The Solar Event of 14–15 July 2012 and Its Geoeffectiveness

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Abstract During Solar Cycle 24, which started at the end of 2008, the Sun was calm, and there were not many spectacular geoeffective events. In this article, we analyze the geomagnetic storm that happened on 15 July 2012 during the 602nd anniversary of the Polish Battle of Grunwald, thus we propose this event to be called the “Battle of Grunwald Day Storm”. According to NOAA scale, it was a G3 geomagnetic storm with a southward component of the heliospheric magnetic field, B_z , falling to -20 nT, minimum Dst index of -139 nT, AE index of 1368 nT, and Ap index of 132 nT. It was preceded by a solar flare class X1.4 on 12 July. This geomagnetic storm was associated with the fast halo coronal mass ejection at 16:48:05 UT on 12 July, first appearance in the Large Angle and Spectroscopic Coronagraph C2, with a plane-of-sky speed of 885 km s^{-1} and maximum of 1415 km s^{-1} . This geomagnetic storm was classified as the fourth strongest geomagnetic storm of Solar Cycle 24. At that time, a significant growth in the failures of the Polish electric transmission lines was observed, which could have a solar origin.

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1. Introduction

Solar activity powered by strong magnetic fields is the principal cause of space weather disturbances, which affect technological infrastructure in space, communications, and GPS signals, and couple through geomagnetically induced currents (GICs) with the large-scale high voltage power grid. Since the famous Quebec blackout in March 1989, there is general consensus that space weather disturbances constitute a severe threat (Bolduc, 2002). The leading cause of this threat is the interaction of the geomagnetic field with the magnetic field carried by coronal mass ejections (CMEs) and the surrounding background magnetized solar wind modulated by them.

Over the past decades, many articles have explored the potential impact of extreme space weather events on the electricity supply infrastructure (e.g. Oughton et al., 2017; Schrijver, 2015; Schrijver et al., 2014, 2015; Juusola et al., 2015; Showstack, 2011). In particular, space weather phenomena may affect the physical infrastructure (e.g. transformers) required to handle electricity transmission and it is necessary to prevent voltage instabilities, which will consequently protect the power system resources from damage. Schulte in den Bäumen et al. (2014) showed that a 10% reduction in electricity supply to the Earth's most populated and highly industrialized regions due to a severe geomagnetic storm could impact the global economy on the same scale as wars and global financial crises. Schrijver et al. (2014) found that insurance claim rates for industrial electrical equipment across North America rose significantly on days with enhanced geomagnetic activity.

The above mentioned failures on energy infrastructure make society aware that geomagnetic storms, and thus GICs, are the result of a very complicated sequence of events derived from the magnetic energy accumulated in the interior of the Sun (e.g. Thorberg, 2012). When developing and maintaining national power systems, it should be taken into account that geomagnetic storms pose an authentic threat and can cause significant damage to both the power system and other critical infrastructures.

Among the main solar-driven phenomena which tend to be associated with a geomagnetic storm one can include events like: solar flares, solar energetic particle (SEP) events, CMEs, ionospheric disturbances creating radio and radar scintillation, disruption of navigation by magnetic compass failures and auroral displays at much lower latitudes than usual. All those phenomena lead to the disturbances of the heliospheric magnetic field and, as a consequence, distort the Earth's magnetic field.

Statistical analysis of a series of sequences of space weather events leading to significant distortions of the geomagnetic field resulting in power-line failures are quite tricky due to their complexity. Thus, in this article, we decided to analyze in detail one geomagnetic storm and all accompanying disturbances in the interplanetary space and discuss how they are related to affect the geomagnetic field. This sequence of events, in our view, has led to an increase in the failures of the electrical transmission lines in Poland. Here we do not mean critical damages leading to a blackout, but the accumulation of minor failures in the transformers that, in some sequence, might cause power outages. If not correctly handled, the socio-economic consequences of such failures can be severe. Significant implications for the power system should be considered locally. Therefore, it is valuable to analyze whether and to what extent space weather effects influence the Polish energy infrastructure.

