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Protection of the Smart City against CME

Krzysztof Lewandowski *

Wroclaw University of Technology, Wrocław, Poland

Abstract

Today life in many cities strongly depends on electricity. In many articles we can find designs of smart, clean and beautiful modern cities. All aspects of activity in cities are based on the use of control and supply systems. All of them use electricity as control signals and as power. A big but underconsidered problem is reliability of city substructures against Coronal Mass Ejection (CME) from the Sun. These events may damage elements of basic importance for life of people in cities. The article suggests some kinds of protection for the city substructures against CME.

Peer-review under responsibility of the organizing committee of Green Cities 2016.

Keywords: Smart city, CME (Coronal Mass Ejection), Resilience Modelling, blackout, electrical networks, communications networks, Carrington event

1. Introduction

Extensive use of electricity is still being developed to power big and small devices in houses and companies. That can be stopped by one accident + massive blackouts of electrical networks. The source of this accident is outside of the Earth. That is our everyday morning star - the Sun. Since the first use of an electrical power network in September 1882, failures of this system have been noticed under the influence of the Sun activity. Flares generated by the Sun are linked with some form of solar activity - the CME (Coronal Mass Ejection). CME has a great kinetic and electric energy. At the time of contact with the magnetic field of the Earth it ionizes the upper atmosphere and generates geomagnetic storms. During normal activity of electrical networks this can generate surge voltages. This can destroy transformers and cables.

* Corresponding author. Tel.:+0-48-320-41-51; fax:+0-48-320-27-15..
E-mail address: krzysztof.lewandowski@pwr.edu.pl

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When the first electric power plant was opened in 1881, at first slowly but then faster and faster, electricity became more and more popular (Koester F., 1913). This revolutionized the reloading equipment in harbors and railway stations (Lewandowski K., 2015) and household appliances. In 1911, the following words were used: *Electricity, the silent, mysterious handmaiden of modern scientific and mechanical progress is knocking at the door of every home. She is mute. She has no followers! She wants no “"afternoon off.” She lets you fix her wages. The children do not bother her. So long as there is a trolley line from which she can obtain necessary encouragement when her spirits are low, she works just as well in the country as in the city. She is never ill, never tired. She does not sleep. She always works at a maximum speed which you fix yourself.* Tarkington H. (1911). Also, electricity was shown as a new possibility for building houses. (Fig.1)

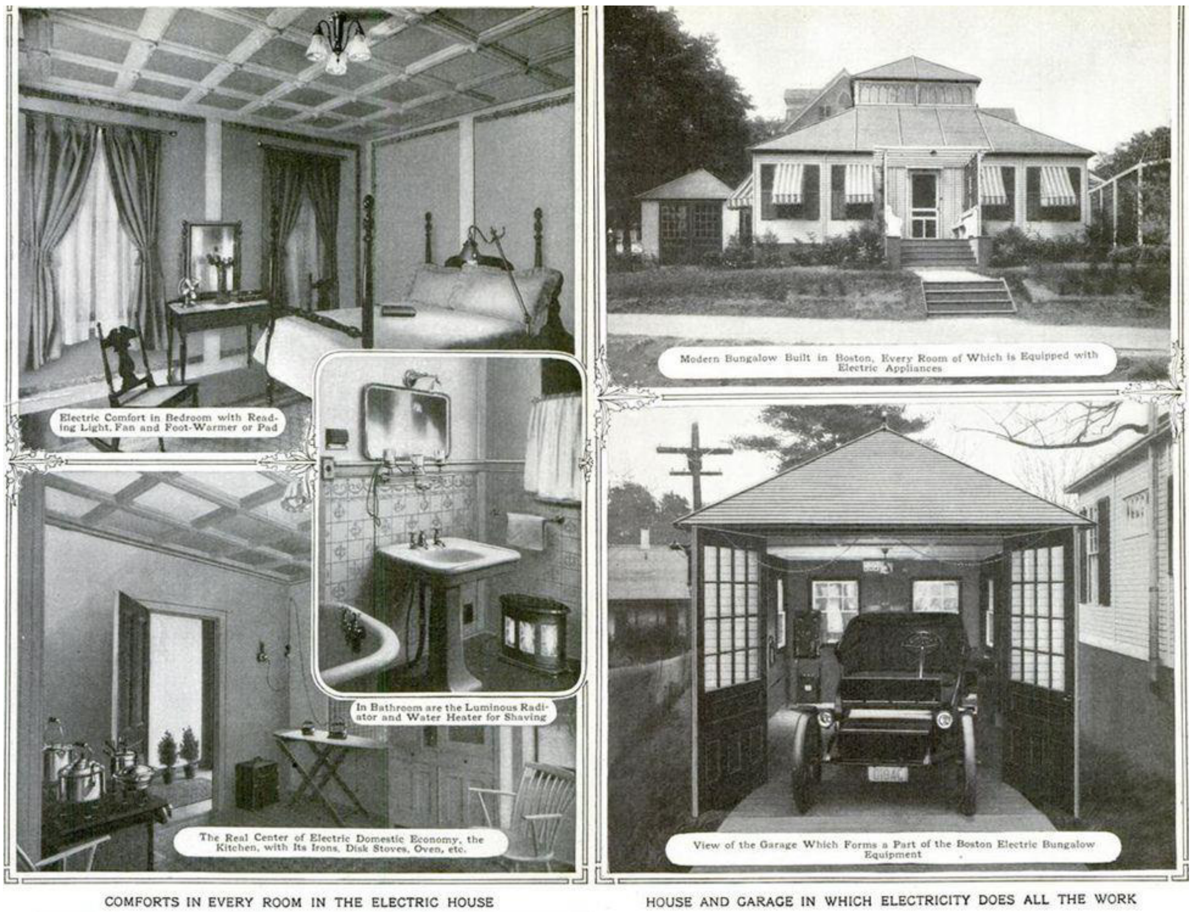


Fig.1. Electricity as the new possibilities for building houses in 1911 Tarkington H. (1911)

In 1912 the applications of electricity were presented as the wonders of the modern world based on the international poll: 1. Wireless 2. Telephone 3. Aeroplane 4. Radium 5. Antiseptics and Antitoxins 6. Spectrum Analysis 7. X-Ray (Windsor H.H., 1912).

