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Emp protection - unsolved seventy-year-old problem: contradictions, incompetence, or premeditation?

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"... should not wait for the federal government to take action, we need to take action now to protect our portion of the grid."

David Gregory,
Chairman of the Special Committee on Government Accountability,
member of the Missouri House of Representatives

Abstract. Since the devastating effect of HEMP on electronics in the military field has been known for a long time, all military systems are equipped with efficient protection against the impact of HEMP. However, HEMP is equally dangerous for all civil electronics used in almost every section of today's most important infrastructure of any country, for instance the power industry. Therefore, the opinion that all technical problems have long been solved by the military and you just need to use their solutions and their experience in the civilian sector can be heard often. It is a very common and very dangerous illusion in the author opinion. The article describes the problems associated with the use of military technology in the civilian sector, as well as numerous fakes from the world's leading research centers, reporting that they have solved all the problems of protecting infrastructure. The article proposes an author's strategy for protecting the civilian infrastructure based on its own researches and developments.

Keywords. EMP, HEMP, nuclear electromagnetic pulse, electrical grid protection, critical infrastructure, protection strategy, civilian electrical equipment.

The ability of the powerful electromagnetic pulse, generated upon the nuclear explosion (HEMP) to destroy all electronics, has been known to nuclear physicists since the first nuclear explosion was performed in 1945 on the Alamogordo range, New Mexico (project Trinity). Upon the explosion, all apparatus that was meant to monitor the explosion parameters became inoperative. Upon all further test explosions performed in all countries, that electromagnetic pulse was registered precisely and was followed with the analysis and study of the parameters. Beginning in the 1970s (50 years ago), that subject has been unclassified. At that time, dozens of Western scientific and technical reports, prepared by numerous military and civilian organizations (working at the military request), were devoted to different aspects of HEMP impact on electrical equipment and electronics. Since then, the electromagnetic pulse had been officially recognized as one of the damage effects of nuclear weapons, along with the detonation wave, the temperature, the light and the radioactive emission. This has been mentioned in all open sources, including booklets and recommendations on protection against the massive weapons distributed amongst the population during the "cold war" between the USA and the USSR. However, at that time only a few people understood. Unfortunately, the situation has not changed a lot, despite hundreds of reports, presentations, articles and books, as well as dozens of open military and civilian standards on this subject. At least in the USA, this subject is in the spotlight of many dozens of organizations listed in [1], including numerous Congress Panels created especially for this. Many years have been spent researching this subject which has been funded prevalently by the government. However, civil engineers working in the field of electrical power supply, water supply, sewage systems, telecommunication, banking, etc., are bewildered about this massive data so far. Why? The following is written in the [2]:

"There are many misconceptions about EMP that are circulating among both technical and policy experts, in press reports, on preparedness websites, and even embedded in technical journals. Because many aspects of the EMP fields and system interaction physics are non-intuitive, misconceptions are inevitable. Uneasiness about the wide-area, ubiquitous effects of EMP and the diversity of systems affected make it convenient to adopt misconceptions that avoid the need for action. Denying the seriousness of the effect appears perfectly responsible to many stakeholder groups. Misconceptions involving consequence minimization or hyperbole have served to deter action in the past. Downplaying the threats places EMP preparedness on the back-burner compared to other effects. Exaggeration of the threats causes policy-makers to dismiss arguments, ascribing them to tin foil hat conspiracy theories."

The problem is that all such numerous organizations which are fed on massaging the HEMP issue and periodically frightening the laymen with a fatal disaster resulting from the HEMP impact are not interested in an early solution to this issue and are discontinuing research. Conversely, they are all interested in keeping this problem afloat and continuation of prolonged funding. They endeavor to put aside simple and effective solutions to many technical issues.

Author learned it first hand when he attempted to contact one of the US officials dealing with this subject. When the official mentioned the very important and not yet settled question of protection of a power transformer against HEMP, author answered that in fact he can offer a simple, cheap and field-proven technical solution. The official immediately rebuffed author and did not even ask about the solution.

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Also, even people devoted to solve the problem do not understand it clearly. When author sent a promotional brochure of its new book about technical means of HEMP protection to one of the leading HEMP protection actors in the USA, the former chairman of one of the Congress Commissions, author received an amazing answer. It stated that all engineers working in the field of protection of equipment against HEMP do not understand the nature of the problem. In his opinion, it does not require any technical advancements (since all technical issues, according to him, have been solved for some time by the military), rather it requires the attention of the government and society. Subsequently, he proposed to stop wasting time (i.e. stop looking for the technical solutions) and join our forces to react on society. When author tried to explain that military technical solutions are not appropriate for the civilian sector and we need to find new solutions from scratch, it became obvious that he did not understand me and adhered to his opinion that all technical problems were solved long ago.

The opinion that all technical problems have long been solved by the military and one just needs to use their solutions and their experience in the civilian sector can be heard often. Here is what Dr. George H. Baker, Prof. Emeritus James Madison University, Director Foundation for Resilient Societies says in his testimony before the Senate Homeland Security Committeein of Congress [3]:

“The U.S. military already has EMP protection approaches that are practical, affordable, tested and well understood that can be translated directly to electric power grid control facilities and supervisory control and data acquisition electronics and networks.”

In his numerous publications Dr. Peter Vincent Pry, Executive Director of the Task Force on National and Homeland Security has said the same thing many times:

“The problem is not the technology. We know how to protect against it. It’s not the money, it doesn’t cost that much. The problem is the politics. It always seems to be the politics that gets in the way”.

The same idea, but in different words, is repeated by Ambassador Henry F. Cooper, Chairman of High Frontier, and an acknowledged expert on strategic and space national security issues [4]:

“Moreover, I emphasized that we have the technical know-how to accomplish this objective; actually, have known how for decades but have not done so for political — not technical or financial reasons”.

The leading research centers also contribute to the creation of such a distorted view of this problem, publishing advertisements about their developments as a panacea for all the ills associated with HEMP, as a unique solution, after which one can do nothing more and to simply rest on our laurels, Figure 1.

Compare these advertisements posted on dozens of websites:

"20 kV Gallium Nitride pn Diode Electro-Magnetic Pulse Arrestor for Grid Reliability

Sandia National Laboratories will develop a new device to prevent EMP damage to the power grid. The EMP arrestor will be comprised of diodes fabricated from the semiconductor gallium nitride (GaN), capable of responding on the ns timescale required to protect the grid against EMP threats. The diodes will be capable of blocking 20 kilovolts (kV), enabling a single device to protect distribution-level equipment on the grid. The team will focus on the epitaxial crystal growth of GaN layers and device design needed to achieve the 20 kV performance target."

"Record-Breaking, Ultrafast Devices Step to Protecting the Grid from EMPs

Scientists from Sandia National Laboratories have announced a tiny, electronic device that can shunt excess electricity within a few billionths of a second while operating at a record-breaking 6,400 volts — a significant step towards protecting the nation’s electric grid from an electromagnetic pulse."