The geomagnetic storm analyzed in detail in this article happened on 15 July 2012, on the 602nd anniversary of the Polish Battle of Grunwald. According to the NOAA scale, it was a G3 geomagnetic storm with a southward component of the heliospheric magnetic field, B_z , falling to -20 nT, minimum Dst index of -139 nT, AE index of 1368 nT, and Ap index of 132 nT. This geomagnetic storm was accompanied by a fast halo coronal mass ejection at 16:48:05 UT on 12 of July, first appearance in the Large Angle and Spectroscopic Coronagraph (LASCO) C2, with a plane-of-sky speed of 885 km s^{-1} and maximum of 1415 km s^{-1} (Gopalswamy et al., 2016, 2014). The overall ionospheric response to this storm was studied by Wang et al. (2013), Liu et al. (2014), Kuai et al. (2017), and Hocke et al. (2019). This geomagnetic storm was classified as the fourth strongest geomagnetic storm from Solar Cycle 24. Around that time in the Polish electric transmission lines infrastructure, a noteworthy growth of the number of failures was observed that could have a solar origin.

The article is organized as follows: in the first section, we introduce the overall scenario during what we call the Battle of Grunwald Day event. In the second section, we describe the solar and interplanetary conditions. The third and the fourth sections introduce the geomagnetic field variability and ionospheric disturbances visible in the total electron content (TEC) during the event, respectively. The fifth section describes the geoeffectivity of the July event on the transmission lines failures. In the last section, we summarize our investigations.

2. Solar and Interplanetary Conditions

A solar flare of X1.4 class started on 12 July 2012 at 15:37 UT from a source located at S14 W02, active region (AR) NOAA number 11520. Its peak time was at 16:49 UT and its end time at 17:30 UT. During the considered time interval six active regions were observed with NOAA numbers from 11518 to 11523. The most complex one AR 11520 is shown in an image from Extreme Ultraviolet Imaging Telescope (EIT) in Figure 1. During the preceding days, they were sources of several C-class and three of M-class flares.

As a result of the solar flare, we observe in Figure 2 the rapid growth of the X-ray flux seen by GOES on the afternoon of 12 July 2012. The X-ray flux reached its maximum around 17:00 UT on 12 July and then gradually decreased, reaching the initial level at noon on 13 July.

The solar flare was also accompanied by a halo CME with the first LASCO C2 appearance at 16:48:05 UT. The estimated second-order speed at 20 Rs (solar radii) was 2265 km s^{-1} (Gopalswamy et al., 2016, 2014). From 01:48 UT on 12 July to 23:48 UT on 15 July according to SOHO/LASCO CME catalogue forty two CMEs were observed.

Figures 3–4 illustrate the interplanetary conditions observed by the Advanced Composition Explorer (ACE) with 64-second resolution and 1-hour data downloaded from OMNIWeb 14–16 July 2012. The horizontal axis indicates the day-of-year (DOY), while the vertical ones correspond to the heliospheric magnetic field (Figure 3) B_z , B_y , and B_x components, solar wind velocity V_z , V_y , and V_x components (Figure 3), both in the GSE coordinate system the proton temperature T_p , proton density N_p , solar wind (SW) speed, and flow pressure (Figure 4).

The first panel of Figure 3 shows that around 18:00 UT on 14 July 2012 (DOY 196) the HMF B_z component dropped below -20 nT, growing to 20 nT at the end of that day and next falling to -20 nT at the beginning of 15 July 2012 (DOY 197), being southwardly directed and below -10 nT for more than 30 hours. It is worth mentioning that the high sensitivity of the magnetosphere to minor solar wind pressure amplifications when the HMF is directed strongly southward during a long time interval, has already been proposed (Lee

Figure 1 Solar disk from EIT 195 (on board the Solar and Heliospheric Observatory (SOHO)) on 12 July 2012 (the leftmost AR is the most complex one, source: www.helioviewer.org).

Figure 2 GOES X-ray flux with a 5-minute resolution for 12–14 July 2012 (source: www.solarmonitor.org).

and Lyons, 2004). The first symptoms of disturbances strengthening reflected in the B_z component of the HMF are also visible in the B_x and B_y components changes. The HMF variability was a consequence of the halo CME passing through the Earth's magnetosphere as seen in Figure 5.

Figure 5 shows results of ENLIL model (Odstrčil, Smith, and Dryer, 1996) simulating of the dynamical 3-dimensional heliospheric conditions by the Community Coordinated Mod-

Figure 3 HMF B_z [nT], B_y [nT], and B_x [nT] components (top panel) and absolute value B [nT] (second panel from the top), V_z [km/s], V_y [km/s], and V_x [km/s] components (third panel from the top), and velocity absolute value V [km/s] (fourth panel from the top). All variables are in the Geocentric Solar Ecliptic (GSE) coordinate system and are shown from 14–16 July 2012 in function of time indicated as the day-of-year (DOY 196–198). Data are from ACE with 64-second resolution.

eling Center (CCMC). A full CCMC animation of the CMEs temporal and spatial evolution around the studied event can be found in <http://helioweather.net/archive/2012/07/vel3e1.html>.

