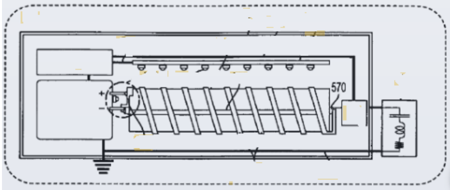

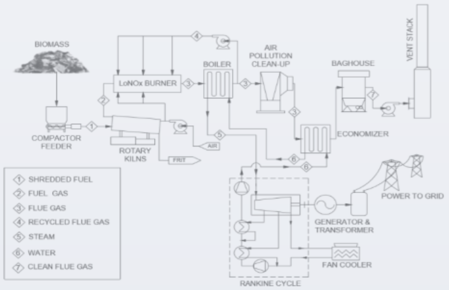

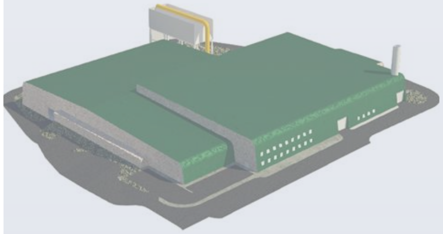

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EMP Hardening with Electric Power Microgrids

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Electromagnetic Pulse Hardening with Electric Power Microgrids

Electromagnetic Pulse (EMP) [1] devices are once again of growing security concern as North Korea joins China and Russia as adversaries capable of using high altitude nuclear EMP (HEMP) to attack and degrade US infrastructure. Weaponized EMP devices range from small man-portable explosively pumped magnetic flux compressors, to air delivered flux compression microwave emitters (E-bombs), to high altitude nuclear weapon detonations. The administration has recently called for increased preparedness against possible EMP attack[2,3] through hardening of the electrical grid and reducing the EMP vulnerability of critical equipment. An unclassified document,[4] assessing the threat of HEMP and high-powered microwave (HPM) attack, was delivered to Congress in 2008 and remains relevant to government installations.

Electrical power grid vulnerability arises largely from the above ground transmission lines that couple well to the high strength electric and magnetic fields that comprise an electromagnetic pulse. As was demonstrated by the widespread collapse of the power grid in Quebec in 1989, EMP generated by the interaction of solar flare or coronal mass ejection (CME) charged particles with the Earth's geomagnetic field can disrupt grid operation by inducing higher than normal currents in above ground transmission lines. A great deal of progress has been made in protecting the grid against the effects of CME. However, electric and magnetic field strengths associated with EMP attacks can be orders of magnitude higher than those from solar activity. Whether operating on fossil fuels or renewable energy sources such as biomass wind or solar, any grid system in which the power plant connected to its load by above ground transmission lines is vulnerable to EMP attack. Any above ground transmission line is a vulnerability that can be exploited in threat scenarios where the installation is the primary target.

Vulnerable sources of electric power are an attractive first strike target in a preemptory attack against the installation itself. While the installation command, control and communication systems may well be hardened against such an attack, base power distribution infrastructure supporting less critical operations is likely to be more vulnerable. Even if mission critical functions are not affected by EMP, or can recover quickly, the loss of power not only degrades overall base operations but may have a negative psychological impact on personnel as well.

This document describes the main types of EMP weapons and the relative threats they represent. Also discussed are ways in which specifically designed EMP hardened thermal power plants, and their associated smart microgrids, can provide a safe, clean and reliable source of electrical power. Properly designed, built and operated, these hardened microgrids can render the installations they serve far less vulnerable to EMP attack than comparable installations dependent on the power grids supported by external transmission lines.

High Altitude Detonation Nuclear EMP Effects

High altitude nuclear explosions release an intense burst of gamma radiation that ionizes the upper atmosphere, can significantly shorten the service life of satellites, and gives rise to three main pulse components that are detected sequentially at ground level [4]. The first is a high strength, primarily electric field pulse with an extremely fast rise time and duration of approximately a microsecond. The rise time and duration of this initial pulse are so short that most conventional protective equipment (fuses, circuit breakers, etc.) may be ineffective.