And compare with real achievements:

"Demonstration of >6.0-kV Breakdown Voltage in Large Area Vertical GaN p-n Diodes with Step-Etched Junction Termination Extensions

Vertical gallium nitride (GaN) p-n diodes have garnered significant interest for use in power electronics where high-voltage blocking and high-power efficiency are of concern. In this article, we detail the growth and fabrication methods used to develop a large area (1 mm^2) vertical GaN p-n diode capable of a 6.0-kV breakdown. We also demonstrate a large area diode with a forward pulsed current of 3.5 A, an 8.3- mΩ ·cm^2 differential specific ON-resistance, and a 5.3-kV reverse breakdown. In addition, we report on a smaller area diode (0.063 mm^2) that is capable of 6.4-kV breakdown with a differential specific ON-resistance of 10.2 mΩ ·cm^2, when accounting for current spreading through the drift region at a 45° angle. Finally, the demonstration of avalanche breakdown is shown for a 0.063-mm^2 diode with a room temperature breakdown of 5.6 kV. These results were achieved via *epitaxial growth of a 50-μm drift region with a very low carrier concentration of <1×10 ^{15} cm^{-3} and a carefully designed four-zone junction termination extension".* [5].

Figure 1. One of the fakes spread by Sandia National Laboratories (SNL) that their microscopic element is a revolution in technology and now you can "sleep well": a national electric grid is protected well against HEMP

Specifically, in fact, we are referring to a laboratory sample of a semiconductor structure (the so-called "wafer") of a diode (namely, a laboratory structure, and not a final product), based on the well-known Gallium Nitride (GaN) material, from which many types of LEDs are produced, including transistors, diodes. Moreover, we are referring to a structure with an area of only 1 mm2, designed for a short current pulse with an amplitude of only up to 3.5 A, while TVS-diodes are widely represented on the market today with the same time response as the advertised GaN diodes, but for currents of tens of thousands of amperes.

The electrical networks themselves and the powerful equipment of electrical networks are protected by very powerful ZnO varistors with voltages of hundreds of thousands of volts and currents of tens of thousands of amperes. Why was it necessary to mislead the public by presenting laboratory samples completely unsuitable for protecting electrical networks from HEMP? Was it to justify the 6.5 million dollars spent by Sandia National Laboratories to develop another kind of small diode from a well-known material?

Figure 2. High-power TVS-diodes for peak pulse power up to several megawatts, manufactured by various companies

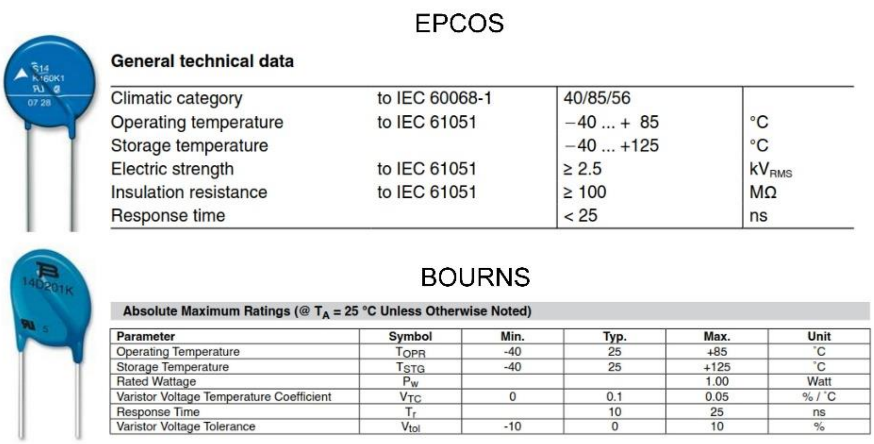
An additional way to justify such a cost for developing an electronic component that is not really needed is to declare that the existing well-known and widely used protection component is not effective and is unusable today. In the 102-page report No. SAN2020-11145 entitled "Early-Time (E1) High-Altitude Electromagnetic Pulse Effects on Transient Voltage Surge Suppressors", seven authors try to prove that the existing Transient Voltage Surge Suppressors are unsuitable for protection against HEMP. It emerged that to prove this thesis, all means were good. For example, the authors criticize "Transient Voltage Surge Suppressors" as if they were talking about one type of element. In fact, this term refers to many types of modern protective elements, such as Gas Discharge Tubes (GDT), Metal Oxide Varistor (MOV), avalanche TVS-diodes and many others. All of these have very different properties and characteristics and a different ability to protect against HEMP. When analyzing this report, it transpired that the authors chose MOV for criticism - far from the fastest of the protective elements and they simply ignored the really high-speed elements: avalanche TVS-diodes, which are no worse than those developed by SNL in terms of response time, but at the same time thousands of times more powerful, and mass-produced by various companies (Bourns, Littelfuse, MDE Semiconductor, Eaton, and others), Figure 2.

The company On Semiconductor back in 2005 published a serious study [6], which contains a table comparing the performance data of various types of surge protection devices, Table. 1.1 These data are well known today and this table can even be found in Wikipedia (see article: "Transient voltage suppressor").

Table 1. Comparison by the response time (protection time) of Transient Voltage Surge Suppressors of some types [6]

Type	Protection Time
GAS TUBE	> 1μs
MOV	10-20 ns
AVALANCHE TVS	50 ps
THYRISTOR TVS	< 3ns

Nevertheless, it is very interesting how the SNL specialists substantiated their conclusion that the MOV with their reaction time 10 - 20 ns (Figure. 3.) are unsuitable for protection against a HEMP (E1) pulse with parameters of 2.5/25 ns.



EPCOS

General technical data

Climatic category	to IEC 60068-1	40/85/56	
Operating temperature	to IEC 61051	−40 ... + 85	°C
Storage temperature		−40 ... +125	°C
Electric strength	to IEC 61051	≥ 2.5	kV_{RMS}
Insulation resistance	to IEC 61051	≥ 100	MΩ
Response time		< 25	ns

BOURNS

Absolute Maximum Ratings (@ T_A = 25 °C Unless Otherwise Noted)

Parameter	Symbol	Min.	Typ.	Max.	Unit
Operating Temperature	T_{OPR}	-40	25	+85	˚C
Storage Temperature	T_{STG}	-40	25	+125	˚C
Rated Wattage	P_W			1.00	Watt
Varistor Voltage Temperature Coefficient	V_{TC}	0	0.1	0.05	% / ˚C
Response Time	T_r		10	25	ns
Varistor Voltage Tolerance	V_{tol}	-10	0	10	%

Figure 3. Parameters of some common types of MOV from manufacturer's data sheets

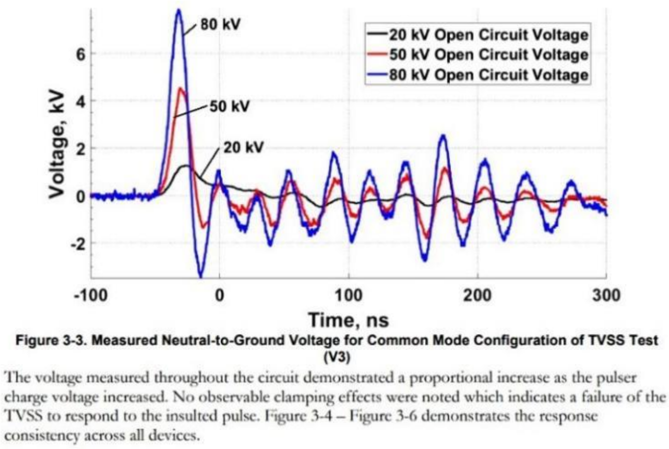


Figure 4. Oscillograms and comment to them from the SNL report

As a consequence: based on such oscillograms, Figure 4 and Figure 5 of which there are dozens in the report. It is very interesting how, based on such oscillograms, it is possible to draw conclusions "*that the TVSS do not activate quickly enough to respond to it*"?! Just amazing!

Today, there are many publications on the reaction time of various types of TVSS in free access. However, the large SNL report (over 100 pages) contains only five literature references, of which three are links to the works of the authors of the report themselves.