Since a CME structure can lead directly its space weather effects to Earth (e.g. Gopal-swamy, 2016): the outermost structure (shock) accelerates particles and causes a sudden commencement, the interior structures (sheath and flux rope) cause geomagnetic storms if they possess a strong southward component of their magnetic field. The negative HMF B_z observed in Figure 3 caused the interconnection between the HMF and the Earth's magnetic field lines. Figure 3, third panel, displays that almost at the same moment, the end of DOY 196, a drastic decrease in solar wind speed V_z , V_y , and V_x components to -255 km s^{-1} , -219 km s^{-1} , and -700 km s^{-1} , respectively, occurs. The accompanying shock, as the HMF discontinuities, compressed, heated, and altered the bulk velocity of the plasma, resulting in pressure, density and temperature increase as seen in Figure 4: it could also accelerate particles as seen in Figure 6.

Figure 4 presents the growth of the proton temperature T_p to $6.45 \cdot 10^5$, a bit later the proton density N_p to 40 n cm^{-3} and solar wind speed up to 695 km s^{-1} . The solar wind dynamic pressure influences the overall magnetosphere state via a pressure balance (e.g.

Figure 4 Proton temperature T_p [K] (top panel), proton density N_p [n/cm³] (second panel from the top), 1-min resolution solar wind speed SW [km/s] (third panel from the top), and flow pressure [nPa] (fourth panel from the top) for 14–16 July 2012 in function of time indicated as the day-of-year (DOY 196–198) from OMNIWeb.

Lopez and Gonzalez, 2017); during the studied event, the flow pressure increased up to 27 nPa.

The interplanetary shock of FF (fast forward) type was registered on 14 July at 17:39:09 UT (www.cfa.harvard.edu). The consequences of the disturbances in the heliosphere are also seen in the cosmic ray flux variability. As an example, Figure 6 and Figure 7 present the cosmic ray proton and helium fluxes measured by GOES and Oulu neutron monitor (NM) for 12–16 July 2012, respectively.

Figure 6 shows the significant growth of cosmic ray fluxes on 12 July 2012 (DOY 194) as a consequence of the solar flare. At 06:00 UT on 14 July 2012, (DOY 196) the subsequent peak is seen in the cosmic ray flux from 0.74–15 MeV/n for protons (top panel), 3.8–20 MeV/n for helium (second panel from the top), and for the integral proton flux > 10 MeV/n (third panel from the top). Starting on 15 July 2012 (DOY 197), due to the CME passage, the depression in cosmic ray flux variability in the wide energy interval from few MeV was observed by GOES. This decrease in cosmic ray intensity was also recorded by ground neutron monitors up to ≈ 10 –15 GeV as confirmed by Oulu NM (Figure 7) for which the maximum depression rate was $\approx 12\%$. This kind of decrease of cosmic ray flux on Earth is known as a Forbush decrease (FD). FDs are usually (but not in all cases; see e.g. Kudela and Brenkus, 2004) related to geomagnetic storms. FDs are sometimes ob-

Figure 5 Solar wind radial velocity contour plots shown in the ecliptic (left panel), meridional (middle panel), and radial (right panel) planes for: (a) 14 July 2012 at 12:00 UT, (b) 15 July 2012 at 0:00 UT (source: <http://helioweather.net/archive/2012/07/vcl3e1.html>, ccmc.gsfc.nasa.gov).

served non-simultaneously. The global simultaneity of FDs depends on the speed and HMF strength of the solar wind overtaking Earth's magnetosphere and its propagation direction (Oh, 2008; Badruddin et al., 2019).

Figure 6 GOES 13 proton (top panel) and helium (second panel from the top) fluxes [MeV/n] for different energy bins with 1-hour resolution, and 5-minute integrated proton flux (third panel from the top) for 12–16 July 2012 from OMNI in function of time indicated as the day-of-year (DOY 194–198).

Figure 7 Galactic cosmic ray intensity by Oulu neutron monitor in [%] with 1-minute resolution for 12–16 July 2012 with the day-of-year (DOY 194–198) marked on the horizontal axis.