Six out of seven of these new wonders used electricity. Similar results were obtained two years later. In 1914, polls from Berlin and Paris were presented. The electric dynamo was chosen as the new wonder in Paris (THE SEVEN. 1914). A much more professional opinion about the influence of electricity for the world can be found in the words of Dr Samuel W. Stratton, President of the Massachusetts Institute of Technology in 1928. Stratton selected **nine** new wonders, (Wheeler E.C., 1928):

1. The discovery of bacteria and application of bacteriology to human welfare,
2. The progress of our knowledge of the constitution of matter and radiation phenomena,
3. The progress of electricity as to light, power and communication,
4. The internal combustion engine and its application,
5. Modern method of structure building with both metal and cement,
6. Modern metallurgy,
7. Process of food preservation, including canning and refrigeration,
8. Aircraft and aerial navigation,
9. The development of the machinery to lessen the burden of labor and to increase its output.

Most of these new wonders used electricity (Fig.2). Today, electricity is in common use. We do not take into consideration how heavily our economy depends on electricity. Each city could lose its power supply by cutting off the electric grid as a result of icing, as in Szczecin in 2008 (Lewandowski K., 2011) or CME.

CME is much more dangerous for the city. Icing usually cuts off an electric line, while CME burns large power transformers. They are not held in stock by the manufacturers, but are produced on request, which takes about one month. Such a long time without electricity can cause significant losses in revenue for the city and the population.

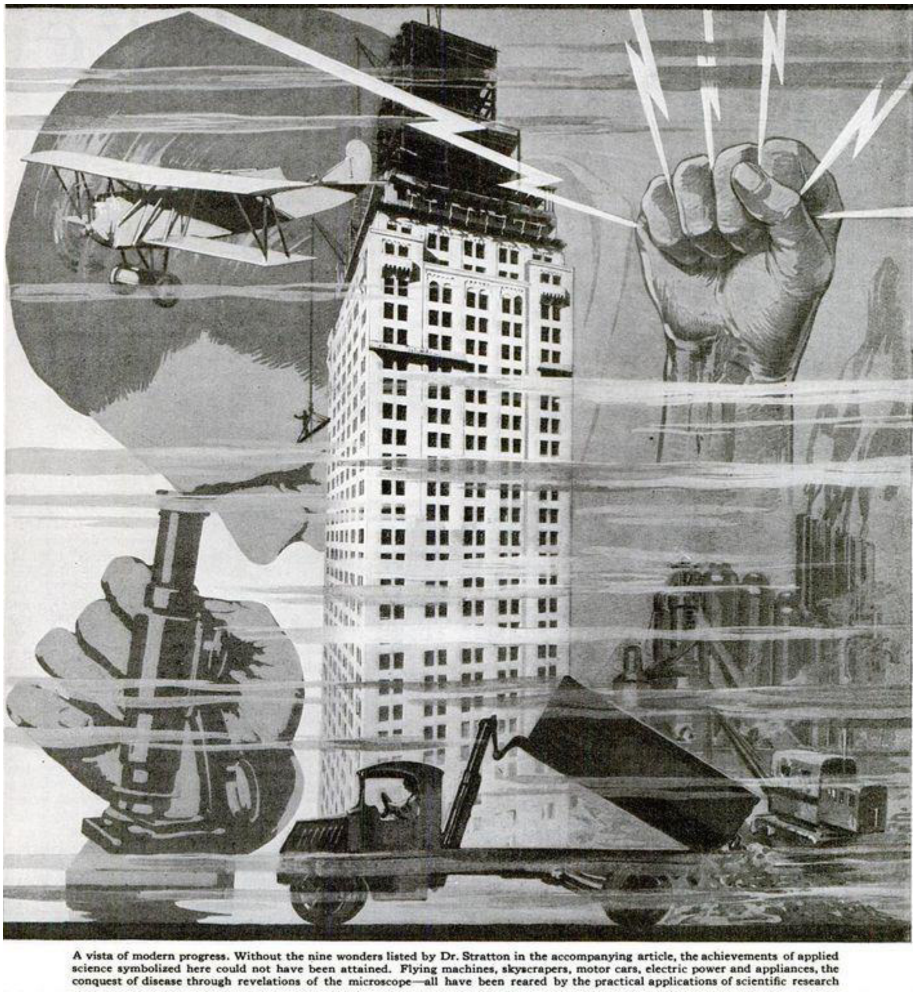
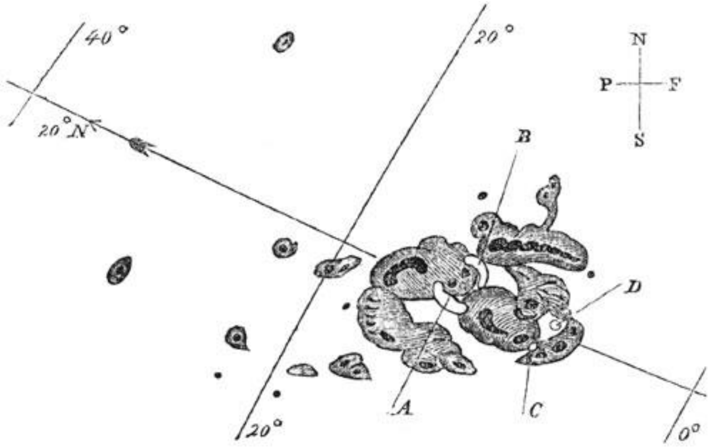


Fig.2. New nine wonders in 1928 (Wheeler E.C., 1928)

2. Review of papers on the influence of CME on cities

In the past, several big blackouts of electrical systems occurred in cities. The first damage caused by CME took place in 1859. In that year, at the end of August, the English astronomers Richard C. Carrington and Richard Hodgson observed numerous sunspots on the Sun. On September 1 they saw a massive solar flare also called the Aurora Borealis or the Northern Lights (Fig.3). This flare was associated with a major coronal mass ejection (CME) and it travelled directly toward the Earth, taking 17.6 hours to make the 93 million mile journey (Odenwald, S. F.; Green, James L. 2008). A giant geomagnetic storm started on the Earth. Activity of this phenomena caused a failure of the telegraph systems in Europe (England, Sweden), North America, the Bahama Islands, Cuba, India and Australia. A lot of telegraph operators suffered from electric shocks (Le Figaro, 1921; Jaworowski Z., 2009; Wik.M. et al., 2012).

