Modernizing Tactical Military Microgrids to Keep Pace with the Electrification of Warfare

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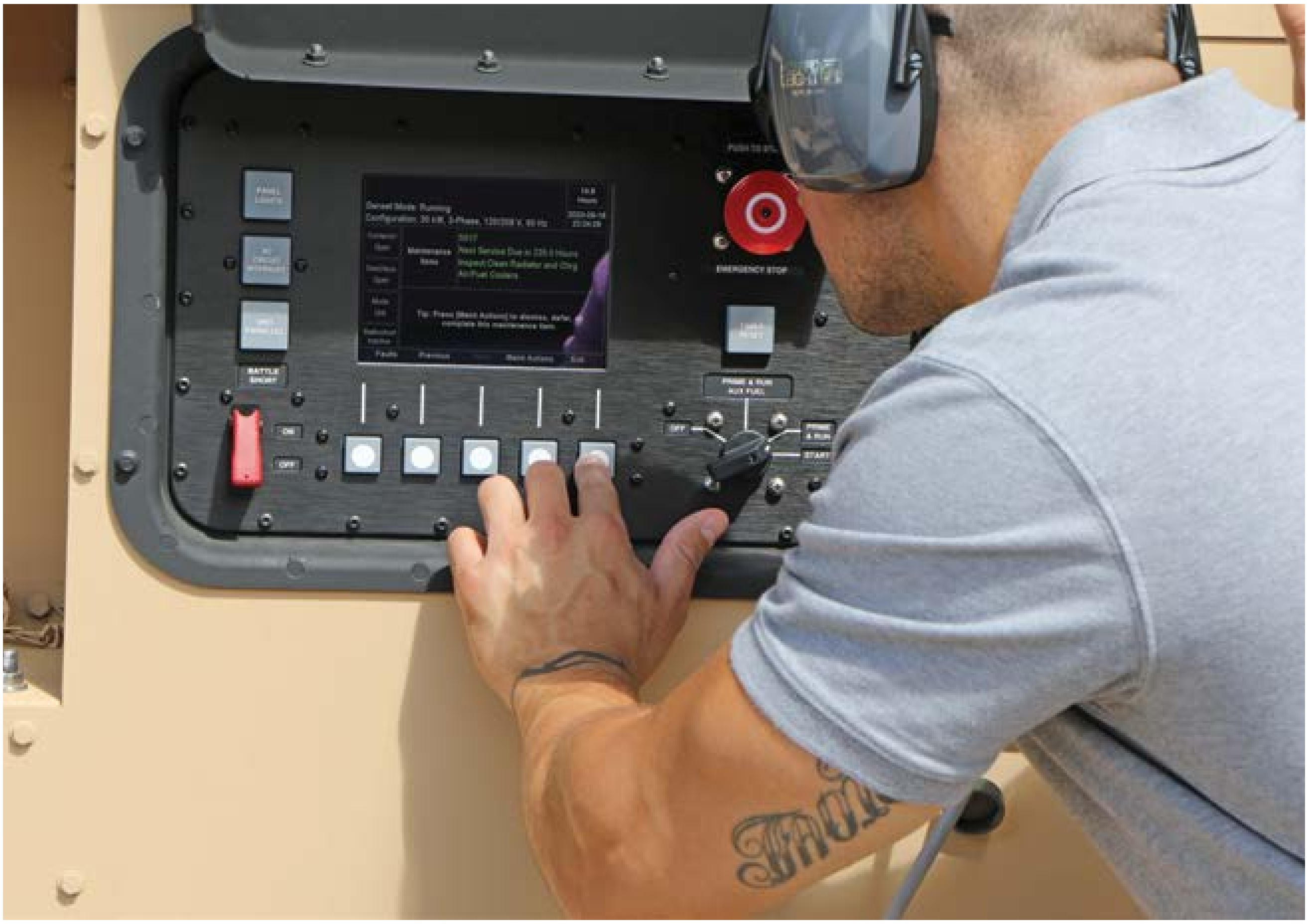
The genius and inventor Nikola Tesla best described the end state of the ongoing electrification of warfare near its inception. In 1900, he said, "The ideal development of the war principle would ultimately lead to the transformation of the whole energy of war into purely potential, explosive energy, like that of an electrical condenser. In this form, the war-energy could be maintained without effort; it would need to be much smaller in amount, while incomparably more effective."[1] He described the logistical, efficiency, and effectiveness improvements promised by the electrification of all aspects of warfare.

