created for these days.

IV. RESULTS AND DISCUSSIONS

In order to avoid possible subjective influence of "usual" technical kind problems, the initial data was "cleaned" using special methods after proper consultations with specialists. Data was separated and grouped and was subjected to mathematical analyses as well.

Analysis of technical data created for selected days with major and severe geomagnetic storms that occurred during present Solar Cycle 23 (14-15 July 2000, 29 September - 3 October 2001, 24 October-4 November 2003) with data corresponding to comparatively quiet periods (geomagnetically favorable days) and data for days with weak and mild geomagnetic storms within years of 1994-2005 has revealed that the number of serious breakdowns (which can not be explained only with the reason of technical character), power cuts and power line voltage disturbances are significantly increased only during severe stormy days, when the geomagnetic field displayed sharp changes (for example, there were significantly increased number of failure events at 27-28, 29-30 October and partially at 4, 11, 20 November 2003).

During severe geomagnetic storms there were registered increased (comparative to relative quiet days with "usual" technical problems) system failures such as differential phase protection, earth protection failure, sudden relay operations (tripping), voltage drops, saturation of power transformers, reactive power consumption, and particularly, harmonics, stray flux, overheating, black-out.

For better visualization, each interruption case was provided with relevant oscillograms; records show number of harmonic oscillations in the current and voltage, which disrupt the signal waveforms that were registered in saturated transformers. It is supposed that the comparatively extra voltage fluctuations produced in the transformer caused false relay operations (tripping) of the protective devices that suddenly prevented power lines from functioning and lead to some additional non-significant losses in various equipments.

Alongside with geoelectric field that governs the GIC magnitudes in a power system, the geometrical and structural details, varying ground resistivity along lines have a significant influence on power system. Detailed analysis has revealed that those transformers, which are positioned at the corners (or at turning points) of an electrical power distribution system, are more vulnerable to geomagnetic storm effects.

The direction of power supply lines plays a significant role. It is revealed that in the case of Azerbaijan, the power lines in the East-West direction (towards Russia) are more influenced than ones in the North-South direction (across the country); in our opinion, it is due to the fact that the induced electric field is oriented mainly in an East-West direction.

Important aspects and uncertainties of the solid-earth geophysics need to be taken into account. Conductivity of the Earth itself is crucial in determining the electric fields produced by a given magnetic field; a high Earth resistivity makes the geo-electric field values larger. Our studies showed that power transmission and supply systems that are positioned in low-conductive ground areas of Azerbaijan are more vulnerable than those in other areas. The deep-earth ground conductivity also provides an important enabling role at higher frequencies. Deep-earth ground response to geomagnetic field disturbances is highly frequency-dependent [26]. Therefore for nearly all ground conditions the higher the spectral content of the incident magnetic field disturbance, the higher the relative geoelectric field response.

As it was mentioned above, local natural earth-conductivity determines the local interaction with any power grid: areas with a ground that permit natural currents to flow are not very likely to be affected, whereas areas with poor natural conductivity provide a possible opportunity for currents to get into the grid through grounded neutrals of transformers.

The most vulnerable areas, from this point of view, for supply system and transformer failures are Absheron Peninsula with spread powerful power stations and transformers in capital city Baku having several millions of inhabitants, Mingachevir region in West (with very big hydro-electrical power station), the area between Absheron Peninsula and Mingachevir region (corridor in the East-West direction with very high voltage power lines), as well as, particularly, Ali-Bayramly region and North-directed coastally located "sea-land boundary" areas.

We suppose that the salted Caspian Sea, as oceans, conducts electricity easily and can carry large electric currents. When these currents reach shore in Absheron Peninsula, particularly when the crust is non-conductive, voltages can jump into wires and pipelines with potentials measuring hundreds of Volts.

Both large geomagnetic storms as well as weaker but repetitive storms can contribute to transformer failure problems. Large storms can cause internal heating damage in a very short period of time. During October-November 2003 storms, few incidents of "unusual" transformer heating problems were registered by JSC "AZERENERJI". Weak, but long-duration storms can also cause transformer-heating damage. These extended duration heating insults raise the likelihood of loss-of-life to transformer insulation. This damage can be cumulative and acquired over repeated exposures.

Daily data on failures and power distribution system behavior in years 2002-2005 created by "BARMEK-AZERBAIJAN" EN LTD in grand Baku area (Absheron Peninsula) was subjected to spectral analysis and Fourier analysis. After "cleaning" the data from such subjective factors as seasonal influence, pure technical kind of effects, etc., the remained data revealed quasi-year (annual), 1.49-year, 60-days, 3-months and other periodicities (in total 8 main modes) (Fig.2.).

