Linemen contracted by U.S. Army Corps of Engineers prepare to be sling-loaded from helicopters to inspect tops of high-voltage transmission towers and anchor lines that hold them in place after roughly 80 percent of grid was affected by storms, Aguadilla Pueblo, Puerto Rico, February 16, 2018 (U.S. Army Corps of Engineers/Michael N. Meyer)

Microgrids for the 21st Century

The Case for a Defense Energy Architecture

By Steven Curtis and Peter D. Rocha

The Department of Defense (DOD) needs a new approach to electrical grid infrastructure to maintain security and access to operational energy. Recent natural disasters and cyber attacks have exposed the vulnerability of the current system, posing threats to military operational readiness. Strategic military facilities currently acquire most of their electric power directly from the national grid, which is increasingly vulnerable to failures. The problems experienced to date could be exponentially worse if targeted by a sophisticated adversary with advanced offensive cyber capabilities, such as Russia or China. Simultaneously, the growth of renewables and increased DOD demand for car-

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bon-free energy create challenges and opportunities for operational energy. To date, only a small fraction of work has been done to create a system for DOD energy that is robust, responsive, and reliable.

A Defense Energy Architecture (DEA) should address these issues by providing a comprehensive approach to microgrid implementation for defense installations and deployable energy capabilities. A DEA would simultaneously deliver increased infrastructure security and carbon-free energy with an advanced microgrid system based on small modular reactor (SMR) nuclear power and renewables, such as wind and solar, when they are available. A DEA should also emphasize the development of energy storage applications beyond batteries, specifically hydrogen. A fully integrated system of baseload (that is, on all the time) electricity production, renewables, and energy storage is necessary to maximize the benefits to DOD in both permanent installation and expeditionary environments. The focus of a DEA should be on efficient resources based on the requirements of each base in which the microgrids would be employed.

DOD needs to advance microgrid systems for several reasons. First, DOD has energy assurance and resilience needs that significantly exceed most civilian requirements, and it therefore requires a separate system for energy production and storage. Second, as one of the largest single energy consumers in the world, DOD has the scale to create a market demand signal strong enough to encourage private investment and drive down hardware costs. Finally, with suitable guidance, DOD could move quickly to reach net-zero carbon goals for energy production.

The defense grid system and energy production mechanisms must improve to increase resilience to natural disasters and terrorist attacks on the national grid and integrate clean energy improvements in a cogent manner. This article defines the concept of a Defense Energy Architecture that may guide the construction of microgrid systems to supply desired energy production while supporting energy independence, security, resiliency, and affordable power. We further recommend that DOD integrate emerging energy concepts, in both garrison and expeditionary environments. Advances in modern energy technologies provide many opportunities for DOD to modernize, increasing security and operational capabilities.

DOD Reliance on the National Electric Grid System and Vulnerabilities

The national grid was designed with one purpose: to deliver electric power from the source of production to end users. However, at the time of its creation, there was little thought given to things such as redundancy in natural disasters and certainly none given to potential problems that could not be imagined at the time, such as cyber attacks and electromagnetic pulse (EMP) weapons. For the security of the Nation, DOD must ensure that it has continuous access to energy, making the entire defense system more robust and able to withstand the emerging threats of 21st-century warfare.

America's electrical grid is the system that powers the garrison operations of DOD and provides a platform for the application of military power worldwide. For decades, the reliability of the grid system was such that the military was confident that when electricity was needed, it would be there. However, this basic assumption is being questioned as the national grid ages, shows vulnerabilities, and grapples with the challenges of incorporating distributed electricity-generating sources like solar and wind energy.[1] These shortcomings—coupled with the realization that the existing system is vulnerable to disruptions from incidents both natural (hurricanes and solar flares) and man-made (cyber attacks and EMPs)—call for more direct control by DOD of energy production systems.

However, rather than simply moving ahead with its current course, DOD should embrace best-in-class technologies to ensure that it is moving forward with the best solutions. Moreover, the system needs to be flexible enough to incorporate new technologies as they evolve to ensure that best-in-class remedies are delivered to address the changing nature of power generation and increasingly sophisticated potential attacks on critical infrastructure.

The current grid system struggles to deal with vulnerabilities that could disrupt power and harm American security, including potential attacks by foreign adversaries or terrorists. For many, Superstorm Sandy in 2012 was a wakeup call—it demonstrated a potential for widespread damage that could affect the national electrical grid, leaving 8.5 million people without power across 21 states.[2] However, to those watching closely, Sandy was not an anomalous event but rather more of a culmination of a long-term trend that has revealed how susceptible the grid is to disruption from severe weather, including wildfires and extreme temperatures.[3] The potential for disruptive events seems to be increasing.