3. Geomagnetic Field Variability in Poland

The above-described situation was mirrored by the behavior of Earth's magnetosphere. The CME-driven shocks (e.g. Reames, Barbier, and Ng, 1996) that compressed the magnetosphere initiated on 14 July 2012 at 18:09 UT a sudden storm commencement, registered by

Figure 8 Geomagnetic field components, B_X [nT] and B_Y [nT], from Belsk Observatory with 1-minute resolution on 14–16 July 2012 (196–198 DOY), on the horizontal axis the day-of-year.

Figure 9 Time derivative of geomagnetic field components, $\frac{dB_X}{dt}$ [nT min⁻¹] and $\frac{dB_Y}{dt}$ [nT min⁻¹], from Belsk Observatory with the 1-minute resolution from 14–16 July 2012 (196–198 DOY).

21 contributing observatories (<http://www.obsebre.es>). Firm compression of the magnetosphere, related to the above-mentioned CME arrival and passage, was detected over Poland, as well as other regions on Earth as shown by Dst and SYM-H. In particular, the horizontal B_X (N-S direction) and B_Y (E-W) geomagnetic field components measured in Belsk Observatory (Figure 8), part of the International Real-time Magnetic Observatory Network (INTERMAGNET), were rather disturbed due to the solar activity starting practically from the beginning of July 2012. The highest B_X value was observed in the evening of 14 July (196 DOY) and the lowest in the morning of 15 July. The highest and the lowest value of the B_Y component, both occurred in the second half of 15 July. The perturbations of the geomagnetic field are more clearly visible in $\frac{dB}{dt}$ shown in Figure 9. The fastest changes in the B_X component were registered on the evening of 14 July and in the B_Y component on the morning of 15 July.

Considering the geomagnetic field disturbances in Poland, that we have just discussed, we show now the local geomagnetic indices. We illustrate the variation of the K-index and

Figure 10 K- and E-index from Belsk Observatory from 14–16 July 2012 (196–198 DOY).

Figure 11 Geomagnetic indices from OMNI Ap [nT], Dst [nT], and AE [nT] for July 14–16 2012 with marked on the horizontal axis the day-of-year (DOY 196–198).

E-index from the Belsk Observatory (Figure 10). The K-index remained in a value of no less than 5 practically for the entire studied period reaching the highest value equal to 7 in the range 18:00–21:00 UT on 15 July. This was the case in other INTERMAGNET observatories in Poland, i.e. Hel and Borowka Gora.

Figure 11 presents the geomagnetic indices: Ap, Dst, and AE for 14–16 July 2012. At the end of 14 July 2012 (DOY 196) at ~19:00 UT, there were strong disturbances observed in the Earth's magnetosphere, reflected in the Ap and AE indices, showing a large variability up to 17 July 2012 (DOY 199). The Dst index was -139 nT on July 15 July 2012 (DOY 197), Ap and AE indices reached the highest values of 132 nT and 1368 nT, respectively, also on 15 July 2012 (DOY 197) closely following the HMF B_z changes.

4. Ionospheric Disturbances Visible in TEC During the Event

Intense X-ray fluxes during solar flares are known to cause enhanced ionization in the Earth's ionosphere. This sudden change of ionospheric electron density profile is a serious problem to radio wave communication and navigation systems. The sudden ionospheric disturbances due to solar flares result in a sudden increase on the total electron content (e.g. Garriott et al.,

Figure 12 Vertical TEC spatial distribution of relative negative and positive changes (in %) to the median TEC based on data selected from Global Navigation Satellite System (GNSS) stations for: **(a)** 14 July 2012 at 12:00 UT, **(b)** 15 July 2012 at 0:00 UT. White squares mark a lack of data. An animation showing the variation of the data displayed in this figure is attached as electronic supplementary material (Temporal and spatial behavior of TEC around the Grunwald Battle Storm).

1967; Mendillo et al., 1974), high-frequency radio wave blackouts (e.g. Thomson, Rodger, and Dowden, 2004), and an enhancement of the magnetic field variation (e.g. Lui, Chiu, and Lin, 1996).

X-rays emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications. Direct radio emission at decimetric wavelengths may disturb the operation of radars and other devices that use those frequencies. Hence, X-ray flux can be used as a good proxy for studying solar flare effects on the lower ionosphere. The ground magnetometers often record the sudden change in the sunlit hemisphere during the enhanced X-ray flux. Due to the sudden increase in the global ionospheric current system caused by the flare-induced enhanced ionospheric conductivity. These geomagnetic field disturbances are known as “solar flare effects” or geomagnetic crochets (Campbell, 2003).