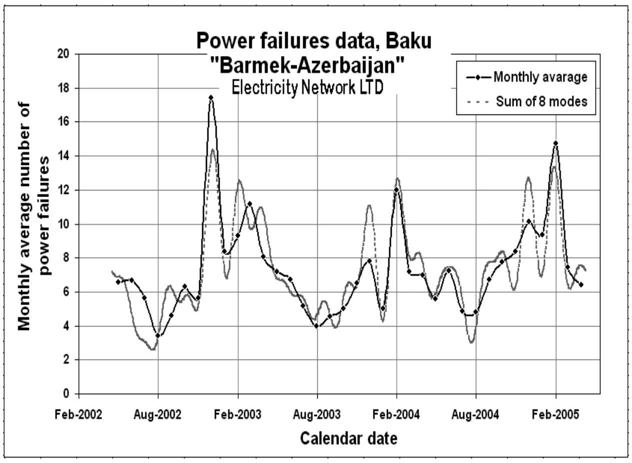

Fig.2. Power distribution system failures.

Obtained preliminary results could be explained by possible influence of variations in solar and geomagnetic activities. Variability in the geomagnetic activity has several sources which includes the variability in the Sun itself that is reflected in the solar wind/interplanetary magnetic field (the 11- and 22-year solar cycles and the 1.3 year variability), the annual variability (the Earth's orbit around the Sun taking it to different helio-latitudes), as well as semi-annual and recurrent (27-day) variations. One of major rhythms in solar-terrestrial system is 1.47-year in geomagnetic indexes while 1.5 year periodicity appears in solar activity [4].

1.039 year periodicity (major peak alongside with other periods of 22.6, 6.9, 3.9, 1.97, 1.61, 1.48 years) - almost the same value obtained in our studies (about one year) -

was found by V.A. Kotov et al. from the Crimean astrophysical observatory (CrAO, Ukraine) in the lower frequency part of the power spectrum of variations of the mean magnetic field (MMF) of the Sun for 1968-2000 on the base of joint 33-years observations conducted in CrAO - Sayan (Irkutsk) - Mount Wilson and Wilcox Solar Observatory (USA) [37]. This period has no clear explanation yet. It could be of solar origin – as a result of existence of solar auto-oscillation harmonics synchronized by the period of orbital motion of Earth. However, this period could be caused by technical reasons – as a result of instrumental effects governed by terrestrial phenomenon.

The solar wind observations have revealed 1.3-year periodicity in the Sun [28, 29], and as any variability in the solar wind, it is reflected in the geomagnetic activity. The 1.3-1.4-year variability originating from the Sun has been observed in the geomagnetic or auroral data by, e.g., Shapiro [30], Silverman and Shapiro [31], and Paularena et al. [32]. According to ground-based studies [30], the importance of this variability fluctuates with a roughly 65-year period, with maximums in about 1948 and 2013. This agrees with the fact that the period has not been observed in solar wind before 1987.

The annual geomagnetic variation relates to the Earth's orbit. Due to the 7.2 degrees tilt of the solar rotation axis with respect to the normal of ecliptic, the Earth reaches the highest northern and southern heliographic latitude (where solar wind speed is higher) on September 6 and March 5, respectively, and crosses the equator twice a year between these dates. Thus, when observed from Earth, one should expect a semiannual variation in solar wind speed with maxima around these dates. However, annual variation is often more clear [33], and this is because the solar wind distribution is asymmetric or shifted with respect to equator [34].

It has been shown that solar wind speed correlates well with geomagnetic activity at time scales longer than about one month [35, 36]. Also the IMF affects the geomagnetic activity, although the energy density of the magnetic field is small in comparison with that of the solar wind plasma. This is because the southward IMF component enhances the coupling between the solar wind and the magnetosphere/ionosphere system.

Our analysis revealed that most vulnerable months for power systems are the end of February and beginning of March as well as autumn months. This agrees with the seasonal dependence of geomagnetic storms.

The vulnerability of an electric power system to geomagnetic disturbances is increased when the system is more heavily loaded. Increasing customer's power demand and industry deregulation have both led to power systems being operated closer to their limits making them more vulnerable to external disturbances. It is very actual problem for Azerbaijani electric power generation and supply systems during winter and, partially, in summer times when the amount of used energy is increased significantly because of heating and cooling needs of consumers.