Fig.3. Sunspots of 1 September 1859 seen by Richard Carrington, Carrington, R. C.(1859)



Later, another CME hit the Earth’s magnetopause.

In November 1882, CME damaged the telegraph systems in Europe and the USA. Telluric currents - five times stronger than normal - were observed (Angot A., 1896).

On 14-15 May 1921, a strong geomagnetic storm was observed on the Earth. This time it affected a large number of electrical networks. This event disturbed the work of telegraph, telephone and electric power networks in the USA, Europe, Australia, New Zeeland. Surge voltages generated in overhead lines moved interference to undersea cables which connected Europe with America and Australia with the rest of the world (NYT, 1921,3; HNS, 1921; NYT, 1921,1). In the USA, telegraphic and telephone lines were paralyzed from northeast to southwest, from Maine to Arizona and New Mexico (BDR, 1921), and from Maine to Ohio (NYT, 1921,1). The signal system of a transport company – the New York Central Railroad - was damaged by fire of the signal tower (NYT, 1921,3; NYT, 1921,2). In Switzerland, 20mA telluric currents were noticed in telegraphic lines in the north regions (SBZ, 1921). In north-west France telegraphic lines were paralyzed (NYT, 1921,4; LeMartin, 1921,2). Between 14 and 15 May 1921, the Aurora Borealis could be seen in Paris (LeMartin, 1921,1; Le Figaro, 1921). In Poland, telegraph and telephone lines were also damaged. At that time, Poland was just after the war with the Soviet Russia. The bad condition of the telegraph and telephone lines was explained as resulting from the lack of proper maintenance (Dziennik, 1921).

On 9 March 1989, the greatest damage caused by CME was observed on the Earth. On that day the CME which had originated on 6 March reached the Earth. On the same day, a big CME occurred on the Sun and arrived on 13 March. This evoked a huge geomagnetic storm. Its activity cut off control over some satellites in the polar orbits and tripped circuit breakers on Hydro-Québec's power grid (Fig.4) and paralyzed the transport systems powered from that power plant. This damaged high-power transformers and, as a result, evoked a huge blackout in the Quebec province in Canada (AGU, 1997). In Sweden, five 130 kV lines were tripped (Elovaara et al., 1992).

Fig.4. Burned Transformer in Hydro-Québec's power grid in 1989 (Schoch R. M., 2012)

On 28-29 October 2003, next CMEs were noticed, called Halloween Solar Storms. They disturbed the operation of some satellites, but did not damage electric systems on the Earth. The Aurora Borealis was seen over Europe (USGS, 2013).
In January 2008, the American National Academy of Sciences (NAS) prepared an extraordinary report entitled: "Severe Space Weather Events - Understanding Societal and Economic Impacts: A Workshop Report" (2008). The paper contained the first calculation of economic results after a CME expected in 2012. They used historical data on CME from 1921 in the analysis. If a similar impact hit the Earth, the total economic cost would be:

- Future severe geomagnetic storm scenario: $1 trillion to $2 trillion in the first year,
- Depending on damage, full recovery could take 4 to 10 years (Workshop, 2008).

In the report, the expected result was shown for the American electrical network system. In NAS' opinion, a severe space weather event in the US could induce ground currents that would knock out 300 key transformers within about 90 seconds, cutting off the power for more than 130 million people (Fig.5). The NAS report suggests that a loss of key infrastructure for extended periods due to the cascading effects of the space weather event (or other disturbance) could lead to a lack of food, given low inventories and reliance on just-in-time delivery, loss of basic transportation, inability to pump fuel, and loss of refrigeration (Workshop, 2008).
In March 2009, "New Scientist" presented an article which contained an opinion that Europe was neither sufficiently prepared, because Europe's electricity grids were highly interconnected and extremely vulnerable to cascading failures. An accident of 2006 was presented as an example. When a routine switch-off of a small part of the electric grid in Germany caused a cascade power failure across western Europe, only in France five million people were left without electricity for two hours (Brooks M., 2009).
In 2011, OECD published a report with a suggestion that in the regions with the highest regional conductivity we would expect the most severe consequences of a CME impact for electrical networks (Molinski, Tom S. et al., 2000), (Fig. 6.), CENTRA, 2011). This means they found a new critical factor for electrical networks.

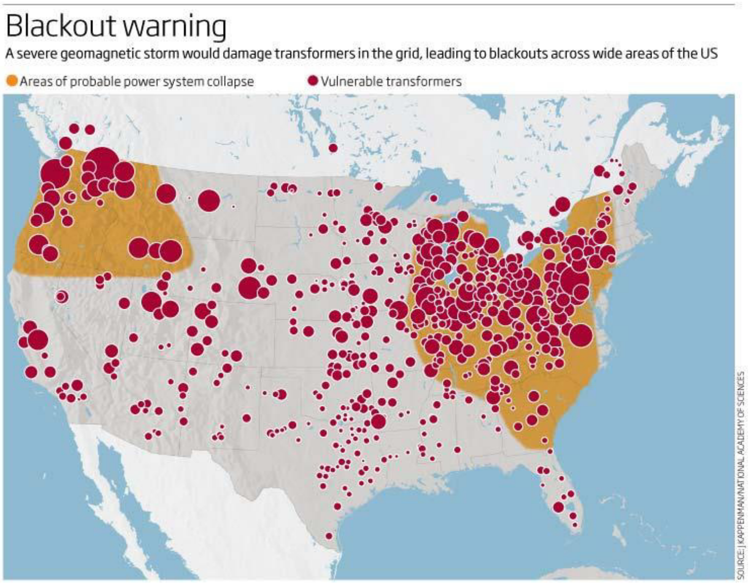


Fig.5. Map of expected blackout regions in the USA after simulated CME with an impact level of 1921 (Brooks M. 2009)