The second EMP component has effects much like those of a lightning strike. If the first pulse component has damaged protective circuitry or devices, then damage from the second component will be more pronounced. Electric and magnetic field strengths of EM pulses can be exceedingly high. From measurements by American and Russian scientists during atmospheric tests, peak electric field strengths at ground zero for a 20 kiloton yield atomic weapon burst at an altitude of 240 miles are calculated to be 15,000 volts per meter (V/m). This increases to as much as 50,000 V/m for a one megaton thermonuclear device (H-Bomb) at the same altitude [5].

The third pulse component is primarily magnetic in nature and can have a duration of a second or more. If the nuclear detonation is at sufficient altitude (> ~50 km), most electrons ejected from air molecules by the gamma ray burst will eventually spiral along the Earth's geomagnetic field lines causing distortions. In the northern hemisphere, this third (geomagnetic) pulse component will be more pronounced south of the detonation point and less intense to the north. Ground zero EMP magnetic field strength (**H**) for a 1 megaton HEMP is calculated at 135 amperes per meter (A/m), with total (full spectrum) energy flux (S) of 650 Watts per cm^2 [5]. (Compare this to an energy flux of about 0.1 Watt per cm^2 for direct sunlight on a clear day.)

This geomagnetic pulse spectrum has a very broad-band with frequency components extending down to the 100 Hz range, and thus couples well with long length above ground transmission lines. As is the case with the explosive flux compression devices described below, rapid field rise and/or collapse (high dB/dt : **Figure 3**) can result high induced currents causing damage to the lines themselves as well as to connected substation and switchgear equipment. In addition, because of substantial local variations in EMP induced currents along the grid, automated control equipment can make adjustments based on local conditions that adversely affect the grid as a whole, leading to widespread outages. Isolated systems do not couple as effectively to this third geomagnetic pulse component and are therefore less vulnerable.

Figure 1 below shows the affected radius, at ground level, of an HEMP at altitudes of 30 miles, 120 miles and 300 miles. While the thermal energy and gamma ray radiation from the blast will not cause human health effects from these altitudes, the rapid and massive ionization of air will give rise to the three types of long range secondary EMP effects described above.

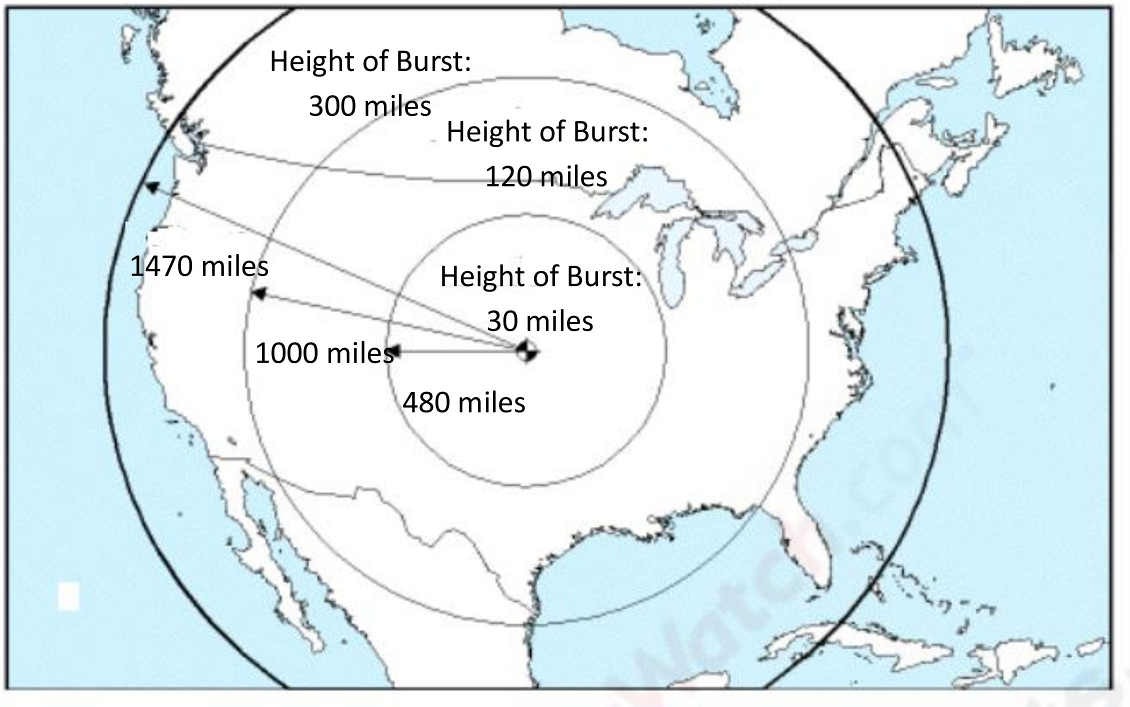

Figure 1. Effective radii of electromagnetic pulse effects from a nuclear detonation as a function of burst altitude [4]