The process began thirty-five years prior to his statement, with the adoption of the telegraph during the U.S. Civil War. For the first time, leaders could receive near real-time reports across a wide battlefield, a revolutionary development. In those days, burning coal provided the energy for electricity generation. Since then, electricity has fundamentally altered human society and warfare. Today, the electrification of warfare is accelerating at an undeniable rate. The burning of diesel fuel and consumption of disposable batteries power today's military electronics. The U.S. Army recognizes the critical logistical vulnerabilities, pollution, and inherent limitations associated with these dependencies. Thus, the U.S. Army seeks to divest its dependence on diesel fuel and disposable batteries while simultaneously continuing the enhancement of its capabilities. Wonderous innovations such as augmented reality vision devices, autonomous resupply robots, artificial intelligence, electric combat vehicles, and directed energy weapons are in various stages of research, development, and deployment. To support these innovations, the U.S. Army's electrical power systems require modernization. Among these innovations, electric combat vehicles and directed energy weapons will prove to be the most disruptive to the U.S. Army's current energy systems.

In 2020, the U.S. Army Futures Command started developing a plan to create electric combat vehicles (ECVs).[2] ECVs offer the advantage of fewer moving parts, improved reliability, and reduced maintenance costs. They also offer instant torque, useful for traversing rough terrain and reduced thermal and acoustic signatures.



An engineer works on a hybrid power system on 16 June 2020 at Aberdeen Proving Ground, Maryland, as part of the Army's ongoing research in tactical microgrids, which will provide resilient and efficient power for soldiers in the field. (Photo by Daniel Lafontaine, Department of Defense)

However, ECVs introduce a new challenge for military electrical systems, an exponential growth in the demand for electrical energy at the forward edge of battle.

Directed energy weapons (DEWs) are also desirable for many reasons. Once constructed and deployed, they are inexpensive to operate, do not require additional ordinance to fire, and eliminate the need to store dangerous explosives.

Supporting the energy demands of these emerging technologies requires a significant modernization and development of the U.S. Army's microgrids. A microgrid is an independent energy system, which at a minimum consists of electrical generation and distribution assets. The stationary microgrids of the Global War on Terrorism, built on forward operating bases, are not up to the demands of maneuver-centric multi-domain conflicts. This new generation of microgrids must be highly mobile, integrate a diverse array of generation assets and energy storage systems, and employ sophisticated control systems to meet the modern warfighter's energy demands. Microgrids will provide the mobile electrical power required for DEWs and ECVs to integrate into multi-domain operations.

This article focuses on modernization recommendations for the U.S. Army's existing mobile microgrids to prepare them for the inclusion of DEWs and ECVs. The recommendations are backed with modeling and simulation studies of microgrids using open-source electric power distribution simulation software.