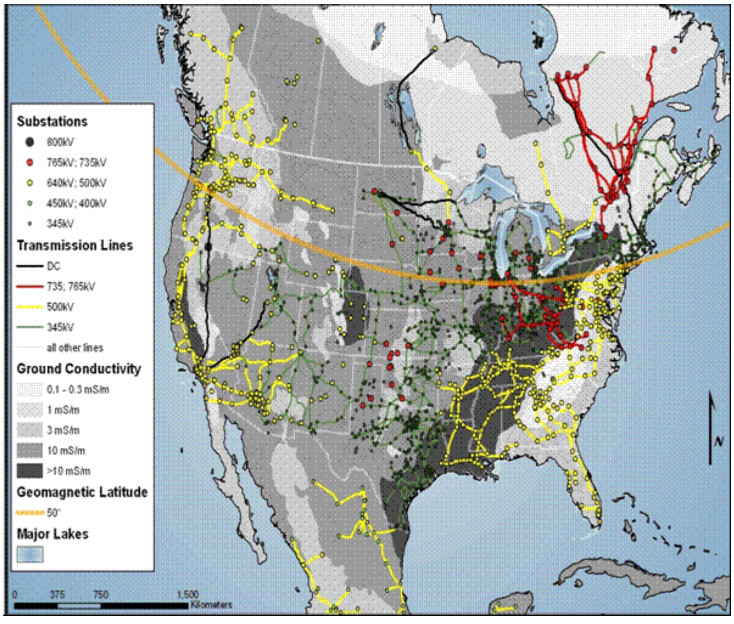


Fig.6. Vulnerability of North American electric power assets to geomagnetic storms (CENTRA., 2011)

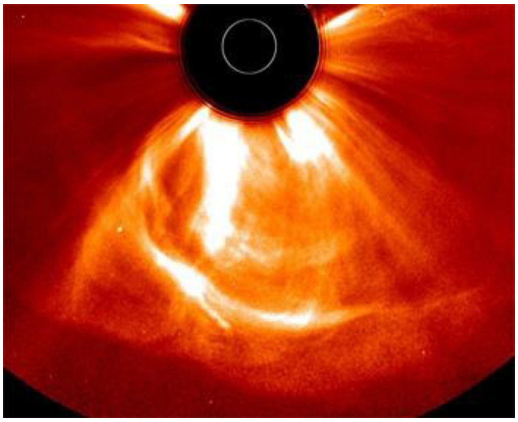


Fig.7. This image captured on July 23, 2012 shows a coronal mass ejection that left the Sun (Sanders R., 2014)

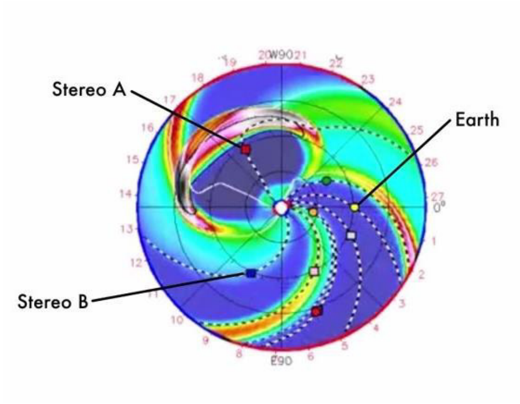


Fig.8. The major solar eruptive event in July 2012, (Phillips T., 2014)

On 23 July 2012, a huge CME was noticed (Fig.7). On that day, two CMEs, separated by only 10 to 15 minutes, went nearly through the Earth's orbit (Fig. 8) (Ying D. Liu et al., 2014).

If this eruption had come nine days earlier, when the ignition spot on the solar surface was aimed at the Earth, through 25 days, our planet would have been on the trajectory of the CME and it would have hit the Earth. This extreme solar superstorm could have evoked severe technological consequences. This would have been a severe threat to the critical infrastructures of the modern society. It could wreak havoc with the electrical grids, disabling satellites and GPS, and disrupting our increasingly electronics dependent lives. The total economic impact in the first year alone could reach $2.6 trillion worldwide. A potential full recovery time would take 4-10 years. The calculations are based on the 2008 Report results (Sanders R., 2014).

Fortunately, it did not happen. The problem is that we do not know the mechanism of production of the frequency and power of Coronal Mass Ejection on the Sun.

Coronal Mass Ejection generated geomagnetic storm on the Earth. The intensity of a geomagnetic storm can be measured by counting the number of solar charged particles that enter the Earth's magnetic field near the Equator. This number is called the Disturbance storm time, or Dst. The power of solar storm was estimated:

1) Dst = -1600,	Carrington event, September 2, 1859	(Masters J., 2009)
2) Dst = -900,	May 14-15, 1921	(Masters J., 2009)
3) Dst = -589,	March 13, 1989 Superstorm	(Masters J., 2009)
4) Dst = -472,	November 20, 2003	(Masters J., 2009)
5) Dst = -401,	October 30, 2003	(Masters J., 2009)
6) Dst = -1200,	July 23, 2012	(Phillips T., 2014)

3. Definition of the problem

The Coronal Mass Ejection can indicate a strong electric current in the electrical grid (Fig.9). Geomagnetically induced currents (GIC) are induced in the transmission lines and flow to the ground through transformers. At the time of flow from the earth, they go into the grounded neutral of a three-phase autotransformer, where they are divided evenly in each phase of the transformer. In the transformers, the AC magnetic field is combined with an extra magnetic field that saturates the transformer core (Lundstedt H., 2006; Molinski Tom S. et al. 2000).