On the other hand, during the spring and fall, when loading is comparatively small, there is evident rise of frequency of geomagnetic storms (so called seasonal dependence of geomagnetic storms). So, during almost whole year there is an increased vulnerability of power systems to geomagnetic storms.

It is established that there are two peaks in the 11-year variability of the recurrent geomagnetic activity, one somewhat ahead or at solar maximum and other 2 or 3 years after it, which is especially noticeable in the descending phase of the solar cycle. There is a larger need of knowledge about geomagnetic storms during these years. Solar maximum years with very intense major geomagnetic storms should be taken into consideration by power industry operators: major storms disruptive to transmission grid operations can literally occur any time over the entire 11-year solar activity cycle.

When power utilities are warned (for example, by ShAO) about an approaching geomagnetic storm they can take different mitigating actions. These include the reduction of the loading in the system, which gives a larger margin, the switching-off of some equipment, the ensuring that the possible series capacitors are operating properly, and being prepared for possible problems. All actions are economically expensive, so unnecessary predictions should not exist. By receiving correct geomagnetic storm alerts and warnings/forecasts, Azerbaijani power generation and supply companies and managers can avoid or minimize possible damages, interruptions to power supplies and power outages, and hence produce cost savings during severe geomagnetic storms. At least, knowledge of geomagnetic storm forecasts and possible effects on power systems will help domestic industrial electric companies to differentiate between power failures produced by space weather effects (i.e., geomagnetic storms) and those of equipment or man-made technical origin.

V. CONCLUSIONS

The list of consequences grows in proportion to our dependence on technological systems. The subtleties of the interactions between Sun and Earth, and between solar particles and delicate instruments, have become factors that affect our well being. Thus there will be continued and intensified need for space environment services to address health, safety, and commercial needs.

It has been realized and appreciated only in the last few decades that solar flares, CMEs, and geomagnetic storms affect humans and their activities. People have long been ignorant of the wide-ranging effects that space weather could have: as a result, the "cosmic causes" behind many disturbances to technical systems probably went unrecognized. Because space weather effects may also damage only components within a system (the insulation in transformers, for example) without causing an immediate problem in whole power grid, other reasons are often suspected as the primary cause: no connection with space weather is recognized.

As technologies have increased in sophistication, as well as in miniaturization and in interconnectedness, more sophisticated understanding of the Earth's space environment continues to be required. In addition, the increasing diversity of power distribution and supply systems that can be affected by space weather processes is accompanied by continual changes in the dominance of use of one technology over another for specific applications.

On a regional scale, geomagnetic activity can be quite localized, differing seriously in intensity over tens of degrees in longitude and over a few degrees in latitude. Forecasting disturbances on a regional scale, with sufficient longitudinal and latitudinal resolution to identify the specific regions where activity is likely to be high, is of great importance to domestic power companies.

A number of long-term trends in power system design and operation have also been continually acting to increase geomagnetic storm risks. These design implications have acted to greatly escalate risks for power grids at all latitude locations. As a result, large storm events may now be of concern even to power grids that have never considered the risk!

Our investigations have shown that geomagnetic storm effects were not so strong in Azerbaijan and the effects on power consumers were small during weak and mild geomagnetic storms, while they became significant at days with severe geomagnetic storms. But it should also be taken into consideration that significant impacts could be triggered at even lower storm levels and not only late at night and not only during the peak of the sunspot cycle.

It is supposed that, despite of less variation in the peak magnitude of delta B, magnetospheric shocks or storm sudden commencements due to large scale interplanetary pressure pulses and caused by them impulsive disturbances followed by large geo-electric field and large GIC flows as well as deep-earth ground conductivity conditions alongside with the design of the power grid might be responsible for low and mid latitude power system failures.

The dramatic complete failure of a transformer does not occur very often. However, there is evidence that the lifetime of transformers in GIC susceptible regions is shorter than the lifetime of transformers in non-GIC susceptible regions. This suggests that GIC more commonly affects transformers by small amounts over time. Since GIC are DC currents, the resistances of the power network are important and GIC cannot flow at all in lines having series capacitors. However, the use of series capacitors in transmission lines or in earthing wires of transformers is expensive and also technically not straightforward.

The interconnectedness, however, can lead to increased vulnerability in some circumstances. When a solar storm damages one system, systems connected to it can experience failure as well, as a chain effect. Enlarging [38] of existing big interconnecting network of electrical supply systems of neighbor countries such as Azerbaijan, Russia, Iran and Georgia makes vulnerable power grids: these kinds of large interconnected power grids have become in effect a large "receiving antenna" to the major geomagnetic storms, GICs and other space weather effects.