Explosive Flux Compression Devices: E-Bombs and Man Portable EMP Weapons

While the probability of a first strike nuclear EMP attack against the United States would seem to be low, there are other less consequential means of carrying out localized EMP strikes. (If the attack on the World Trade Center on September 11th of 2001 taught anything, it was to never to under estimate the resourcefulness of a determined rogue adversary.)

The fact that the information that follows on man portable and air delivered explosively pumped magnetic flux compression devices was derived from open source literature and is not now classified, should be a reason for some concern. Simple but effective versions of the man or vehicle portable devices described below can be built by anyone with a basic knowledge of electronics, some machining skills, and access to C4 or PBX quality explosives.

An example of a non-nuclear and easily ground transportable EMP device is the Explosively Pumped Flux Compression Generator [6]. These devices provide a means of converting the rapidly released energy in high explosives to a high-powered pulse of electromagnetic energy. Such devices range from man or vehicle transportable devices to air delivered E-bombs.

The basic design of an explosively pumped magnetic field flux compression device on which these weapons are based is shown in **Figure 2** without its associated electronic circuitry. They consist of a cylindrical or conical shaped explosive charge (C4, PBX), around which a coil or stator of heavy wire is wrapped. The stator is connected via a fast switch to a large, pre-charged capacitor. In operation, the switch to the stator is closed, discharging the capacitor into the stator wire. Detonation of the explosive charge must be precisely timed to coincide with maximum current flow in the stator. The explosion progressively opens the circuit formed by the stator from one end to the other. For C4, the detonation velocity is over 8,700 m/s.

The magnetic flux created by the current flowing through the stator coil is rapidly compressed as the circuit is opened turn by turn. At the point that the stator is completely destroyed and can no longer conduct current, the compressed field rapidly collapses, creating a strong electromagnetic pulse. These large magnitude changes in magnetic flux with time (high dB/dt) give rise to strong electromagnetic pulses or transients that can pose risks to nearby electronic installations and equipment at ranges of ten to many hundreds of meters, or more.