We consider here the state of the ionosphere given by the total electron content (TEC) around the Grunwald Battle event. The TEC shows the electron columnar number density, i.e. it is integrated between two points along a cylinder of one meter squared cross-section (e.g. Jakowski, Schlüter, and Sardon, 1999; Grynshyna-Poliuga et al., 2015). We computed the vertical TEC based on data from Receiver Independent Exchange Format files obtained from the International Global Navigation Satellite System (GNSS) Service and the Regional Reference Frame sub-commission for Europe network. Raw data were used to compute the TEC for each station and slant TEC for every direction to the satellite. Slant TEC values have been reduced into vertical TEC using a single layer ionospheric model. TEC values have been binned into 5 degrees latitude by 5 degrees longitude grid and for each cell the median value has been computed every 15 minutes. The derived TEC data, namely the deviation from the mean value, is presented in Figure 12. The left panel shows that at the beginning of the studied event, on 14 July 2012, the TEC was undisturbed, but the right panel indicates large deviations from the average TEC behavior on 15 July 2012. The relative TEC variability during the storm passage becomes noticeable, without significant spatial fluctuations in the considered area of southern Poland, exceeding in this sector $\approx 50\%$. Our results follow the pattern described by Hibberd and Ross (1967), with TEC variations being mostly positive during the first 24 hours of the storm. It must be underlined that the primary mechanism responsible for the TEC time profile during this storm was the disturbance dynamo electric fields effect (Liu et al., 2014). In the supplementary material to the article,

there is a full animation of the temporal behavior of the TEC around the Grunwald Battle Storm.

5. Impact of the July 2012 Event on the Transmission-Line Elements

Currently, on the Polish energy market, apart from the Tauron Group (TG), there are three large vertically integrated energy groups: the Polish Energy Group (Polska Grupa Energetyczna, PGE), Enea as well as Energa. In 2018, gross electricity production in Poland amounted to 170 TWh while domestic energy consumption in the country amounted to 176 TWh and was higher by $\approx 2\%$ than the previous year.

The share of Distribution System Operator (DSO) TAURON Capital Group in the domestic electricity generation market, measured by gross electricity production, in 2018 amounted to $\approx 10\%$. The TG is the third-largest electricity generator on the Polish market (with an installed capacity of 5.0 GW). The TG supplies approximately 50 TWh of electricity to over 5.6 million customers per year, which makes it the largest distributor of power in Poland. The length of the line calculated per track with connections is 270 189 km. The overall TG system includes, among others, 11 143 km of high voltage (HV) lines, 487 HV/MV stations and 58 611 transformers (e.g. Gil et al., 2019). In this article, we considered data from the region of Poland, which is covered by radial grids with a single power supply by TG. The TG routines implement power supply based on modern technological solutions having the potential of guaranteeing the clients security of supply (e.g. Szmitkowski, Gil-Swidorska, and Zakrzewska, 2019).

We have studied all the logs from the DSO around the July 2012 event. Three types of failures, which might have been connected or at least strengthened by the space weather phenomena, have appeared: failures associated with the ageing of infrastructure elements, related to breakdowns or switching-off of electronic devices, and failures having unrecognized causes. This labeling is in agreement with that noted by Zois (2013), where it is stated “GICs should not be thought of as a single cause of a fault, but as a stress that exposes relative weaknesses, which become localized hot spots and eventually lead to failure. Thus in many cases, these failures can be attributed to ‘ageing’ or ‘manufacturing defects’”. We do not consider here the failures which had objective causes, i.e. vandalism, operational shut-downs, and meteorological effects (details about all categories of failures can be found in Gil et al., 2020).

Figure 13 displays quantitative changes in the transmission-line failures during the studied interval. It shows that the first growth, up to 99, in the number of failures having unknown reasons appeared precisely at the time when solar wind speed and flow pressure reached their maximal values, 695 km s^{-1} and 27 nPa , respectively (Figure 4, third and fourth panels from the top, respectively). The second, smaller increase occurred after the time when the K index from Belsk reached the highest value, when the geomagnetic conditions were still unsettled. It is also clearly visible the delay effect, which we connected to the cumulative impact as a consequence of transient state (e.g. Fujita, Watanabe, and Akagi, 2001) propagation in the distribution network. In transmissions lines repeatedly appear short circuit faults. One of main triggers is lightning (Martinez-Velasco, 2020; Parsi and Crossley, 2018; Hashim et al., 2018). Transient states are sometimes connected with cascade failures (Yan et al., 2015). Their propagation was discussed in (Tarczynski, 2006). Various power-system analysis approaches in transient studies are widely discussed in the literature (Gertrudes, Tavares, and Portela, 2011; Grivet-Talocia et al., 2004; Smith, 1969).