As we considered the period of relative economical and social stability in Azerbaijan, possible negative factors as a result of the occurrence of major socioeconomic changes in newly independent country towards the end of the 20th century, in our opinion, did not influence so deeply the major results of this paper. Despite these changes, however, the solar and geomagnetic activity parameters were in effect all the time, and studies conducted in other parts of the globe have confirmed the existence of similar effects even in mid-latitude-located developed countries [26, 39].

If an electric company or national grid network supplier is warned in advance of an approaching a strong local geomagnetic storm, it can take mitigating actions and/or various controlling measures including reducing system load, testing the capacitors, or disconnecting some system components for protection. Even systems in the middle latitudes (in our case, in the Northern Hemisphere) are at comparatively less increased risk caused by weak and mild geomagnetic storms, but during extreme events, like Great Geomagnetic Storm in March 1989 or in October-November 2003, boundaries of disturbances can be extended further towards mid-latitudes or even equator-ward. Considered period of 1994-2005 corresponds to the current 11-year solar activity cycle-23. This cycle had quite enough extreme solar events such as "Halloween" event in October-November 2003 with proton storms. Geomagnetic storms' effects were well displayed and enhanced especially in years of declining phase of solar activity cycle. Coming years of minimum activity, starting at 2006, will allow comparing results with ones obtained in years of high solar activity.

There are following tasks and plans to be implemented in near future:

- Very detailed consideration of problem for grand Baku capital city and Absheron Peninsula area (high dense population and electric supply systems);
- Study of phenomenon at the regional level (Azerbaijan, Georgia, Russia, Iran);
- Applying of "Metatech Applied Power Solutions" (US) developed Space Weather/Geomagnetic Storm System Impact Analysis and Forecast Service (POWERCAST) in Azerbaijani power industry with aims of deep study of considered problem for mid latitudes;
- Collaboration with domestic and regional power companies for nowcasting and/or forecasting of possible failures, damages during days with major geomagnetic storms;
- As it is now thought that fast coronal mass ejections (CMEs), which frequently accompany flares, are the main causes of geomagnetic effects on and around the Earth, we intend to study an influence of CME, particularly, fast halo-CME-caused geomagnetic storms on power systems, as well as proton flares', solar wind, solar cosmic rays' impact.

A space weather prediction service would enable power supply generators to take mitigating actions (to apply circuit protection measures such as capacitors or to disconnect some system components for protection, etc.) which would reduce the risk of transformer damage and minimize interruptions to power supplies, and hence produce cost savings.

Benefits for power distribution and supply industry will be: identification of worst case scenario, identification system behavior, identification the total risk, and identification of links to space weather. Analysis of these effects would help power operators in making preventive measures in order to provide uninterrupted power to customers.