If the authors of the report had read numerous publications on this topic, they would have known that the "clamping voltage" of MOV, indicated from the technical documentation, refers to a current not exceeding 100 A. If the current pulse in the experiment had a significantly larger amplitude, then the residual voltage on the MOV will be much higher than the reference value and can reach thousands of volts. Such a high residual voltage has nothing to do with the reaction time.

Additionally, if the authors of the report had read numerous publications on this topic, they would have known that the pulse supplied from the generator to a separate TVSS lying on the laboratory table is completely different from the pulse supplied to the real TVSS placed in the control cabinet, via a cable ten to hundreds of long meters in real operating conditions of equipment in the electric power industry. However, not noticing any difference between laboratory tests and real conditions, the authors extend their conclusion about the unsuitability of MOVs for protecting electrical equipment in substations:

“Both common mode and single-ended test configurations demonstrated the TVSS’ failure to protect against the E1 pulse. The TVSS’ internal MOVs did not respond to the fast pulse due to their activation time… Understanding substation equipment response to the conducted pulses observed in this test due to the failed response of the TVSSs will help determine the level of concern for grid resilience”.

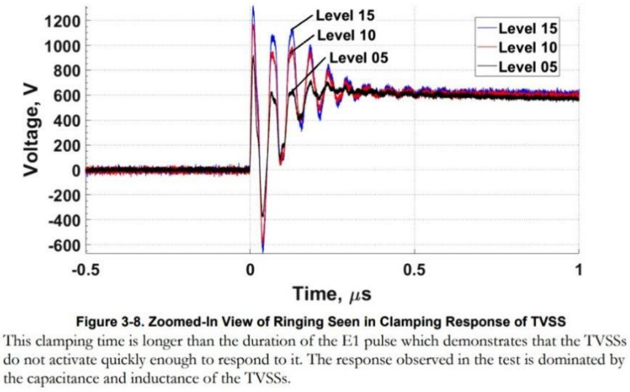


Figure 5. Oscillograms and comment to them from the SNL report

Such publications cause great harm because they mislead specialists.

Moreover, the harm from them is no less than the harm caused from publications of a different kind, proving that allegedly all technical problems have long been resolved. Unfortunately, this is a very common and very dangerous illusion that is replicated by people who are very far from the real technical problems of the civil infrastructure sector. Instead of involving technical experts for solving technical problems, such statements only replicate empty talks and delay the practical solutions of the problem. From this, the pessimism of specialists working in the electric power industry becomes understandable, who directly say that they do not have specific, understandable and affordable means in order to start protecting power energy systems:

"Managing that kind of threat right now — no one really has the resources to do that"

Richard Mroz,
President of the New Jersey Board of Public Utilities

"*Much of the available information is not specifically applied to electric utilities, making it very difficult for utilities and regulators to understand effective options for protecting energy infrastructure".*

Robin Manning,
Vice President for transmission and distribution for the Electric Power Research Institute (EPRI)

It is clear that the more such empty talk and the fewer specific technical solutions suitable for the civilian sector, the longer the problem will remain afloat and the more money can be obtained for this problem.

No less harm and confusion are caused by publications of the opposite meaning, which generally deny the existence of a problem and the need to protect infrastructure from EMP:

EPRI report says existing tech would protect U.S. grid against electromagnetic pulses

"Three years of electromagnetic pulse simulations and testing by the Electric Power Research Institute (EPRI) show that America’s electrical grid could withstand the impact of an EMP triggered by a nuclear weapon, according to research findings released on Tuesday by the independent, nonprofit group" [7].

Report: Electromagnetic Pulse Would Not Have Widespread Impact on Electric Grid

"EPRI’s study found that, while direct exposure to the initial pulse could damage or disrupt some transmission electronics, existing resiliency built into the grid would likely prevent catastrophic failure. Recovery from an EMP would be similar to that from other large-scale power outages, EPRI said" [8].

Scientists Are Zapping Fake Electrical Grids to Help Us Survive an EMP Attack

"The results showed that although some parts of power lines and transformer equipment were damaged by the pulses, they weren’t as drastically affected as some predictions presumed. And with the control houses, some structures held up

better than others — namely the ones made with mostly metal, not concrete. The conductive qualities of metal make the control house act like a Faraday Cage, absorbing and dissipating the incoming energy so none reaches the electronics inside. While the modern-day metal control house designs weren't totally EMP-proof, they did have better shielding qualities than their concrete counterparts" [9].

"The Grid Might Survive an Electromagnetic Pulse Just Fine

A new report enters the debate over whether an EMP from a nuclear blast or a solar flare would cripple the power grid and concludes that actually, we'll probably be OK. Over the past few years, speculation has risen around whether North Korea or any other nation could detonate a nuclear weapon over the United States that would create an electromagnetic pulse and knock out all electricity for weeks or months. This doomsday hypothesis has been promoted by a former CIA director, a commission set up by Congress, and a book by newsman Ted Koppel. But a sober new engineering study by industry experts finds that key equipment on the grid can be protected from any such EMP. Even if it could happen, the resulting blackouts would affect a few states but wouldn't turn the US into a backdrop for The Walking Dead." [10].

All of these publications refer to the EPRI report, which addresses the issue of the vulnerability of some types of power transformers, and not the entire power electrical grid.

Another sensation. This time from such a serious organization as Department of Homeland Security (DHS): "*News Release: DHS Releases Recommendations to protect National Public Warning System from EMPs*", Figure 6.

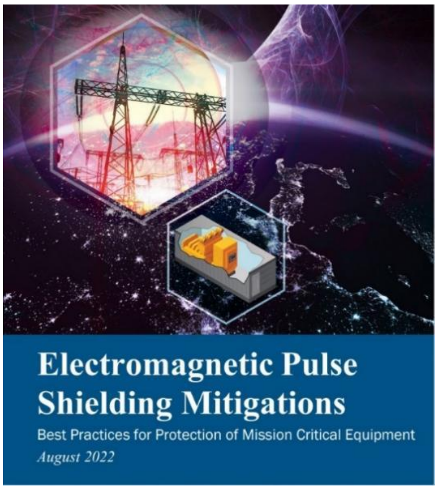


Figure 6. Promotional publication about the "outstanding achievement" of the DHS Science and Technology Directorate

Seriously?! Is electromagnetic shielding the new panacea for all EMP problems?! It's a very original achievement of the DHS, Figure 6 and Figure 7.

It turns out that in order to protect against EMP, it is necessary to shield important equipment and place it in EMP-protected shelters and rooms. What a remarkable discovery nine authors from four government organizations made in their outstanding ten-page report [11] that so many media write about!

Such an important discovery must have cost a lot of money to the American treasury... But how could it be otherwise: such important discoveries are usually well paid. In such important matter, DHS does not lag behind SNL…

In fact, as the reader has already guessed, this is a "much of ado about nothing", because the use of metal shells for protection against electromagnetic radiation was proposed by Michael Faraday in 1836. Such protective shells and screens have been widely used in technology for more than 180 years. As for the specific problem of HEMP, this means of protection is discussed in the old articles, reports and standards 30 - 60 years ago [12-18]. In truth, the mountain gave birth to a mouse!

EMP-protected shelters and rooms are widely used in practice to protect military and special governmental installations. Unfortunately, electromagnetic shielding alone, without the use of other means of protection, cannot protect the equipment of power systems and other important infrastructure facilities against EMP. Therefore, next sensation about next "cure for all diseases" should be treated as next fake.

It seems that the topic of EMP and protection against it has become a good "trough" for numerous government organizations. How else can one explain such "outstanding" reports? One would like to ask: aren't you ashamed, gentlemen, for this "olde tyme snake oil"?