As devastating as these natural events have been, many national security experts predict that damage from man-made attacks could be multiple times worse. The insurance company Lloyd's of London has modeled a plausible scenario in which a cyber attack on the Eastern Interconnection, which services approximately half of the United States, could leave large areas—including dozens of military installations—without power for days.[4] This is not a distant theoretical scenario: Russia has already demonstrated the ability to successfully attack electrical grid infrastructure in Ukraine, and China is believed to have similar offensive cyber capabilities.[5] Additionally, the ransomware attacks on Colonial Pipeline in 2021 demonstrated that criminal organizations and other nonstate actors also possess the tools to sow chaos in American energy infrastructure.[6] The national grid is susceptible to large-scale disruption, whether from devastating natural weather events, military attacks from near-peer competitors, or terrorists or international crime syndicates. Therefore, response readiness largely depends on a secure supply of electricity from the main grid.

We know that the military is susceptible to the same threats that menace civilian energy infrastructure. In recent years, weather events have disrupted energy service to military installations, such as Tyndall Air Force Base during Hurricane Michael in 2019 and Joint Base San Antonio–Lackland and others during the winter storms of February 2021.[7] While the effect on operations was relatively minor in these instances, it does not take much to imagine that targeted attacks on military infrastructure could be orders of magnitude more harmful and severely impact readiness. DOD recognizes this possibility and has conducted a series of exercises to better understand "the growing threat associated with natural or nefarious events . . . such as missions being separated from access to the national grid."[8] The effects from such events could have major consequences on the military's ability to respond rapidly to crises.

Defense Energy Architecture

The goal of a DEA is to ensure that the advancement of microgrids for DOD use is comprehensive and standardized. A *microgrid* can be defined as "a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously."[9] For our purposes, we believe this encompasses both energy generation and storage. Defining the concept must not only focus on near-term needs, but also keep options open for future adaptations. It is beyond the scope of this article to prescribe what a fully functional standard for a DEA would look like. However, we can outline key principles that must be addressed to answer the challenges that face the future of DOD energy systems.

Floating solar microgrid consisting of 2,700 solar panels on lake at nearby Camp Mackall provides clean energy to Fort Liberty, North Carolina, July 28, 2023 (U.S. Army/Jason Ragucci)

The following should be considered as the essential tasks for a DEA to address the emerging energy needs:

- provide carbon- and pollution-free energy and baseload power as much as possible
- provide continuous energy on demand
- provide defense against attacks and resilience in the case of natural disasters
- provide expeditionary capability.

Provide Carbon and Pollution-Free Energy

In recent years, DOD has increasingly focused on the potential threats posed by climate change. An example of this is the Army Climate Strategy, which set goals for 100 percent carbon- and pollution-free electricity for Army installations by 2030.[10] Given this policy priority, we believe a DEA should follow the same path. The current focus for the source of this energy is renewables, primarily solar and wind. However, wind and solar power suffer from the fact that they are intermittent (they supply energy only about 30 percent of the time, and wind is not predictable). This creates reliance on fossil fuel–based electrical plants to meet operational demands for energy, which not only runs counter to low carbon goals but also maintains the vulnerable linkage to the main grid.

An ideal solution to this intermittency problem is to use small modular reactors (SMRs) to integrate baseload nuclear energy as the carbon-free backup for solar and wind. In 2021, 60 percent of the electricity generated in the United States came from natural gas and coal.[11] So when renewables are not available in the desired amount, DOD and other electricity consumers plug into a system that generates over half its power from carbon-producing and -polluting resources. Instead of backing up renewables with fossil fuels, SMRs can assure that clean energy is available on demand. This shift would allow DOD to phase out fossil fuels in the energy mix over time. Each individual installation could be configured to maximize the natural resources available—for example,

Participants of Active Communications International's 9th National Conference on Microgrids toured the Otis Microgrid, DOD's first wind-powered microgrid, which provides energy resiliency for 102nd Intelligence Wing's intelligence, surveillance, and reconnaissance missions, April 16, 2019, at Joint Base Cape Cod (Massachusetts Air National Guard/Thomas Swanson)

relying more on wind for installations on the Great Plains. Once the optimal mix of renewables is designed, SMRs would be deployed to make up the balance. The units are modular and can be added to provide more energy. This would enable DOD installations to sever themselves completely from the national grid over time and achieve clean energy goals.