Figure 13 Electrical-grid failures (EGFs) which might be of solar origin with 1-hour resolution on 14–16 of July 2012 (196–198 DOY).

Discussion of various time-delay durations can be found in Vybostokova and Svanda (2019). The visible increase in the number of failures caused by the ageing of infrastructure elements appeared precisely at the time of rapid changes of $\frac{dB_X}{dt}$ [nT min⁻¹] and $\frac{dB_Y}{dt}$ [nT min⁻¹] (Figure 9), especially visible in the second component. It was also the time of the highest K index value. The only rise in the number of failures caused by the electronic-device disturbances appeared right after the highest variability in $\frac{dB_Y}{dt}$ [nT min⁻¹]. It might also be connected to the time when the lowest value of the B_X geomagnetic component was registered.

6. Discussion

Solar Cycle 24 did not abound in strong space weather events. The studied event was, according to the NOAA scale, a G3 geomagnetic storm. The B_z heliospheric magnetic field component dropped to -20 nT and the geomagnetic indices: Dst to -139 nT, AE reached 1368 nT, and Ap 132 nT. The storm was preceded by a solar flare of X1.4 class on 12 July 2012. This geomagnetic storm was preceded by a fast halo CME. This case study shows that geoeffective space weather events may strengthen the growth of transmission-line failures in Poland, which are categorized as: disruptions linked with electronic devices, ageing of the infrastructure elements, as well as having unidentified reasons. Belakhovsky et al. (2017) summarized that interplanetary shock effects might be considered as a substantial factor in power stability issues. During the Grunwald Battle event, the first increase of failures having unknown reasons (up to 99) appeared precisely at the same time when the flow pressure reached 27 nPa being at its maximal value (fourth panel from the top in Figure 4). The following growth occurred during still unsettled geomagnetic conditions, after the time of rapid changes in the geomagnetic field horizontal components $\frac{dB_X}{dt}$ and $\frac{dB_Y}{dt}$ (Figure 9), as well as the time the K index from Belsk reached its highest value (Figure 10). It also matches exactly the time of disturbances visible in the TEC (Figure 12). The noticeable intensification in the number of failures caused by the ageing of infrastructure elements occurred exactly at the time of prompt changes in geomagnetic field components $\frac{dB_X}{dt}$ and $\frac{dB_Y}{dt}$ (Figure 9), especially visible in the latter. It was also the time of the highest K index value. The single increase of the number of failures caused by the electronic-device disturbances was noticed

right after the highest variability in $\frac{dB_Y}{dt}$. It might also be linked to the time interval of the smallest registered value of the B_X geomagnetic component. Moreover, the observed delay in transmission-line disruptions may have appeared due to the cumulative effect as a consequence of a transient-state propagation in the distribution network.

Efforts to develop a universal solar wind–magnetosphere coupling function are still ongoing without a success in revealing a unique coupling function valid in any conditions. It was shown by Newell et al. (2008), that if this unique coupling function existed, it must contain the solar wind velocity and the transverse HMF component. Incorporation of the interplanetary electric field in this coupling function gave also good results (e.g. Spencer et al., 2009).

Summarizing, an investigation of each of the space weather events which have impact on Earth, from a perspective of failures occurring around the event time in transmission lines, may result in the emergence of a mutual characteristic of the state of the ionosphere, geomagnetosphere, and near Earth space. This type of work may contribute to revealing the reasons leading to the increase in the number of failures.

7. Conclusions

- i) Individual analysis of each of solar active and geoeffective events in the context of transmission-line failures can lead to knowledge of the set of features of the state of the Sun and the near heliosphere, ionosphere, geomagnetosphere, which may contribute to the growth in the number of failures.
- ii) During the Battle of Grunwald day, around 15 July 2012, we found that space weather geoeffective events could have strengthened the growth of transmission-line failures in Poland having the following causes: disruptions linked with electronic devices, ageing of the infrastructure elements, and some having unknown reasons.
- iii) The noticed delay in transmission lines disruptions might have appeared due to the cumulative effect of a transient-state propagation in the distribution network.

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