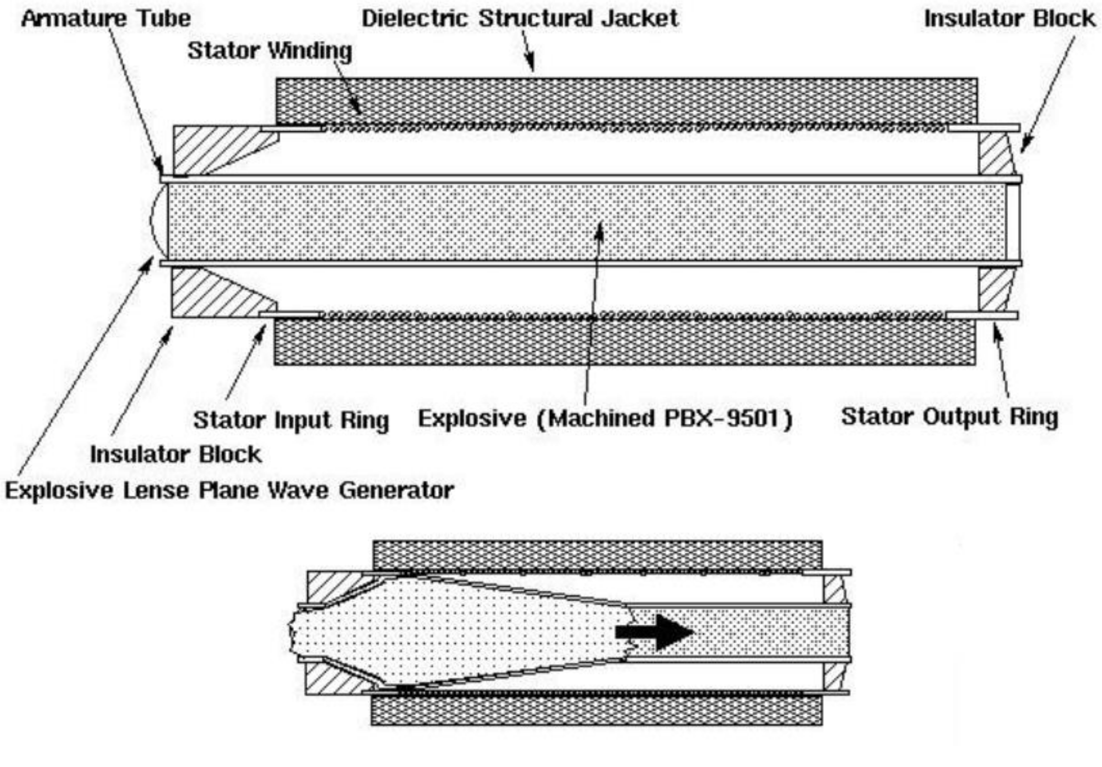

Figure 2. (Top) Basic diagram of an explosively pumped flux compression generator [4] with the PBX material, more commonly referred to as plastic explosive, packed inside a copper armature, (Bottom) Diagram showing the direction of travel of the explosive front as it moves along the armature after being initiated by the explosive lens

More sophisticated variants of the flux compressor may use a copper armature tube into which the explosive charge is placed and may use high temperature superconducting materials for the stator winding [6]. Other variants may have one or two flux compression stages with an antenna fitted on the end opposite the detonation point. The heavy wire stator is wound annular to the copper clad armature. When the explosive charge is detonated, the copper armature progressive opens, short circuiting the stator and compressing the magnetic field. In an E-bomb variant, a microwave oscillator comprised of an anode, cathode and antenna system, a type of vircator, projects the energy created by the device, via the antenna, toward the target.

For the man or vehicle deployed flux compression devices, it should be noted that electromagnetic field strength falls off as a function of $1/r^2$. That is, a doubling of the distance between the source and the target reduces the delivered field strength to by a factor of 4. Thus, increased set-back distances between the closest possible approach by an attacker and the target, such as a security perimeter fence line, should be considered a component of hardening.

Figure 3 below shows the normalized pulse forms for a nuclear EMP transient, a lightning strike and a flux compression generator pulse. Note that the nuclear EMP transient can be very fast with steep leading and trailing edges. The lightning strike shows a steep leading edge, where most of the energy is released. As described, the highest magnitude *d*B/*d*t for the explosive flux compressor is at the trailing edge when the stator magnetic field collapses.