Provide Continuous Energy on Demand

A second aspect of a DEA is to ensure the availability of continuous operational energy. Again, the intermittent nature of renewables causes issues with instantaneous accessibility to energy. For an organization with 24/7 operational needs, this would not do. Much of the DOD focus thus far has been to look at battery storage to preserve the electricity generated by solar and wind sources.[12] However, lithium-ion batteries, which are the current state of the art, are best suited for intra-day storage, as their ability to store energy competitively is capped at around 8 hours.[13] In a normal operating environment, this is possibly adequate since it provides overnight storage and dispersion when demand for electricity is low. However, in a crisis scenario when high energy loads are present around the clock, this may lead to shortfalls. In addition, if a natural disaster took solar and wind capabilities offline, battery storage capability would be diminished rapidly after only a few hours. Therefore, a truly independent microgrid system should have autonomous power that could be provided in the case of a prolonged interruption.

While SMRs are ideal for providing continuous energy, a microgrid system should have backup power available in case the unit does need to go offline for any period. As stated, batteries have limited ability to provide anything beyond intra-day energy storage, which itself is a system vulnerability. Hydrogen has much greater capability to integrate with a microgrid system to meet energy storage needs. Hydrogen can be produced by splitting water molecules (H_20) into their component parts of H_2 and elemental oxygen. When this is done with renewable electricity, the resulting hydrogen is carbon-free or "green." Once hydrogen is formed, it can store energy indefinitely.[14] Therefore, H_2 could maximize the total amount of energy produced by renewables.[15]

Furthermore, hydrogen can be produced by nuclear power, so it is also carbon-free and can store an almost unlimited amount of energy. Infrastructure investments would be required to store the hydrogen in a safe manner, but this is currently done globally in many industries that use hydrogen. If the SMR ever went down, hydrogen could provide a long-term bridge of operational energy until the issue was resolved. Though currently less efficient for short-duration storage than batteries, the flexibility that hydrogen provides in a microgrid system makes it extremely valuable for energy assurance. In fact, coupling hydrogen with battery storage may provide the most overall benefit for the entire system.

Provide Security and Resiliency

A third requirement for a microgrid system for defense use is the ability to safeguard it from potential attacks. We have noted that one of the vulnerabilities of the current grid is susceptibility to cyber attacks. The nature of warfare is constantly evolving. A World War I–era general transported to the 21st century would barely recognize how warfare is conducted in the age of long-range missiles, precision-guided munitions, and stealth bombers. It is not difficult to believe that future warfare may become as unrecognizable to us, since the main contested spaces in the future might not be air, land, and sea but space and cyberspace.

A tipping point may have been reached already with advances in the sophistication of offensive cyber capabilities and society's increasing reliance on digital technology.[16] The national electric grid is vulnerable because of age and the threat to the Supervisory Control and Data Acquisition (SCADA) control system from cyber attacks. An additional threat comes from EMP weapons, which deliver a pulse of energy from a nuclear or electromagnetic detonation "that creates a powerful electromagnetic field capable of short-circuiting a wide range of electronic equipment," including computers and telecommunications equipment.[17] The conventional grid is exposed to EMP attacks in the form of high-voltage control cables and transformers that regulate the grid. High-voltage transformers take 2 years to build, and the United States is inadequately stocked with backup transformers. Thus, a large-scale EMP attack could bring down a large section of the grid for an extended time.[18]

Certainly, military operational readiness would suffer if military installations were still integrated in the national grid at the time of such an attack. Again, this is not a scenario found only in science fiction novels and dystopian Hollywood films. Today, China is already believed to possess super-EMP weapons and to have developed procedures to execute a first strike.[19] This rationale is arguably enough for DOD to explore alternative power delivery systems to maintain response capabilities in the event of such an assault.

Fortunately, a microgrid system based on SMR technology has significant defensive advantages to the national grid. First, by definition, a *microgrid* is a discrete system that provides power locally. An SMR acts as an "island of power," which decouples from the larger grid and from other military installations, so a successful attack on one installation would be an isolated incident and not a systemic failure. In the case of a cyber attack or EMP detonation on the larger grid infrastructure, a military microgrid would simply not be affected because it is separate from the rest of the system.