It is a serious problem when incompetent journalists begin to disseminate sensational report about the scientific research in the media, without caring about their thorough verification and that they are correctly presented. Alas, here the most important sensation! It doesn't matter if it's correct or not!

Figure 7. Promotional publication about the "outstanding achievement" of the DHS Science and Technology Directorate

One additional problem described in [2]:

"North American Electrical Reliability Corporation representatives maintain that EMP protection should be addressed by DoD. The DoD points to DHS as responsible for EMP protection of the civilian infrastructure. DHS explains that electric power grid EMP protection belongs DOE since they are the designated Sector Specific Agency (SSA) for the energy infrastructure. EMP protection has become a finger pointing, 'duck-and-cover' game. Our bureaucracy has enabled gaps for addressing the difficult problems of EMP, resulting in no substantive action to protect the nation. We have the classic Washington problem of issues that span departments or fall between departments, which we're all very familiar with, but then we add to that the involvement of the private sector, without central leadership, we're foundering."

In the field of military technology, no one discusses such topics. All weapons systems are reliably protected from HEMP. But why are they still not suitable for the civilian sector?

There are several very important problems detailed in [1, 19]. Here are some of them:

Problem 1. Unlike the civilian systems, over the last few decades, all critical military systems vulnerable to HEMP have been designed with HEMP protection. It is much easier and cheaper to include HEMP protection means in the design stage than try to protect the existing critical civilian equipment, such as digital protection relay cabinets used in the power generation industry. Such cabinets, sometimes overstuffed with apparatus, have dozens of inputs and output multicore cables and each separate core requires protection. Who will attend to this?

Problem 2. Internal electrical wiring of military systems (tanks, airplanes, ships, missiles) are made with preassembled wire harnesses or with separate wires in strict adherence to drawings and sizes. Thus, the electrical characteristics of such wiring at high frequencies (HEMP frequencies) are identical to the equipment of the same type. It means that it is sufficient to test the HEMP immunity of one finished typical sample in order to be sure that all other units will have the same characteristics. In the power generation industry, it is hardly possible to find two identical cabinets with electronics having absolutely identical internal wiring. Since at HEMP frequencies range (100 kHz to 100 MHz), the minor change of wire length, even to 20 cm - 30 cm, or in its placement inside the cabinet, results in a dramatic change of cabinet internal apparatus vulnerability to HEMP [19], a typical test model does not exist. Thus, the results of testing any individual cabinet for very short electromagnetic pulse impact cannot be extrapolated over other cabinets, i.e., in practice, there is no "typical" cabinet for such tests. Based on conclusions made in [1, 19], it is not feasible to conduct such tests for this type of equipment.

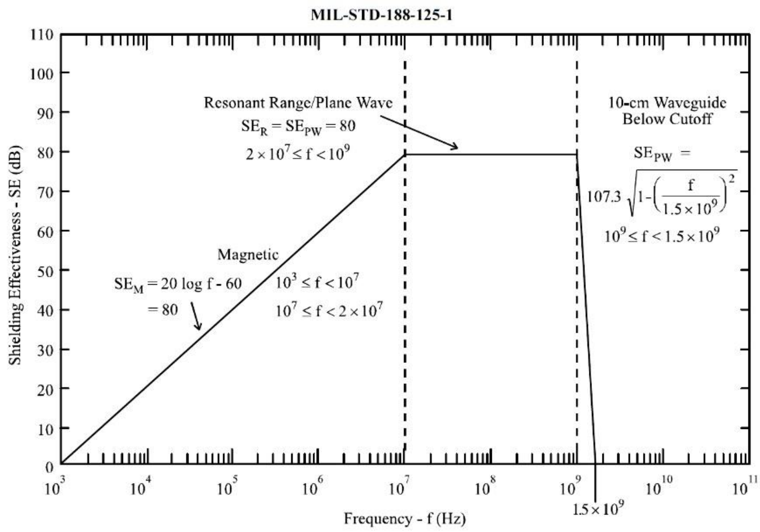


Figure 8. Minimum HEMP shielding effectiveness requirement according to MIL-STD-188-125-1

The data presented in [1] regarding the resilience of computers and computer networks also confirm an extremely large scattering of test results, depending on the influence of a very large number of almost unpredictable factors and the inability to transfer the results of single tests of specific devices and systems to other devices and systems.

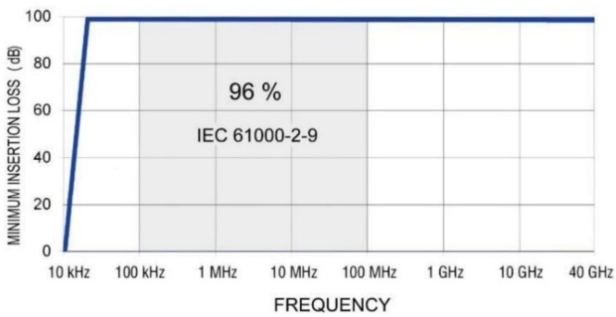


Figure 9. Typical attenuation features of HEMP filters described in ETS-Lindgren's promotion materials

Problem 3. The military apparatus is protected within the electromagnetic range both from HEMP and Intentional Electromagnetic Interferences (IEMI), as well as from data leak through the electromagnetic fields (TEMPEST). The higher frequency range of IEMI and TEMPEST is far beyond the HEMP range (20 GHz–40 GHz).

Figure 10. HEMP filters installed in a military bunker protected against the nuclear explosion

However, such means must ensure at least 80 dB – 100 dB attenuation of an electromagnetic interference (signal), Figure 8. Many manufacturers want to be holier than the Pope and offer on the market EMP filters with parameters that exceed the requirements of this standard, Figure 9. The frequency range is allocated in Figure 9, in which 96% of the total HEMP energy is released (in accordance with the standard IEC 61000-2-9).

From this it is clear what military protection means, such as electromagnetic filters for electrical circuits of the above-ground electronics in secured bunkers, which by satisfying such high requirements, will resemble the cabinets with a mass of several dozen kilograms, but will cost several thousand USD each.

Does anyone really believe that civil power engineering can use the same filters simulating the ones used in the underground military bunker? The answer to this question can be obtained from the results of a study carried out by the National Coordinating Center for Communications (USA) [20], Table 2.

From the presented table, one can see the inexpediency of applying the requirements of military standards to the means of protecting civil equipment. It appears that it is quite enough to attenuate HEMP by 20 - 30 dB only. This significantly changes the attitude towards the problem of protecting civilian equipment.

Table 2. HEMP modeling results of damage and upset mitigation for nuclear burst 100 kT at a height of 400 km over the territory of the United States

Equipment	Protection level, dB	Damage and upset area, sq. km	Damage and upset equipment, %
Ethernet with 30 m cable	0	~5.000.000	69.7
	10	~3.000.000	40.8
	20	~600.000	8.2
	30	0	0
Ordinary telephone system for analog signal transmission over twisted pair (POTS Telephone)	0	~4.000.000	51.5
	10	~900.000	12.9
	20	0	0
	30	0	0
Cordless telephone	0	~6.000.000	78.0
	10	~2.500.000	32.8
	20	~300.000	4.4
	30	0	0

Such a conclusion is also confirmed in [21], where it is shown that even for military equipment, the requirements of the basic standard MIL-STD-188-125 [17] should not be applied directly to military facilities of all echelons:

“If shielding facilities applying the MIL-STD-188-125 standard are installed in all national infrastructures, it is estimated that a huge budget will be required. MIL-STD-188-125 does not consider the blocking and attenuation characteristics of regular buildings or underground facilities in terms of EMP protection. Furthermore, it requires the use of a huge amount of concrete, rebar, and steel plates in heavyweight structures to disallow even a single failure in mission-critical facilities. Hence, there is no need to apply MIL-STD-188-125 to military facilities of all echelons… Therefore, it was confirmed that EMP protection measures could be changed from the current shielding room-oriented, fixed-type protection facilities to mobile lightweight protection facilities using shielding fabrics, shielding racks, redundant equipment, spare equipment, and failure recovery."