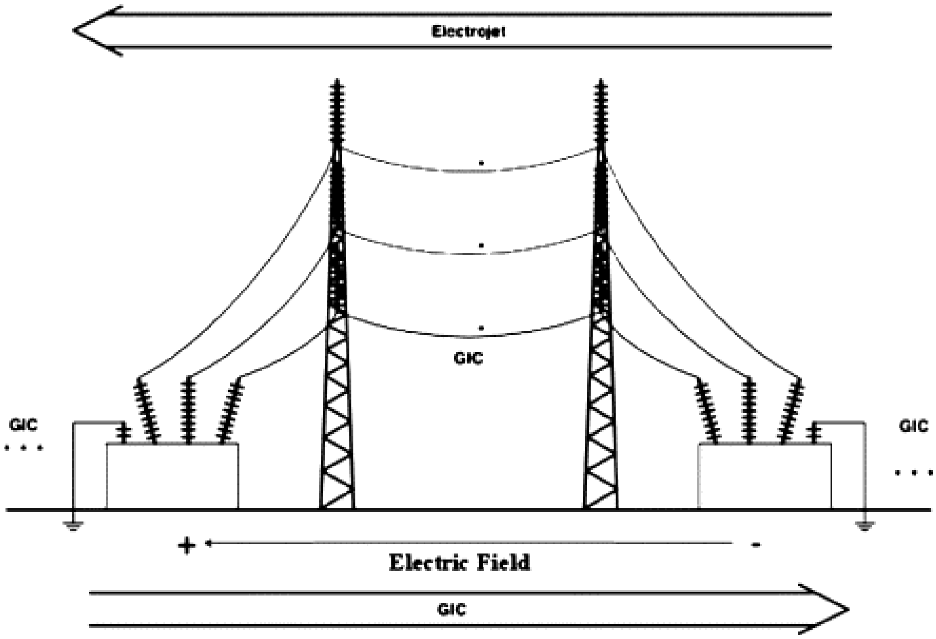


Fig.9. Mechanism of geomagnetically induced currents (GIC) (Lundstedt H., 2006)

The powerful electric currents that would flow through the electrical grid are likely to cause melting and burn-through of large-amperage copper windings and leads in high-capacity electrical transformers. Owners of electrical networks have only a handful of high-power transformers in reserve. Most of the regions affected by the collapse would remain without power until new transformers could be built. It also may paralyze the land transport systems powered by the electrical grid.

If spare ones were not available, new custom-built transformers would be required, potentially idling the power plant for years. The typical manufacture lead times for these transformers are 12 months or more (Masters J., 2009).

Since the European Union enlargement, the EU Parliament would like to free up the energy market. The basis for this activity is Directive 2005/89/EC of the European Parliament and of the Council of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment. It says that with a view to ensuring the functioning of the internal energy market, the largest competitive market for electricity and gas in the world, the European Union (EU) establishes obligations to safeguard security of electricity supply and undertakes significant investment in electricity networks. Blackouts in both the EU and US have highlighted the need to define clear operational standards for transmission networks and for correct maintenance and development of the network (Directive 2005), to safeguard security of electricity supply and infrastructure investment (Brussels, 2007).

The EU decided to finance several important technological solutions, especially the common electrical network (Fig.8).

The area of this network is connected with the regions in which CME consequences occurred in the past (Fig.10). The reach of the 1859 CME impact is beyond the map borders. Then the border of the map (Fig.11) is reach of 1859 CME impact. dditionally, the map (Fig. 11) shows the reach of the Aurora Borealis from 2004 and 2014 to compare the potential area of CME influence.

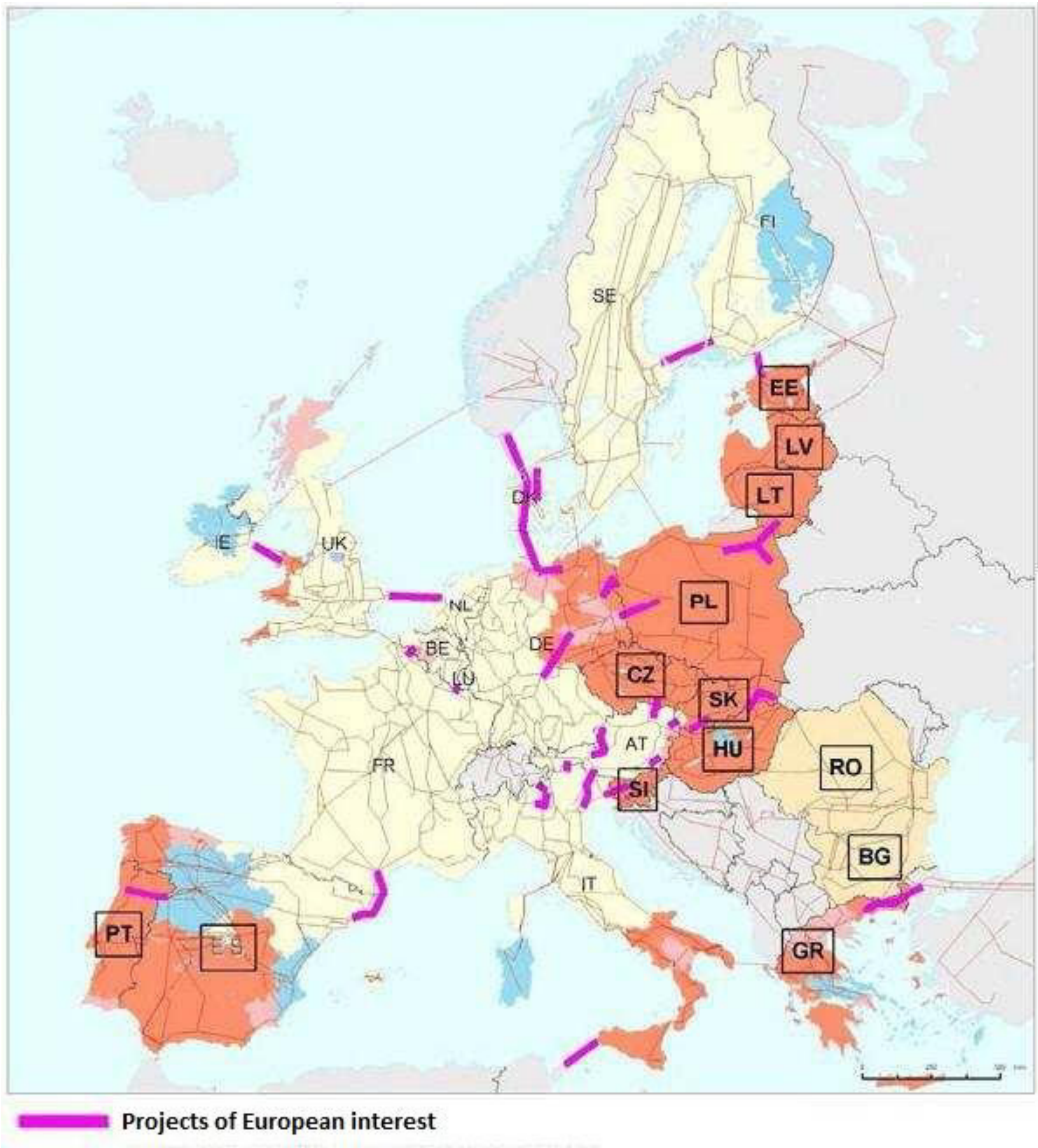


Fig.10. Electrical network in the project of the European interest (Gawlikowska-Fyk A. 2007)