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REFERENCES

1. Space storms and space weather hazards, I. A. Daglis (ed.), NATO Science Series, II. Mathematics, Physics and Chemistry. Kluwer Academic Publishers, vol.38, 2001.
2. Solar-terrestrial magnetic activity and space environment, H. Wang, R. Xu (eds.), COSPAR Colloquia series, vol. 14, 2002, 474 pages.
3. *T.K. Breus, S.I. Rapoport*. Magnetic storms: medical-biological and geophysical aspects. Moscow: PH "Sovetskii sport", 2003, 192 pages (in Russian).
4. *B.M. Vladimirskii, et al.* Space weather and our life. Fryazino: PH "Vek 2", 2004, 224 pages (in Russian).
5. *F. Jansen, R. Pirjola, R. Favre.* Space Weather Hazard to the Earth? Swiss Re Publishing, Zurich, 2000, 40 pages.
6. *E.S.Babayev*. Scintillation of transionospheric radio waves. European Space Agency (ESA) Publication EWP-2064. The Netherlands, ESA PD: ESTEC Repro, 2000, 185 pages.
7. *E.S.Babayev*. Space weather studies in Azerbaijan. Paper presented at the ESA Space Weather Workshop "Developing a European Space Weather Service Network (SWENET)", 3-5 November 2003, ESTEC, Noordwijk, The Netherlands". In: Abstract Book, 2003, p.83.
8. *E.S. Babayev*. Some results of investigations on the space weather influence on functioning of several engineering-technical and communication systems and human health. In: Astronomical and Astrophysical Transactions, UK: Taylor & Francis, vol.22 (6), 2003, pp.861-867.
9. *E.S. Babayev*. Space weather studies in Azerbaijan: influence on technological, ecological and biological systems. In: Program and Abstract Book of the International Symposium on "Solar Extreme Events of 2003: Fundamental Science and Applied Aspects", 12-14 July 2004, Lomonosov Moscow State University, M.I. Panasyuk and V.V. Kalegaev (eds.), Moscow, Russia. In: Abstract Book, 2004, p.63.
10. E.S. Babayev. Solar energetic events and their possible impact on some technological and ecological systems: results of studies carried out in Azerbaijan. Paper presented at AGU Chapman Conference on "Solar Energetic Plasmas and Particles", 02-06 August 2004, University of Turku, Turku, Finland. In: Abstract book, 2004, pp.48-49.
11. E.S.Babayev. Space weather influence on technological, biological and ecological systems: results of complex studies carried out in Azerbaijan. Paper presented at the 10-th Scientific Assembly of the International Association of Geomagnetism and Aeronomy (IAGA-2005), 18-29 July 2005, Toulouse, France. In: Abstracts CD, Abstract IAGA2005-A-00325, Copernicus Gesellschaft, 2005, p.64.
12. *E.S.Babayev, A.B.Asgarov, F.R.Mustafa.* Space weather studies in Azerbaijan: results and perspectives of investigations. In: Abstract Book of the Memorial International Conference "Astronomy and Space Physics at Kyiv University", 22-26 May 2005, Kyiv, Ukraine, 2005, p.96.
13. *E.S.Babayev.* An influence of changes of heliogeophysical conditions on the geosphere: results of complex investigations conducted in the Azerbaijan National Academy of Sciences. In: Abstract Book of the All-Russian Conference "Experimental and theoretical investigations of basis of forecasting of heliogeophysical activity", 10-15 October 2005, IZMIRAN, Russian Academy of Sciences, Troitsk, Russia, 2005, p.5. (in Russian)
14. *E.S.Babayev.* Space weather influence on the geosphere: results of complex studies conducted in the Azerbaijan National Academy of Sciences. The First IHY European General Assembly, Centre National de la Recherche Scientifique (CNRS), Paris, France, 10-13 January 2006. In: Abstract Booklet, 2006, p.19.
15. *E.S. Babayev, A.M.Hashimov, N.A.Yusifov*. Space weather and possible effects on the electric power generation and supply systems in Azerbaijan. In: Abstracts of the ESA Space Weather Workshop "Space Weather Applications Pilot Project", 16-18 December 2002, ESTEC, Noordwijk, The Netherlands, 2002. http://www.estec.esa.nl/wmwww/wma/spweather/workshops/spw_w4/index.html.
16. *E.S.Babayev, A.M.Hashimov, N.A.Yusifbeyli, A.B.Asgarov.* Space weather influence on electric power industry: potential impacts of geomagnetic storms on the electric power transmission and supply systems in Azerbaijan. In: "Technical and Physical Problems in Power Engineering" (Proceedings of the 2-nd International Conference "TPE-2004", Tabriz, 6-8 September 2004), Tabriz, I. R. Iran, 2004, pp. 512-521.
17. *E.S.Babayev, A.M.Hashimov, N.A.Yusifbeyli, A.B.Asgarov.* Solar extreme events of October and

November 2003 and their possible pnfluence on the electrical power supply systems in Azerbaijan. In: "Solar System Researches: Perspectives of Collaboration with ShAO" (Proceedings of the International Conference, ISBN: 9952-8003-2-0 & 5-8066-1700-9), 14-17 June 2004, ShAO, Shamakhy, the Republic of Azerbaijan. Baku: PH "Elm", 2004, pp.37-43 (in Russian).