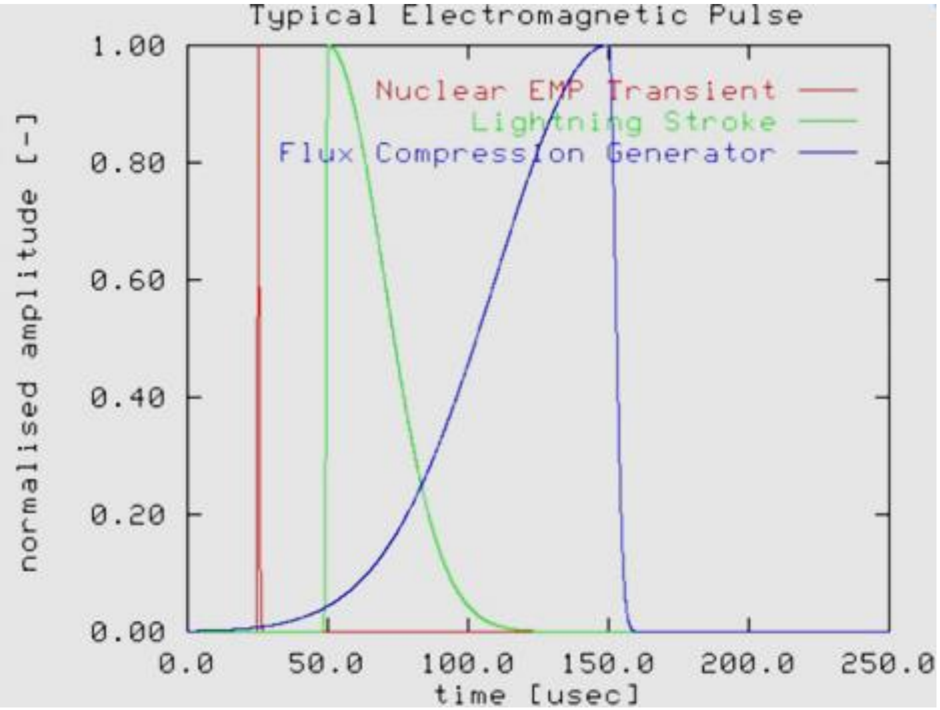

Figure 3. Graphic showing comparative shape and duration of the electromagnetic pulses resulting from a HEMP event, lightning strike and explosive flux compression device [5]

EMP Hardening Advantages of Gasification Based Smart Microgrids

Properly designed and operated distributed generation systems, configured as smart microgrids, offer inherently reduced vulnerability to EMP damage relative traditional transmission line dependent power grids. Microgrid advantages include:

- elimination of the need for highly EMP vulnerable above ground transmission lines as the main means of delivering electrical power,
- ability to build smart microgrid generation and local distribution systems that are EMP hardened by design and capable of self-healing in the event of an upset,
- ability to have sufficient onsite fuel stores for extended periods of operation in the event of fuel supply disruption.

More specific design features of a hardened microgrid system with power provided by a 12 to 24 MW gasification fired steam turbine plant include:

- construction of a Faraday cage around the entire facility to include a grid and spike ground plane structure as normally used in substations,
- minimized number openings in the well-grounded conducting metal building,
- well shielded underground transformer vaults and distribution lines,
- fast breakers with spark suppression for rapid disconnection and isolation of the microgrid from the transmission line fed power grid, when needed,
- EM airlock entry system and for EMI-sensitive control portions of the facility,
- use of optical fibers, running in shielded cables wherever possible, for communication, monitoring and control signal routing,
- EMP hardening included as part of the construction of the buildings themselves and not as subsequent add-ons, which would result in a much lower cost for this protection,
- a much smaller footprint to protect against EMP attacks as compared to solar or wind renewable energy systems.

Many of the isolation and shielding principles incorporated into TEMPEST [7] communications signals security protocols, familiar to the military, can also apply to hardening against EMP from the smaller man portable or vehicle transportable devices. Minimizing the opportunity for unintended EM signal leakage by use of setbacks, screening, shielding, bonding, filters, grounding, isolation, and specially designed electronic components can also minimize the risk of intrusion and interference by externally produced electromagnetic transients.

In addition, the USAF has classified EMP hardening protocols that can be implemented at the discretion or the Air Force during design and construction of the power plant and associated smart microgrid. Senior management and staff at EPR have worked on TEMPEST, EM interference and EMP issues, both in the military and in the DOE National Laboratory system. These individuals have held TS and Q clearances and can be re-cleared to assist in the design and implementation of any classified design features and protocols requested by the USAF for such a facility.

Gasification Based Renewable Baseload Onsite Power Generation

EPR gasification based renewable energy power plants, using biomass fuel derived from construction and demolition debris, are described in white papers available in the EPR website library at www.eprenewable.com. In brief, and as described in recent EPR presentations at Nellis AFB, these power plants use proprietary rotary kiln gasifiers to thermally convert combustible biomass materials to a fuel gas, which is cleanly burned to produce thermal energy to make steam that drives conventional steam turbine generators. Unlike wind or solar, these industry-proven and reliable steam turbines generate consistent, transient free, power 24/7.

Refuse derived fuel (RDF) for the power plant is prepared offsite and delivered as a clean, dry, presorted and pre-sized mixture of mainly wood, cardboard, paper, textiles, brush and green waste. RDF can be safely stored onsite in quantities that allow independent operation of the plant for several weeks in case of an emergency or external supply interruption.

Air emissions of criteria pollutants from the plants are lower per kWh of energy generation than for either diesel or natural gas fired prime movers, allowing stand alone plants to be readily permitted as minor stationary sources. The gasification plants can also thermally convert municipal solid waste from the host installation, thus greatly reducing its carbon footprint, as well as the cost of base solid waste management. Power generated by the gasification of biomass is renewable and thus helps in achieving renewable energy generation requirements.