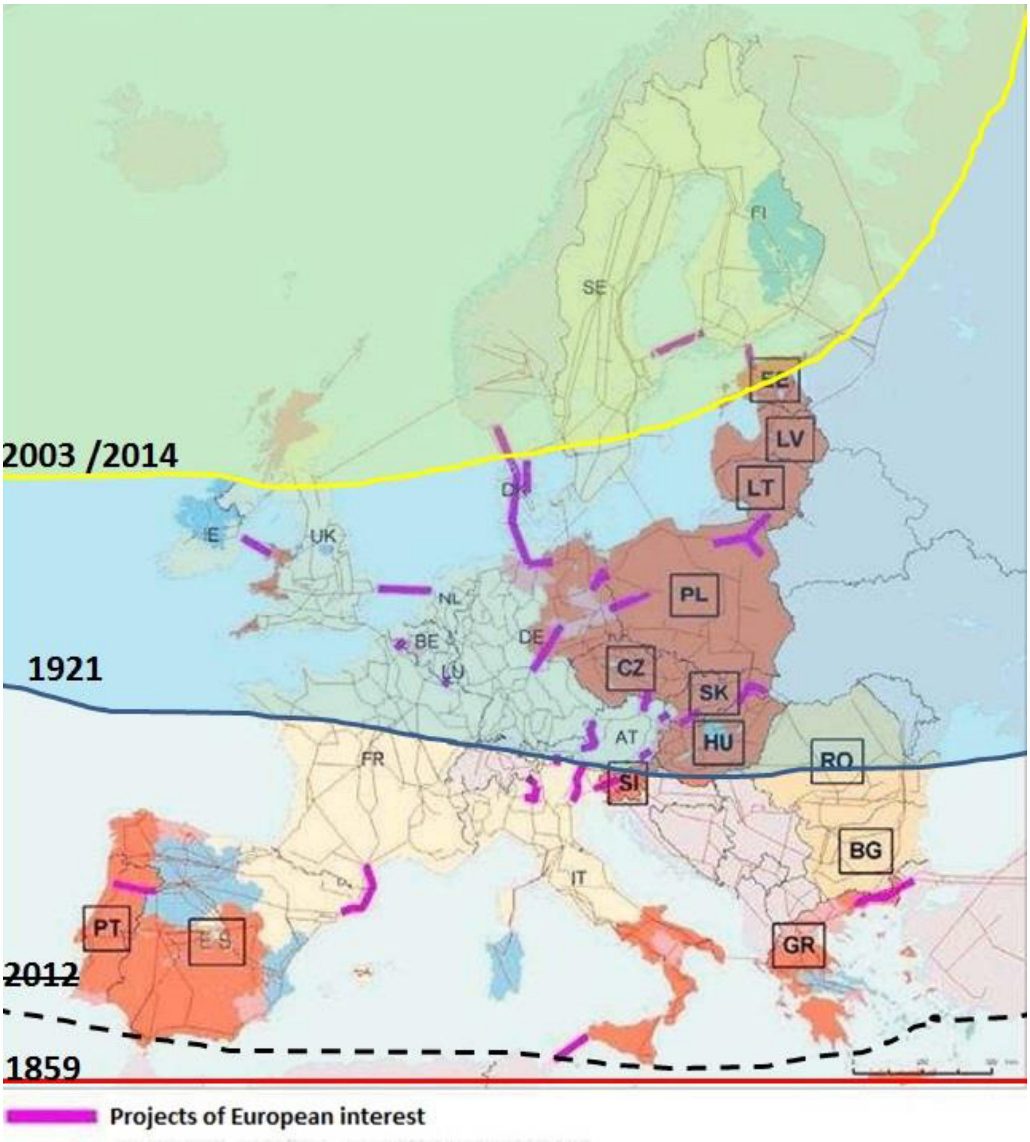


Fig.11. Network of high voltage lines in Europe with reconstruction of the range of visibility of the Aurora Borealis from 1859, 1921, 2003, 2014, and suggestion of outside of the reach of the 2012 CME which fortunately for us not happened. Own work based on: Workshop 2008, Gawlikowska-Fyk A., 2007, Jaworowski Z. 2009, Silverman S.M., Cliver E.W. 2001, Stanisławski P. 2013, SBZ. 1921, NYT. 1921,4, LeMartin 1921,2.

The question is: Is the European Common Electrical Network Ready To Contact With Coronal Mass Ejection ?

According to the opinion expressed in “New Scientist” of March 2009, responsibility for dealing with space weather issues is “very fragmented” in Europe (Brooks M., 2009).

Based on the report of NAS, it is possible to show that in Europe there are a number of actors:

- ESA (European Space Agency) with SWENET, Space Weather European Network, the authors of the NSA reports suggest that it is ideally positioned to be the foundation of an operational European space weather infrastructure. But to do that, it now needs to find an appropriate long-term home in the broader European landscape.
- EU (European Union) which has been supporting several space activities:
  - COST (Cooperation on Space and Technology) support of human networking and trans-ionospheric radio propagation (including space weather effects)
  - DIAS (coordinated system for digital ionosonde measurements and their dissemination),
  - SOTERIA (science exploitation of space weather data)
- A number of national space weather programs exist in several countries - Belgium, France, Germany, Spain, Finland, Italy, Poland, Portugal, Switzerland, Sweden, and the United Kingdom. Denmark and Norway are engaged with specialized interests, playing leadership roles in specific projects: in the case of Denmark - the ESA/SWARM mission to study the Earth’s magnetic field with a greater resolution, and for Norway - the use of Svalbard as a super-observatory for space weather phenomena.