18. *E. S. Babayev, A. M. Hashimov, N. A. Yusifbeyli*. An influence of changes of heliogeophysical conditions on the mid-latitude electric power supply systems. In: Proceedings of the 8-th Baku International Congress "Energy, Ecology, Economy" (under UNESCO auspices), Baku, 1-3 June 2005, F.Aliyev, I.Mirzaee and S.M.Pesteei (eds.), Baku, 2005, pp.25-29.
19. *E.S.Babayev, A.B.Asgarov*. An influence of severe geomagnetic storms on the electric power supply systems in Azerbaijan. In: Abstract Book of the Memorial International Conference "Astronomy and Space Physics at Kyiv University", 22-26 May 2005, Kyiv, Ukraine, 2005, p.95.
20. *E. S. Babayev.* An influence of space weather on electric power supply systems in the mid-latitudes. Paper presented at the 8-th Congress of EAAS and International Symposium "Astronomy-2005: current state and perspectives of development". In: Transactions of Shternberg State Astronomical Institute of Astronomy, Lomonosov Moscow State University, 2005, vol. LXXVIII, p.33.
21. *L.J. Lanzerotti.* Geomagnetic induction effects in ground-based systems. Space Sci. Rev., vol.34, 1983, pp.347-356.
22. *J.G. Kappenman, L. J. Zanetti, W. A. Radasky*. Space weather from a user's perspective: geomagnetic storm forecasts and the power industry. EOS Transactions of the American Geophysics Union, vol.78, No. 4, 1997, pp. 37-45.
23. *J.G. Kappenman*. An introduction to power grid impacts and vulnerabilities from space weather. NATO-ASI Book on Space Storms and Space Weather Hazards, I.A. Daglis (ed.), Kluwer Academic Publishers, NATO Science Series, Vol. 38, 2001, pp.335-361.
24. Space Weather Scales of the National Oceanic and Atmospheric Administration's Space Environment Center: http://www.sec.noaa.gov/NOAAscales/
25. *J.G. Kappenman.* Geomagnetic storms and their impact on power systems. IEEE Power Engineering Review, vol. 16, 1996, pp.5-8.
26. *J.G. Kappenman*. Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at low-latitude and midlatitude locations, Space Weather, vol.1 (3), 2003, p.1016.
27. *J.G. Kappenman*. An overview of the impulsive geomagnetic field disturbances and power grid impacts associated with the violent Sun-Earth connection events of 29–31 October 2003 and a comparative evaluation with other contemporary storms. Space Weather, vol.3(8), 2005, S08C01, doi: 10.1029/2004SW000128.
28. *J.D. Richardson, et al*. Solar wind oscillations with a 1.3-year period. Geophys. Res. Lett., vol. 21, 1994, pp.1559–1560.
29. *K. Mursula, B. Zieger*. The 1.3-year variation in solar wind speed and geomagnetic activity. Adv. Space Res, vol. 25, 2000, pp.1939-1942.
30. *R.Shapiro*. Interpretation of the subsidiary peaks at periods near 27 days in power spectra of geomagnetic disturbance indices. J. Geophys. Res., vol.72, 1967, p.4945.
31. *S. M. Silverman, R. Shapiro*. Power spectral analysis of auroral occurrence frequency. J. Geophys. Res.,vol. 88, 1983, pp.6310-6316.
32. *K. I. Paularena, A. Szabo, J. D. Richardson.* Coincident 1.3-year periodicities in the Ap geomagnetic index and the solar wind. Geophys. Res. Lett., vol. 22, 1995, p.3001.
33. *S. Bolton*. One year variation in the near Earth solar wind ion density and bulk flow velocity. Geophys. Res. Lett., vol.17, 1990, pp.37-40.
34. *B. Zieger, K. Mursula*. Annual variation in near-Earth solar wind speed: Evidence for persistent north-south asymmetry related to solar magnetic polarity. Geophys. Res. Lett., vol. 25, 1998, pp.841-844.
35. J.T. Gosling, et al. Solar wind speed variations: 1962-1974. J. Geophys. Res., vol.81, 1976, p.5061.
36. N.U. Crooker, J. Feynman, J. T. Gosling. On the high correlation between long-term averages of solar wind speed and geomagnetic activity. J. Geophys. Res., vol. 82, 1977, p.1933.
37. V.A. Kotov, V.I. Haneychuk, T.T. Tsap. Why does the Sun look like a magnetic S-polarity monopole? In: Proceedings of the 1st Potsdam Thinkshop on Sunspots and Starspots, K.G.Strassmeier & A. Washuettl (eds.), AIP, 2002, pp.137-138.
38. N.A. Yusifbeyli. Tasks of dispatcher management in new conditions of functioning and development electro-energetic system. Baku: PH "Elm", 2004, 199 pages (monograph in Azerbaijani).
39. N.A. Bobko, P.V. Vasilik. An influence of cosmogeophysical factors and day times on the breakdown rate in the energetics of Ukraine. In: Abstracts of the 4-th Interdisciplinary Seminar "Cosmos and Biosphere. Physical Fields in Biology, Medicine and Ecology", 1-6 October 2001, Krym, Partenit, Ukraine. http://cosmobio.science-center.net/ russian/conf/c01/4_11. html.