EPR Designs for Onsite Renewable Energy Power Plants

Figure 4 below shows a 27.5 MW waste to energy steam power plant that is under development by EPR in Europe. This approach to the design of smaller steam power plants (< 50 MW), wherein the thermal reactors, boilers, and flue gas clean up equipment are all enclosed in a metal building, is common in northern Europe especially in areas of high precipitation and cold winters. Such designs lend themselves to EMP hardening because most critical equipment can be effectively shielded in a well-grounded metal building. In this design the air-cooled condenser is exterior to the building and would require shielding for the fan motors.

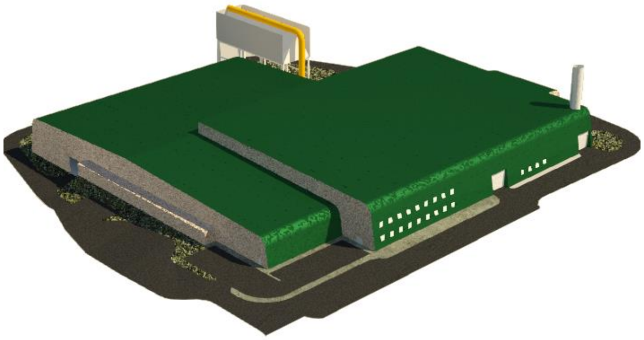

Figure 4. EPR 27.5 MW gasification waste to energy facility design showing the full enclosure of the fuel preparation and generating equipment with a well-grounded metal building

Figure 5 shows an 18 MW, hurricane resistant, gasification power plant under development in the Caribbean. In this case the entire system is enclosed in Quonset structures that can be shielded and grounded. This system uses once-through water for cooling and thus has the added benefit of no external cooling tower structures as are shown in **Figure 4**. In an EMP hardened facility the exhaust stacks would be electrically isolated from the rest of the equipment and have their own lighting arrestor and grounding system.

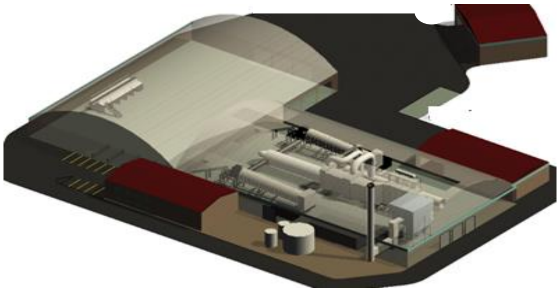

Figure 5. EPR 18 MW gasification power plant enclosed by Quonset covered buildings to reduce wind loading, the risk of fugitive particle emissions and to allow for easier equipment maintenance in adverse weather conditions

EMP hardening of an on-site gasification power plant, when designed in and installed during plant construction, would add approximately 3% to the total cost of the facility. It is estimated that retrofitting of EMP hardening after construction is complete could increase total costs by up to 30%.

References

1. Washington State Dept of Health (2003); Electromagnetic Pulse Fact Sheet 320-290 https://www.doh.wa.gov/Portals/1/Documents/Pubs/320-090_elecpuls_fs.pdf
2. Trump Moves To Protect America From Electromagnetic Pulse Attack https://www.forbes.com/sites/arielcohen/2019/04/05/whitehouse-prepares-to-face-emp-threat/amp/?utm
3. Trump orders Feds to prep for EMP attack https://www.washingtontimes.com/news/2019/mar/27/donald-trump-orders-emp-protection/
4. Wilson, C. (2008); High Altitude Electromagnetic Pulse (HEMP) and High Power Microwave (HPM) Devices: Threat Assessments, CRS Report to Congress Order Code RL32544 https://www.wired.com/images_blogs/dangerroom/files/Ebomb.pdf
5. Socol, Yehoshua (2009) High Altitude Nuclear Explosion: EMP Protection http://www.modernsurvivalonline.com/Files/EMP/articles/EMP.pdf
6. Blaise, L. et al., (2010); Flux Compression Generator https://patents.google.com/patent/US8723390B2/en
7. (NSA/CSS) TEMPEST https://apps.nsa.gov/iaarchive/programs/iad-initiatives/tempest.cfm

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