The NSA report suggests that European decision makers have limited awareness of space weather (Workshop, 2008).

4. Discussion

Protection of high-voltage electrical network conductors and transformer windings, the transformer type and mode of connection, and the method of station grounding and resistance are based on the directional orientation of the transmission lines, their lengths, the electrical Direct Current resistance of the transmission (Molinski, Tom S., et al., 2000).

In regions with the highest regional conductivity, we would expect the most severe consequences under CME impact for electrical networks (CENTRA, 2011). In Europe, ground conductivity is high on the southern coasts of the North and Baltic Seas. (Fig. 12.)

The USA have performed an analysis of the risk of damaging the power grid, and Europe has not. If a CME occurs in the future with at a scale comparable to that of 1921, similar as in 1859 and 2012 the damage to the European electric network will be huge. Based on the report by OCED (CENTRA, 2011 and Molinski, Tom S., et al. 2000), it is possible to see that if a CME with high energy hits in the middle of Europe, it can generate an induced current, which due to the high ground conductivity in that area can cause severe damage to electrical network systems (Fig. 10).

Currently, transformers are directly grounded for the points zero. During a geomagnetic storm that could become a source of GICs, flowing to the network from the ground. However, prevention from entering GICs into the network through a combination of grounding is the best long-term solution.

The challenge of building new systems for protecting for transformers against the GIS event is create a path, which automatically bypassing of the capacitor during the downtime and allows the flow of high value directly to the ground of lthe AC (Malko J., 2012). The other possibilities include (Jaworowski Z., 2009) large capacitors to protect transformers at power plants, which are the elements of critical power systems, adaptation of power networks so that they can be quickly and safely turned off the alarm after the announcement of the CME event from the Sun.

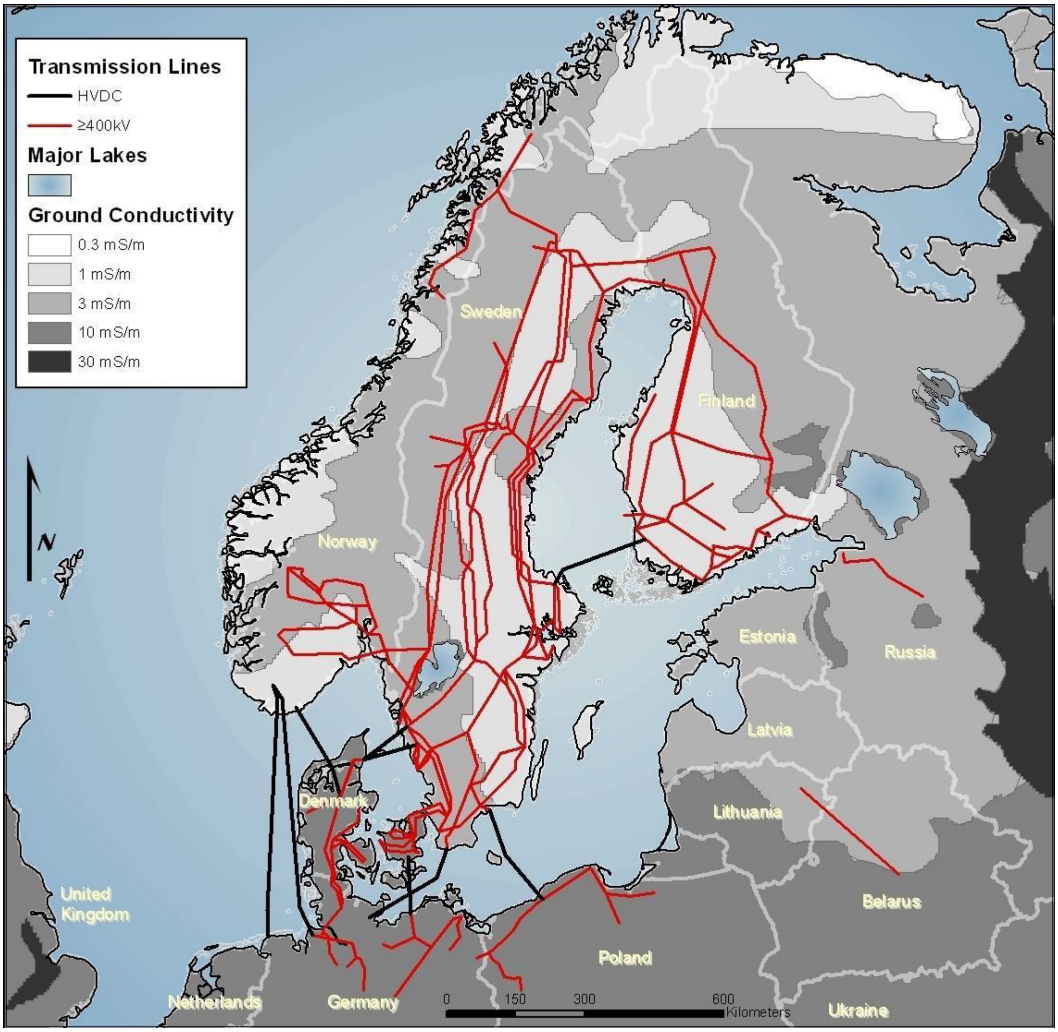


Fig.12. Locations of the main electrical lines in Europe against the ground conductivity areas, showing the vulnerability of European electric power grids to geomagnetic storms (CENTRA 2011, p. 29)

Since 2002 ESA has created a Pilot Project "Real-time forecast service for geomagnetically induced currents." The goal of the project is to develop a forecast service to be used by electrical power companies to mitigate the effects of geomagnetically induced currents (GIC) caused by the space weather (Wik.M. et al. 2012).

Preparation of the new solution for high-power transformers would be a new path for the European Framework Program. This could help develop a new construction of fast circuit breakers for high voltage and new construction of effective grounding systems for electric devices.

In 2014, the British Government decided that the Met Office open a new forecast center dedicated to so-called ”space weather“ as solar storms can have a disruptive influence on the surface of the Earth (BBC 2014).

In my opinion, the scope of its operation should be extended to include the whole of Europe. Possibly, this service would enable a rapid response to secure data grids, telecommunications and internet networks before losing the power supply due to CME.