Direct cyber attacks on microgrid infrastructure are also possible, but this infrastructure is more resilient because of its independent computer control. We recommend that both buried SMRs and underground power lines are a standard part of a DEA microgrid configuration. By virtue of being below surface, they are less vulnerable to overhead EMP explosions, which is not an option for systems based on solar panels and wind turbines. Increased sophistication and sheer volume of monitoring sensors required on a large grid necessitate the automated monitoring capabilities of a SCADA system. Automation not only provides efficiency of operation but also affords efficiency of disruption if cyber security systems can be breached. A series of smaller grid systems could be better protected individually, thus vastly increasing cyber security.[20] Furthermore, the use of hydrogen as an energy storage medium provides a long-term reservoir of energy, and if the SMR were taken offline for a period, a reversible hydrogen stack could return the stored power in the form of electricity, assuming no damage to the transmission infrastructure.

Provide Expeditionary Capability

The fourth concept underpinning the DEA is the idea that any investments in energy production and storage systems should be applicable in expeditionary environments as well as at installations after the strategic systems become mature. The military uses doctrine, organization, training, materiel, leadership, personnel, and facilities (DOTMLPF) to assess organizational systems and the resources required to support those systems. DOD should avoid redundancy of DOTMLPF for separate systems for energy production and delivery in garrison and expeditionary environments. This just represents waste and opportunity cost.

Second, the challenges faced in deployed operations are equally well addressed by the microgrid systems that we advocate. In the wars in Afghanistan and Iraq, powering forward operating bases was one of the most challenging and deadly aspect of the conflicts. Diesel generators and vehicles required constant fueling, which gave the enemy ample opportunity to attack resupply convoys. The Army Environmental Policy Institute calculated that every 39 fuel-resupply missions resulted in a U.S. casualty.[21] These are lives that are lost or irreparably changed, and no price tag can be placed on them. Additionally, it has been estimated that the financial cost of delivering fuel to the end user in the operational theater exceeded $400 per gallon.[22] Given the personal and fiscal costs that result from current in-theater energy systems, the clear challenge is to develop systems that remove military operations from the "tether of logistics" as much as possible. This would not only save blood and treasure but also enhance operational flexibility of commanders since they would experience more autonomy in deploying forces.

In addition to installation energy systems, SMRs have the potential to act as the centerpiece of deployed energy systems. As DOD better understands the capabilities of mobile reactors, we expect to see the technology migrate further to the tactical level. The Navy is certainly no stranger to small nuclear reactors, as they have been employed in the fleet since the USS *Nautilus* launched in 1955. Project Pele, conducted by DOD,[23] envisions an SMR that can be used at remote operational bases.[24] Analysis has shown that SMR technology allows for production units that are small enough to be moved by a heavy truck but are large enough to produce up to 20 megawatts of energy, enough to power an Army division headquarters.[25]

As discussed, an SMR can be buried underground, making it a hard target in a deployed environment. While SMRs address the need for a forward operating base's energy, they do not directly address vehicle mobility. However, the electricity from nuclear generation can

Technical Sergeant Marquelle Willis, 23rd Civil Engineering Squadron, Moody Air Force Base, Georgia, Prime BEEF, electrical systems noncommissioned officer in charge, works to repair high-voltage power lines supplying electricity to tent city, Tyndall Air Force Base, Florida, October 28, 2018, after Hurricane Michael (U.S. Air Force/Kelly Walker)

be used to power electric and hybrid electric vehicles that the U.S. military is already experimenting with.[26] As stated, nuclear energy can be used to create hydrogen and other fuels, and higher operating temperatures of SMRs are ideal for producing hydrogen. Because hydrogen is energy-dense, it can extend the operational range of vehicles. In fact, H_2 is nearly three times as energy-dense as petroleum diesel, which means less refueling and fewer halts in missions for refueling operations.[27] These expanded operational capabilities are simply not available with batteries, which have one-hundredth the energy storage capacity of hydrogen on an equal-weight basis.[28] The nuclear-hydrogen synergy could provide all the energy needed for military operations in deployed environments and eliminate the fossil-fuel supply chain altogether.[29] We believe a Defense Energy Architecture should unequivocally embrace an SMR-hydrogen system in deployed operations to save lives and resources and increase operational range and flexibility.

DOD Role in Advancing Energy Technology

Both SMRs and green hydrogen production can be considered emerging commercial technologies. That is, there are commercial units available, but the industries have not yet scaled to optimize production costs. The general trend in technologies over time is to become smaller and cheaper as the technology evolves. However, this takes place only if demand for the product is such that the product is seen as having long-term profitability, and companies have the incentive to invest in research and development that keeps technology moving forward.