Accordingly, what should be said about civilian equipment?!

Problem 4. This problem is related to the test benches simulating HEMP.

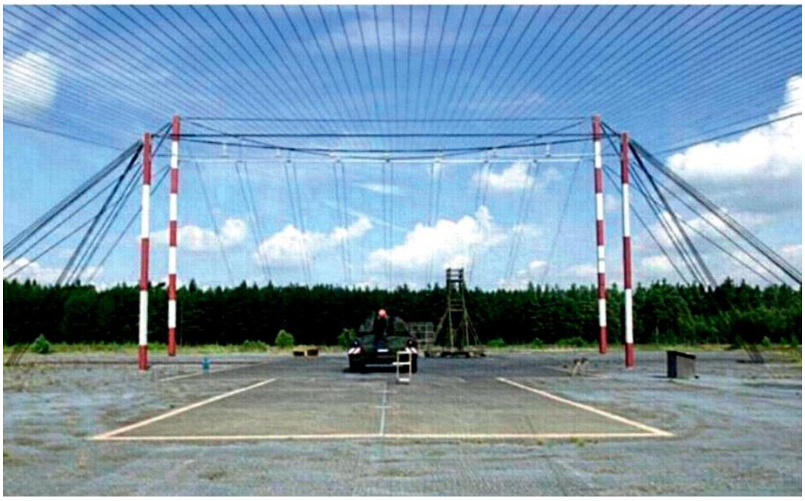


Figure 11. The antenna system of the test bench simulating HEMP

Within such a test bench, such as the guided-wave type HEMP simulator that has been primarily developed for testing pieces of military equipment), the bottom part of the antenna is embedded into a concrete base and has ground potential, Figure 11. It is not a problem for tanks, airplanes, missiles, or other military equipment. However, in the case of civilian equipment, such as cabinets with digital protective relays with grounded internal electronic circuit (i.e. connected directly to the antenna bottom part), the test bench pulse impact on such a cabinet will differ from the real HEMP, since it will not be related to Earth potential in any way.

One other problem of the HEMP simulators. Electronics cabinets used in the power generation industry have dozens of input and output cables, tens and hundreds of meters long. The cables act as antennas absorbing electromagnetic energy over the large area, delivering it directly to the sensitive electronics inside the cabinets. The findings of computer simulation reported by Lawrence Livermore National Laboratory [22] suggest that the amplitude on the ends of 45 and 65-meter-long control cables can reach as high as 100-120 kV at an established rating of E1 HEMP's electric field of 50 kV/m. How can such long cables be modeled on a compact test bench? The above image in Figure 9 shows one of the very big benches not available in every country.

As shown in [1, 19] most existing test benches are of little help for testing cabinet-type equipment, which is used in the civil power industry and the results of these tests are illogical.

Problem 5. Despite a large number of civil and military standards, including the still classified standard [23], describing the parameters of HEMP that affect equipment, the real values of these parameters remain completely unpredictable due to objective reasons.

For example, all HEMP-related standards define a field strength of 50 kV/m as a factor affecting the equipment. But in fact, this field strength can be completely different, both much more and much less.

Much more:

"On 3 September 2017, immediately after the sixth nuclear test, North Korea claimed that they were capable of attacking with an ultra-powerful EMP by detonating a hydrogen bomb high in the atmosphere" [21].

"*Russia has "Super-EMP" weapons specialized for HEMP attack that potentially generate 100,000 volts/meter or higher, greatly exceeding the U.S. military hardening standard (50,000 volts/meter)… Super-EMP is a…first-strike weapon," according to Aleksey Vaschenko, who describes Russian nuclear weapons specially designed to make extraordinarily powerful HEMP fields as Russia's means for defeating the United States"* [24].

Much less:

"Through calculations we found that, early-time HEMP has the property of a steep rise time and a slightly slower trailing time; the maximum electric field on ground is located in the area of 1–2 explosion heights to the south of the burst point on the ground; the area of minimum electric field is located at 50 km to the north of the burst point on the ground, about one magnitude smaller than the maximum value, as shown in Table I. This depends upon the inclined angle between the motion trail of the Compton electrons in the transmission direction and the geomagnetic field. If the inclined angle is smaller, the incited Compton currents will be smaller, and the field intensity will be smaller; if the inclined angle is bigger, the field intensity will be bigger" [25].

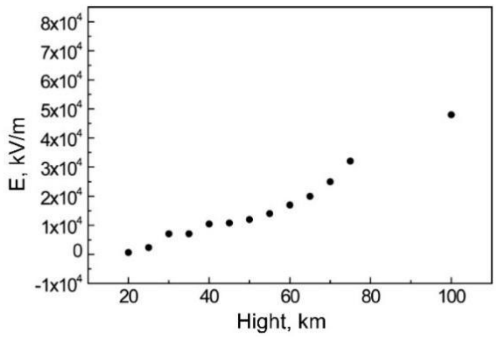


Figure 12. Changes of the electric field intensity at different HOBs over the explosion center for 1Mt yield [25]

Table 3. Electric field peak value distributed on the ground from a 100 km height of burst (HOB), 1Mt yield burst [25]

Location on the ground (projection point on the ground from the explosion center)	Peak electric field, V/m
50 km to the north	2866
26 to the north	11447
ground zero	20777
57.7 km to the south	35494
100 km to the south	40042
173 km to the south	40227
247 km to the south	37071
290 km to the south	34802
514 km to the south	30796

Table. 3 and Figure 12 show only some of the possible variations of the HEMP field strength depending on external conditions, which cannot be predetermined.

There is also a nonlinear relationship between the power of the nuclear charge and the strength of the electric field:

"The power of the 100 kT explosion is 10 times less than that of the 1 MT nuclear explosion, with the electric field intensity peak down by 2.5 times; the power of 500 kT explosion is two times less than that of the 1 MT nuclear explosion, with the field intensity peak down by 15% only" [25].

"Due to a limiting atmospheric saturation effect in the EMP generation process, low yield weapons produce peak E1 fields of the same order of magnitude as large yield weapons if they are detonated at altitudes in the 50-80 km range. The advantage of high yield weapons is that their field on the ground is attenuated less significantly at larger heights of burst (that expose larger areas of the Earth's surface)." [26].

As can be seen, unpredictable variations in the intensity of HEMP exposure to equipment are possible over a very wide range, Figure 13, 14 [26].