I think that it is possible to start building a new construction of transformers with a full return path, and a power grid with the fourth cable as the return path power line. But these new construction can generate an increase in the cost of electric power transmission.

A solution to this problem is creating by TSO and DSO the " power supply islands", functioning similarly as local small power plants inside city centers, which may supply power on a local level or develop sources of electric power from small, low-power renewable energy resources to supply power to few public facilities important for safety and health (hospitals, water supply and sewage evacuation to protect from epidemic diseases such as cholera or hepatitis (Lewandowski K. 2011).

Electric power can be transported by means of a well know structure usually used in many cities. These are underground multi-cable technical tunnels. Still, the increase in the price of ground in cities and pressure to increase density of buildings in city centers generates high costs of all new structures built in cities. Underground space is underused and a better integration of overground space with underground space is possible (Fig. 13). Thus, the use of the multi-cable technical tunnels is possible to reduce the risk of massive blackouts in cities even as a result of CMEs and GICs, because covering with earth reduces the difference of electric potentials between the core of earth and underground cables.

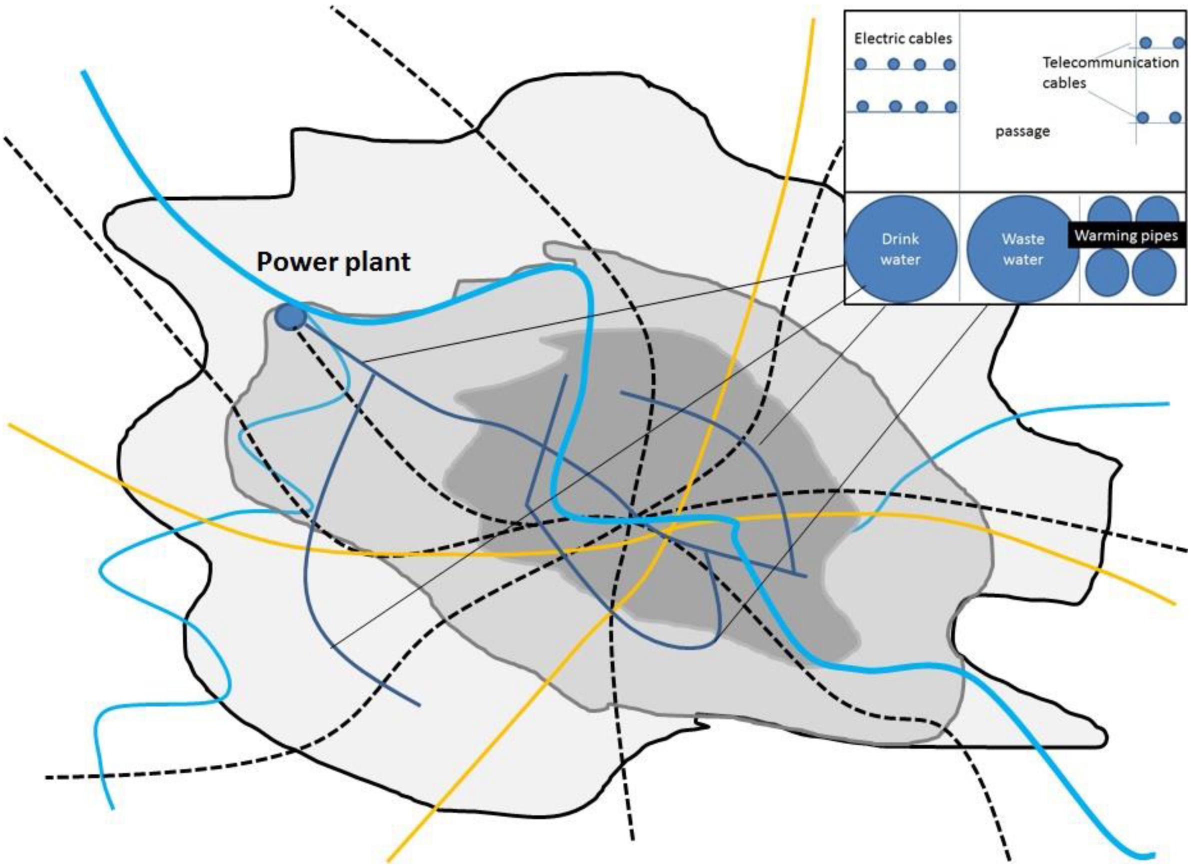


Fig.13. Growing city with underground multi-cable technical tunnels as protection against the CME

5. Conclusion

Expanded use of electricity in city management increases its vulnerability to a power supply cut-off. A lot of literature on urban logistics presents the ever increasing control of the situation in a city. This may be street traffic monitoring, including adaptive traffic control, public safety monitoring, which was demonstrated by the events in Paris on 15 November 2015, or in Cologne on 1 January 2016. Such large extensive systems are very vulnerable to cutting of the power supply. Usually, it is the headquarters that have a backup source of power, but not the entire system infrastructure.

The idea of the Smart City is based on access to information and the land public transport system - metro or underground trains, tramways or light rail or the subway, which all require electric power. Without electric power, the entire signaling system may be paralyzed. That is why it is important to provide continuous electric power supply to the information systems and the selected infrastructure - water supply and sewage systems. City dwellers may live without transport, but without water and hygiene it is impossible. This requires consideration of various hazards of being cut off from the national power grid. Hence, the suggestion to take into account the coronal mass ejection of the Sun.

No analysis of the various hazards to a city's electric power supply may lead to a situation when a city deprived of electricity will be romantically (?) lit up in the evening with candles in the windows of houses. And without the desperately leaving residents of the city, it will become desolate and overgrown with vegetation. Is that the idea of Green City we want? The desire to build smart cities makes it necessary to take safety measures in view of CMEs as the technical solutions protecting before the geomagnetically induced currents GIC generated during the magnetic storm. t can happen in any country and in many cities. We are unable to predict the time and force of the next coronal mass ejection in the Sun.

The situation of August 2012 can occur again. We are unable to predict or stop it. The problem of electrical network safe operation should be discussed at each meeting about the Smart City. These management solutions could not exist without electricity.

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