The military operates nearly 800 installations worldwide.[30] If even a fraction of these installations were to develop SMR capabilities, it would provide a clear signal to producers and investors. The first SMRs would be much less risky to financiers if they had long-term contracted customers once completed. In fact, the Special Capabilities Office (SCO) within the Office of the Secretary of Defense has already narrowed the selection for the first such SMRs to two commercial designs under Project Pele.[31] However, this project cannot be seen as a one-off event if the scale benefits for DOD are to be realized. Project Pele could drive the procurement of the first few units within years and lay out a comprehensive plan for future purchases in the out years. A similar effort to identify promising hydrogen technologies would serve to spur investment and bring down costs for long-term, flexible energy-storage options.

The current moment is favorable for this transition in energy systems. SMR designs are being developed by more than 50 startup companies with private capitalization of greater than $2 billion.[32] Instead of paying for the entire technological development cost, the

Marine Corps Colonel Thomas M. Bedell (right), commanding officer of Marine Corps Air Station Miramar, and Mick Wasco (MCAS), MCAS Miramar energy program manager, discuss microgrid and its benefits at station's Energy and Water Operations Center, on MCAS Miramar, San Diego, California, January 21, 2022 (U.S. Marine Corps/Jose S. GuerreroDeLeon)

military need only pay for the adaptation to military standards. Based on this, the SCO predicts the initial non-Navy military SMR market will be 300 units and the civilian market 1,000 units.[33] The Department of Energy (DOE)'s Office of Nuclear Energy is already collaborating with the SCO to move the project forward and coordinate national laboratory efforts. In fact, the coauthor has personally been involved in extensive meetings at Creech Air Force Base, Nevada, to discuss the possibility of "assured energy" being supplied to the base through a prototype SMR as early as 2030.

Similarly, there is much interest in advancing green hydrogen technology. DOE has launched an initiative called the Hydrogen Shot to reduce the production cost of green hydrogen by 80 percent by 2030.[34] Furthermore, the Inflation Reduction Act has announced an investment of up to $8 billion in creating regional hydrogen hubs.[35] These programs will stimulate significant private investment as well and help advance the current state of hydrogen technology. DOD can draft off these efforts to ensure that developing hydrogen technologies meet the military specifications of an advanced microgrid system. The earlier the demand signal from the military (vs. DOD hoping for the appropriate solutions to emerge organically), the more likely that customized offerings will be available. DOD can play an important role in providing a market for these emerging technologies.

Conclusion

For the military, energy is the lifeblood to maintain military capabilities. In the event of a large-scale natural disaster or infrastructure attack, the military needs to maintain its own systems to ensure readiness. For these reasons, DOD needs to keep advancing SMR-based microgrid systems with adequate long-term energy storage in the form of hydrogen. For strategic facilities, this would mean that bases control their own destiny without counting on an ever more vulnerable electric grid. With SMR microgrids, military bases can isolate their power supply from the grid when necessary. In fact, during crises, excess power could be supplied to the civilian sector as it is available.

DOD should double down on the current efforts of developing microgrids to increase the resilience of its installations, retain the ability to deploy forces globally when needed, and provide expeditionary power without exposed refueling logistics. The benefits would be multifold. In addition to decreasing vulnerability, DOD adaptation of SMR-based microgrids would allow the military to meet clean energy goals and separate itself from carbon-producing fossil fuels. Increased DOD adaptation would drive demand, resulting in greater competition and lower prices. Furthermore, it would serve as a model to civilian energy planners who could observe the positive outcomes and adapt the technology to civilian requirements.

The military has already determined that SMR microgrids have merit, as evidenced by the maturing of Project Pele. The final solution to base supply of electricity should consider long-term efficiencies to the military of the 21st century. All sources of clean energy integration should be considered on a case-by-case basis to meet the individual needs and priorities of each base mission. Success could drive a successful transition to tactical use of SMR microgrids as well.

The national electric grid is becoming vulnerable because of age and the threat of the SCADA control system being compromised through cyber attacks, EMP disruptions, intermittent power outages, or terrorist threats. Military electric power supply, both strategic and tactical, must adapt to this reality and plan for increased future use of microgrids within a generation in the name of mission assurance. Availability, affordability, and uninterrupted power are the force multiplier requirements governing the transition away from legacy systems toward independent microgrids. It is critical that a transition to a defined Defense Energy Architecture, based on these principles, be developed and implemented soon. **JFQ**

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