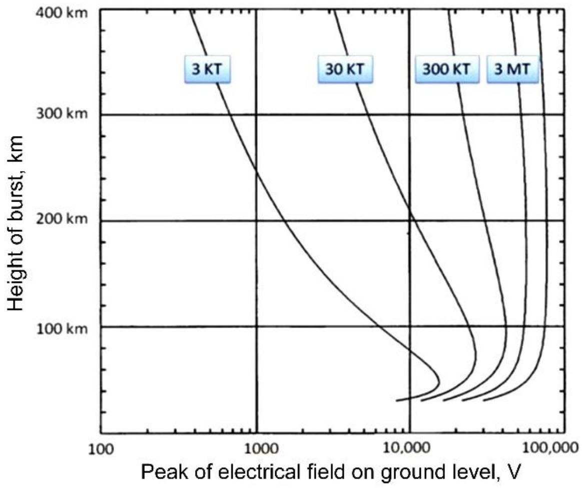


Figure 13. Variations in the intensity of HEMP exposure

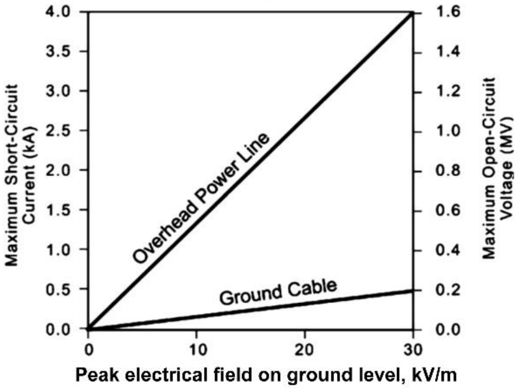


Figure 14. Voltage and current induced in long overhead lines and ground cables by E1component of HEMP from kiloton-class yield weapons

Problem 6. The next problem is using the requirements of the MIL-STD-188-125-1 [17] concerning injection of current pulse at testing resilience of electronic equipment to HEMP. Table B-I in section B "Pulsed Current Injection (PCI) Test Procedures" of this standard stipulates technical requirements for testing equipment, particularly for a high-voltage pulse generator. This device should generate a current pulse with an amplitude of up to 5,000 A with the source impedance of 60 **Ω**. According to the standard: "source impedance is the ratio of the generator peak open-circuit voltage to the peak short circuit current", i.e.: $R_{SOURCE} = U_{OPEN}/I_{Sh.C}$. Thus, the requirement to "open-circuit voltage" can be determined as: $U_{OPEN} = R_{SOURCE} \times I_{Sh.C.} = 60\Omega \times 5{,}000$ A = 300,000 V. The generator providing such parameters really exist on the market. For example, the Marx type generator, manufactured by Montena EMC company.

In other words, output voltage of the generator, the output terminal which is connected to a circuit with high source impedance, (such as inputs/outputs of low-voltage electronic equipment) can reach as high as hundreds of thousands of volts! Which electronic circuits could sustain this voltage? Why should this voltage be applied to these circuits as they are subject to civil standards [27] restricting voltage at 8 kV (level EC8) or 16 kV (level EC9), depending on specific placement of equipment?

These simple calculations, multiple references in the standard to "conductive circuits" and "short-circuit currents", as well as lack of tests for "differential mode", imply that the requirements of this standard are not applicable for electronic equipment. They are rather suitable for testing of conductive protection devices, such as filters, which are connected into a "common mode", and grounded cable shields. Author assumed this previously [1, 19] and thus he did not mention pulse current tests as a recommended method of HEMP-resilience testing of electronic equipment. However, some specialist dealing with these tests insists on adhering to requirements of this section of MIL-STD-188-125-1 when testing electronic equipment. It is globally true that HEMP simulators are usually maintained by military men or military industry representatives. These representatives used to work with military standards and often have no idea about existing sets of civil standards. When civil specialists test civil equipment on military test benches, they have no choice but to accept the rules established by the owners of the testing equipment. Hence, a supposed necessity of testing civil equipment based on MIL-STD-188-125-1 is also suggested in various scientific and technical papers. This is the reason why this discussion was necessary to challenge a common opinion.

Consequently, my conclusion is: requirements of section B “Pulsed Current Injection (PCI) Test Procedures” of MIL-STD-188-125-1 are not suitable for testing civil electronic equipment by supplying test pulses to its input and output terminals. Thus, these tests should be excluded from the testing schedule of this equipment to HEMP-resilience. Industrial electronic equipment, meeting the requirements of standards on electromagnetic compatibility, will also be resilient to current pulse flowing through additional input-placed transient suppression protecting elements upon HEMP impact, and thus requires no additional tests to be carried out on special testing equipment stipulated by MIL-STD-188-125-1.

Problem 7. The inability to consider the specific conditions in which thousands of specific types of equipment are located: types of buildings; the location of rooms with interior equipment; the presence of windows; cables, their length, depth in the soil; specific soil properties (which, moreover, change significantly depending on weather conditions), etc. Specifically, the inability to consider the weakening properties of the environment surrounding the equipment in order to assess what additional protective equipment and with what properties are needed. There are thousands of options here.

This raises a very important question regarding assessment of efficiency of applied protection measures and protection means. In this situation I rely on three rationales:

- it is fundamentally impossible to formulate clear technical requirements for HEMP protection of equipment that would be universal for all types of civilian equipment;
- it is impossible to ensure absolute protection for every piece of electronic equipment employed at power facilities;
- any level of protection which can attenuate (at least partially) HEMP impact on electronic equipment is useful.

Based on this, the general strategy should be based on ***maximum use of maximum amount of known protection means with restrictions to be determined by technical and economic capabilities of a specific power system only.***

This approach makes testing of complete protected equipment on simulation test benches absolutely senseless, even if we forget about the downsides of guided wave-type simulators. Nevertheless, some tests are necessary and important. They include testing of specific means (elements) selected for protection, such as varistors, filters, cabinets, cables, etc. The purpose of these tests is to check parameters declared by the manufacturer and to select the most efficient protection elements from the diversity offered in the market. These tests can be performed using generally accessible instruments, manufactured by companies described in [1].

All these problems have been detailed in my previous books on this subject [1, 19].

But what is the status in terms of drawing the government's and society's attention to this problem? Just as bad as in terms of technical problems! For many years, the US Presidents have been implementing programs to protect the country's infrastructure, but before President D. Trump there was not even a hint of protection against HEMP (in any event, as if this problem was known at the time). But unfortunately, US bureaucrats and officials have managed to convert the renowned Directive of former President D. Trump "Executive Order on Coordinating National Resilience to Electromagnetic Pulses", into another example of bureaucratic sophistry and verbosity. It was detailed in my previous book [19].

As a consequence, nothing essential was done in this regard, and "*the current state of EMP protection is random, disoriented and uncoordinated*", - according to Dr. George H. Baker, Prof. Emeritus James Madison University. Regarding that situation, there is a big range of views amongst different specialists in this field, including the very opposite ones [1].

For example, Dr. Peter Vincent Pry, Executive Director of the Task Force on National and Homeland Security mentions: "*The problem is not the technology. We know how to protect against it. It's not the money, it doesn't cost that much. The problem is the politics. It always seems to be the politics that gets in the way*". However, other experts take great issue with it. "*I don't think we have an illusion we will prevent it. That's really the government's job*", - says Mike Bryson, Vice President of Operations for the Valley Forge, Pennsylvania-based operator. His words are echoed by another representative of the US electrical energy sector, Richard Mroz, President of the New Jersey Board of Public Utilities: “*Managing that kind of threat right now — no one really has the resources to do that*” [1]. General M. V. Hayden, Ex-Director of the National Security Agency (NSA), Ex-Director of the Central Intelligence Agency (CIA) sums up: "*I don't mean to be so flippant, but there really aren't any solutions to THIS, so I would just leave it at that*" [1].

"…leave it at that"? Therefore, let us forget and do nothing...Brilliant strategy, isn't it? Nonetheless, the developers of the new weaponry from all countries clearly understand the chosen strategy and the present situation and relentlessly work on the new electromagnetic weapon types, including a super-EMP bomb – a nuclear explosive with a manifold magnification of pulsed electromagnetic radiation, while understanding that there is no protection against it and it will not be available in the near future.

It should be noted here that opponents to any measures on protection of infrastructure against HEMP often say that such protection does not make sense, since any nuclear explosion initiated by any side will immediately result in a massive attack with all nuclear weaponry and a single electromagnetic pulse will be meaningless. In fact, this is not true. Recently, nuclear weapon strategy and tactics have evolved. It is no longer just a strategic deterrent weapon. For example, there are programs on creating new tiny nuclear warheads for tactical cannon shots actively developed in many countries. Here it should be noted that in order to generate a powerful EMP, the nuclear warhead must be activated at a high altitude (more than 30 km), therefore such a warhead is not a mass lethal weapon. This fact should be deemed as an important motivation to apply such weapons. If the weapon will cause no direct human losses, the opponent will hardly initiate the regular overland nuclear attack resulting in millions of deaths. The response will likely be symmetric. That is why it is very important to protect the infrastructure against HEMP, and this problem will evolve over time.

In his testimony before Senate Committee on Homeland Security, Dr. Peter Pry says [28]:

“Today’s microelectronics are the foundation of our modern civilization, but are over 1 million times more vulnerable to EMP than the far more primitive and robust electronics of the 1960s, that proved vulnerable during nuclear EMP tests of that era. Tests conducted by the EMP Commission confirmed empirically the theory that, as modern microelectronics become ever smaller and more efficient, and operate ever faster on lower voltages, they also become ever more vulnerable, and can be destroyed or disrupted by much lower EMP field strengths. Microelectronics and electronic systems are everywhere, and run virtually everything in the modern world. All of the civilian critical infrastructures that sustain the economy of the United States, and the lives of 310 million Americans, depend, directly or indirectly, upon electricity and electronic systems…. Another key vulnerability to EMP are Supervisory Control and Data Acquisition systems (SCADAs). SCADAs essentially are small computers, numbering in the millions and ubiquitous everywhere in the critical infrastructures, that perform jobs previously performed by hundreds of thousands of human technicians during the 1960s and before, in the era prior to the microelectronics revolution. SCADAs do things like regulating the flow of electricity into a transformer, controlling the flow of gas through a pipeline, or running traffic control lights. SCADAs enable a few dozen people to run the critical infrastructures for an entire city, whereas previously hundreds or even thousands of technicians were necessary. Unfortunately, SCADAs are especially vulnerable to EMP.”

It is related to the expanded application of microelectronics and micro-chips over all technical and technological fields, i.e. to the increased vulnerability of all our lives to HEMP.

In 1969, the American scientist George D. Rockefeller published an article: "Fault protection with a digital computer", in which is considered the beginning of the era of digitalization of relay protection and, in general, the entire electric power industry.

Digital protective relays and automatic control systems built on microprocessors, distributed power generation controlled with the artificial intelligence devices, digital substations, etc. All these great and most advanced systems are particularly vulnerable to HEMP.

"*While this digital transformation has been accepted in our everyday lives and we are all walking around with multifunctional devices in our pockets that function as a phone, TV, radio, GPS receiver, photo camera, videorecorder, etc., for many people in our industry it is a very different story at work. There are still PAC specialists that do not accept the digitization and digitalization of our industry because they prefer to do everything as they always did with the electromechanical devices of the last century, regardless of all the problems they have to deal with… The ones that hesitate to do it are the ones that are going to fail."* - writes the Editor-in-Chief of the popular magazine "Protection, Automation & Control World” (PAC), Alex Apostolov [29].

"*...phone, TV, radio, GPS receiver, photo camera, videorecorder in our pockets*" – these are the same as multifunctional relay protection system of power plant or high-voltage transmission system?!!! In my opinion, this is (to put it mildly) not a very smart comparison…

"…specialists that do not accept the digitization and digitalization of our industry because they prefer to do everything as they always did with the electromechanical devices"?! And in my opinion, this is because some experts are used to thinking before deciding, deeply weighing all the pros and cons, not succumbing to general euphoria.

A very dangerous modern phenomenon in the electrical power industry called "digital substation" should be mentioned here. No, of course, it is not dangerous in itself, but in the way it is “implanted” into the power electrical industry. However, no threats stop the digital substation apologists. For them, all ways are good, and possible problems along the way are not even discussed:

“*It was not that long ago when people were asking should we build a digital substation and the answer to this question is already obvious – **yes, we should**”* - say Alex Apostolov, Editor-in-Chief of well-known journal “PAC World” [30].

“*Not IF but WHEN*” – this is how the Alex Apostolov, puts the question.

And digital substations begin to march widely across the vastness of the "energy space!", accompanied by resounding advertisements in the technical magazines. Listed below are outstanding features of “digital substations” stated in the such advertisements:

"Reliability – Flexibility – Interoperability

- *40% reduction in maintenance work and outage time*
- *Reduced Footprint, from 10% to 40%*
- *Up to 80% reduction in wire cable*
- *Increased stability and reliability*
- *Low investment and life-cycle cost*
- *Higher efficiency and more safety*
- *Enhanced cyber security"*

Indeed, why not, if they have such outstanding features as stated in the advertisement above?!

Here is just one small feature of a digital substation its apologists are silent about: a sharp increase in the vulnerability of the electrical power industry (and therefore of the entire infrastructure) to intentionally destructive electromagnetic impacts, in particular to HEMP. And author appeals to him with a request to pay attention to this danger that Mr. A. Apostolov simply ignored.

As usual, big businesses are indifferent about the consequences of its activities. Profit is above all!

Especially dangerous is the combination of an unprotected digital substation with the concentration of the basic functions of relay protection in a single module.

The concentration of not only all protective functions in one single digital protection relay continues, but also the protection of a whole group of important energy objects in single protection relay, (SEL-400G, for example, that combined all function of generator, bus and step-up transformer protection). If such a single module will damage due to HEMP impact, all power equipment of the power plant will remain unprotected (in the best case) or will be damaged due to improper actions and commands of this protection relay (in the worst case).

Likewise, as my articles and books are absolutely ignored by companies offering their products in the field of digital substations. Why? It is all very simple [31]:

"… in 2020 the global business in digital substations was more than 6 billion U. S. dollars with the prediction that this number will go above 9 billion in 2025".

The development and implementation of artificial intelligence systems in the electric power industry continues without any limitations and without regard to the increasing significantly vulnerability of the electric power industry to HEMP with such development trends. Thus, the modern electrical power industry's development tendency is accompanied by its increasing vulnerability. Is it progress? There is rather a strange situation – while everyone is concerned with the cyber security of today's civil electrical power industry, no one (except me) thinks about its protection against HEMP.

Moreover, author's articles and books inviting the attention to the fast-paced increasing of power systems vulnerability face strong push-back with full rejection and antagonism against its position, including ranting that author try to stop the advancement of the technology. This position of the leading power engineering experts, and all-around appeals to fasten the power engineering sector digitalization by any and all means, without any consideration of the problem or intention to simultaneously develop measures on protection of all those digital technologies against HEMP, are hair-raising.

However, this does not eliminate the need to search for and select the most effective means of protection of the civilian infrastructure from those offered on the market, which have the best price-performance ratio.

Despite the seemingly routine and simplicity of the problem, for a number of reasons this becomes a very difficult task in this specific field of technology. One of the problems is that civilian sectors of the economy have not yet started real work anywhere in the world to protect civilian infrastructure from HEMP, and therefore these sectors are not consumers of protective equipment. For this reason, manufacturers of this protective equipment are primarily focused on military orders and produce products according to military standards that meet the requirements of the military. As a result, the means of protection offered on the market today have parameters that are excessively high for the needs of civilian infrastructure and, accordingly, a high cost that is completely unacceptable for civilian needs. Specifically, even if in some country, in some sector of the economy, they decide to deal with the problem of protection against HEMP, they will not find anything suitable on the market.

In this regard, the only solution may be to conduct research and development of protective equipment specifically designed for civilian infrastructure with the new strategies and methods for their application. It can be stated that today these tasks have not yet been solved, and numerous reports and recommendations published by dozens of organizations are too vague, not specific, and do not help to solve the problem of protecting civilian infrastructure. They create only a background noise and the illusion that all technical problems have already been resolved and it is only a matter of government decisions.

One example is the report of such a serious organization as the United States Department of Homeland Security [32], in the preparation of which more than 10 state organizations took part, such as: US Department of Defense, US Department of Energy, Defense Threat Reduction Agency (DTRA) and many others.

This document is relevant because:

*"Assessments of the risks to civilian critical infrastructure from electromagnetic incidents are intrinsically difficult to produce due to the rarity—or complete absence—of actual events, as well as the fundamental complexity of predicting real-world interactions between electromagnetic pulses and **thousands of diverse infrastructure installations**."*

But the strategy and methods for solving this problem are set out in the document in a very wordy and vague way:

"Increase coordination…"
"Improve EMP-related intelligence gathering…"
"Review test data on the effects of EMP on critical infrastructure systems that are representative of those currently deployed throughout the Nation…"
"Prioritize new tests of specific infrastructure associated with national critical functions…"

"Improve EMP-related intelligence gathering…"?! Seriously? And this is after 60 years of research and practical experiments on this phenomenon?!

"*Review test data*" and *"Prioritize new tests"* for "*thousands of diverse infrastructure installations"*?! However, isn't that unintelligent? Especially after it has been proven that among these "*thousands of diverse infrastructure installations*" there are not even two completely identical ones in terms of their high-frequency properties and susceptibility to HEMP.

It is a pity that the authors of the report do not understand that the most important for protection against HEMP parameters of "*thousands of diverse infrastructure installations*", are not determined in fact and any "*EMP-related intelligence gathering"* not will help here.

Moreover, even the parameters of the HEMP itself and the degree of its influence on the infrastructure are uncertain [24]. Specifically, in fact, there is complete uncertainty not only of the objects of protection, but also of the impact itself:

"Any electric power outage resulting from an EMP event would ultimately depend upon several unknown factors and effects to assets that are challenging to accurately model, making it difficult to provide high-specificity information to electric system planners and system operators. These variables include characteristics such as the EMP device type, the location of the blast, the height of the blast, the yield of the blast and design and operating parameters of the electric power system subject to the blast" [33].

"The technical impact of a HEMP event on the electric infrastructure is uncertain…

Some proposed the electric industry should install a particular protected device or fully gold-plate the entire grid so that it could survive a HEMP event. However, there's really no consensus on what measures should be taken at this point. The potential unintended effects of that type of protection on the grid or how successful the efforts would be if we, in fact, tried to do that at this time. Cost is a significant factor." [34].

"I read the EMP Commission report, I struggled to understand how I could take the plethora of information that was available on EMP and practically apply it to create some sort of a plausible approach for risk management… Certainly impacts from HEMP are real; however, evaluating the effects of such events on complex systems like our electric power grid requires concrete, scientifically-based analysis from people who understand the power system. With greater understanding, cost-effective mitigation and/or recovery options can be developed and deployed." [35].

What is there left to do in such a situation?

And here is what, it turns out, needs to be done in such a situation:

"Disseminate EMP and GMD risk assessment information and research findings with relevant owners and operators of critical infrastructure using existing information-sharing platforms",

as prescribed by the American Strategy [32].

Unfortunately, in fact, this is the only task that all such reports solve. But this does not bring us closer to solving the problem of protecting critical infrastructure.

Despite all these problems listed above, serious organizations prefer to simply ignore them. Ultimately, if you notice, then you will need to solve them. It is much easier to issue empty "recommendations" [36] that do not bind anyone to anything:

"Recommendations:

-Develop a long-term comprehensive plan to address the full spectrum of interrelated EM threats;
-Employ red-teaming to improve operational planning processes in a way that integrates the full threat spectrum;
-Develop and implement EM-specific deterrence policies;
-Improve strategic communications to shape perceptions and strengthen deterrence;
-Seek incremental hardening and threat-level testing;
-Develop an early warning and response system;
-Put in place training and processes for smart reconstitution;

-Prioritize among protection initiatives based on an analysis of societal functionality;
-Establish a political process for prioritization among infrastructure functions;
-Use models and experiments to understand society-wide vulnerabilities and responses;
-Develop and hold regular national preparedness exercises;
-Create insurance mechanisms to mitigate vulnerabilities;
-Expand public-private partnerships to improve standards"

And this is called "recommendations" for protecting infrastructure against HEMP in 2015, after 50 years of studying the problem?! It has recently become just a fashionable business to issue such recommendations.

It is not surprising that after such "recommendations" the country's infrastructure remains completely defenseless.

From the foregoing, we can conclude that military strategies, means and technologies for protecting against HEMP are too expensive for the civilian sector, and suitable strategies and technologies for the civilian sector simply do not exist now. Therefore, a new absolute different strategy and means are required for the protection of the civilian infrastructure.

Author already developed and described such a strategy and numerous technical protections means in my previous books [1, 19]. The main principles of this strategy:

- It is impossible to ensure protection of any and all types of electronic equipment in the power systems.
- It is impossible to ensure absolute protection even for the most important types of equipment being used.
- The cost of protection devices budgeted during the design stage (in case of new equipment and facilities) will be much lower compared to upgrading the existing equipment.
- Instead of protecting specific types of employed electronic equipment, it is sometimes feasible to use back-up equipment of the same type stored in a metal container directly at the facility being protected.
- Existing HEMP-simulating test benches provide insufficient information at immunity testing of the power system's electronic equipment and thus testing such equipment (e.g. each cabinet with electronic equipment) on such test-benches is not feasible.
- Due to technical and economic reasons, protection should only be provided to the most important (critical) types of electronic equipment installed at critical facilities of the power industry, rather than to any and all types of equipment employed at the power industry.
- Critical types may include equipment which is directly involved in electrical energy generation and transmission, as well as main types of relay protection, control and automation systems, AC and DC power supply systems.
- Consequently, measuring systems, communication (but not telecommunications used by digital relay protection devices), remote control and remote signaling systems do not belong to equipment without which temporary generation and distribution of electrical energy will be hampered in emergency situations.
- HEMP protection of equipment is multi-layered:

-*The first (top) layer* includes protected buildings and structures.
-*The second layer* includes protected rooms (halls) where equipment is installed.
-*The third layer* includes protected cabinets with electronic equipment.
-*The fourth layer* includes protection input and output terminals of the equipment itself placed into control cabinets.
-*Some additional "layers"* of protection may include means for attenuation electromagnetic interferences penetrating into the equipment through the input and output cables (grounding, control and power).

However, the use of all these "layers" in any situation is not feasible. In some cases, it is feasible to use just some of the "layers" in various combinations.

In other words, the **general strategy** should be based on maximum use of maximum amount of known nonmilitary protection means (selected based on the above-mentioned strategy), with restrictions to be determined by technical and economic capabilities of a specific power system, only because any level of protection which can attenuate (at least partially) HEMP impact on electronic equipment is useful.

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