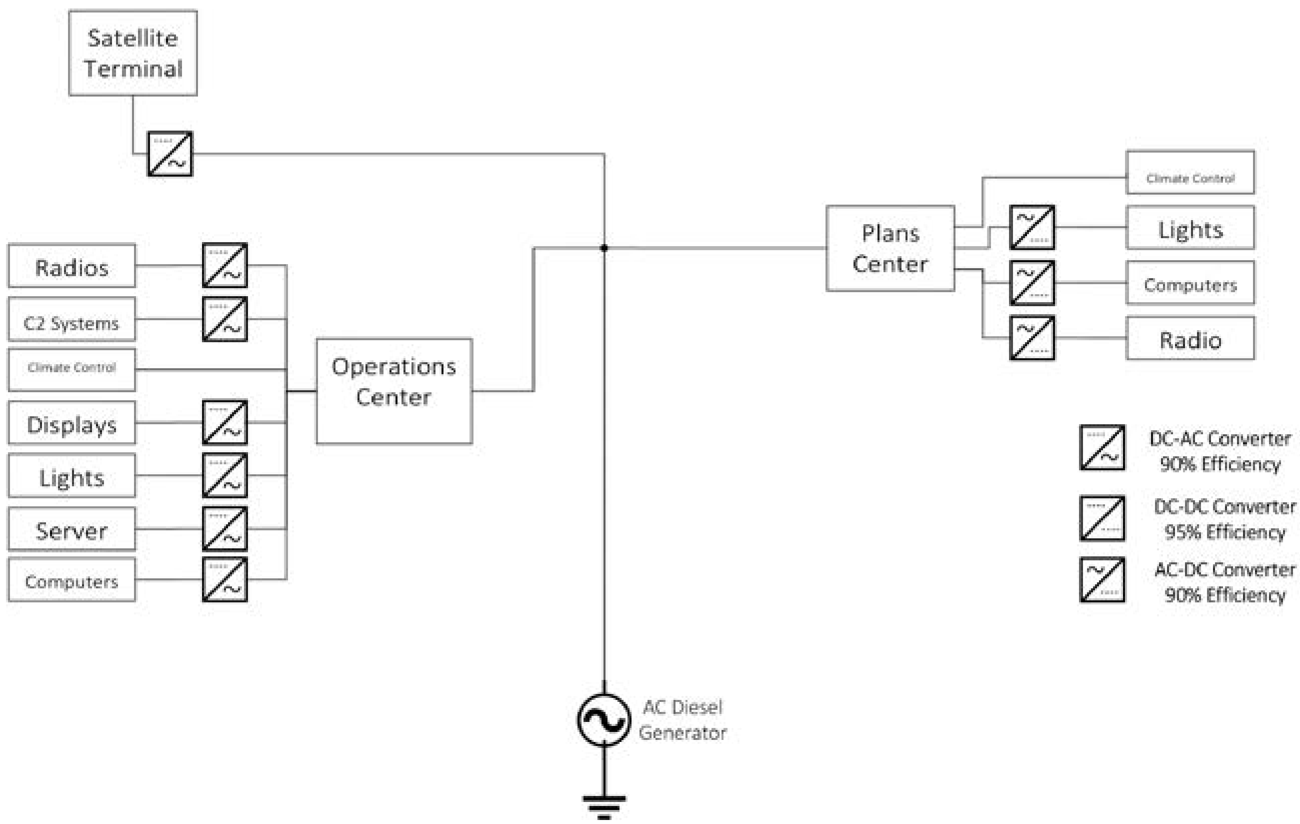
Today's Tactical Microgrids

Today's mobile command posts, which vary in size and complexity from the battalion to division levels, are microgrids. They are highly mobile electric islands providing electrical energy for communications, planning, operational management, and logistics. In a modern near-peer conflict, these command posts must move every twenty-four hours to ensure their survivability.[3] They typically have one system voltage level (no transformers are used for power transmission) and are powered by one diesel generator. Units often hold an additional generator in reserve, and while technically possible, cooperative generation is extremely rare in practice. Typically, the diesel generators are rated at less than 25 kW, and the microgrids include no energy storage or renewable generation. In their present form, these grids are ill-suited to support the products of the electrification of warfare. Figure 1 shows an example electrical diagram of a battalion command post.

Current and Emerging Challenges Facing Military Microgrids

The entire U.S. military relies primarily on diesel fuel for energy production, distribution, and storage. It has an expansive logistics network, supporting its annual 3.65 billion-gallon fuel consumption.[4] Fuel distribution under combat conditions is very risky, with up to one casualty incurred every twenty-four fuel convoys during the Iraq war.[5] This dependence on diesel fuel is a critical vulnerability shared by both combat vehicles and command posts. Fuel supplies cannot be guaranteed in near-peer, maneuver-based conflicts.

Furthermore, today's military microgrids have only one method to produce electrical energy: the humble and ubiquitous diesel generator. Universally oversized, these generators suffer from wet stacking (when unburned fuel passes through a generator and accumulates in the exhaust system) due to underloading. A recent study determined that most U.S. Army generators run at 30 percent of their rated capacity.[6] Wet stacking leads to poor fuel economy and increased maintenance requirements. The lack of redundancy, except in the form of a backup diesel generator, presents a serious risk to electricity production. Additionally, there is no protection against a disruption in fuel supplies. Forward units depend upon fuel tankers, which will not travel the battlefield with impunity under contested airspace.



(Figure by author)

Figure 1. Example Battalion Command Post Electrical Diagram

Today, there is no renewable energy penetration for these microgrids. The chief advantage of renewable energy generators is their fuel independence. However, they are non-dispatchable, meaning they are entirely dependent on ambient resource availability to produce energy (solar panels do not produce energy without sunlight). The power and energy requirements of directed energy weapons and electric combat vehicles are orders of magnitude larger than that currently required from U.S. Army command posts. Current generators cannot provide the near instantaneous high-power requirements of DEWs.

The military's continued dependence on diesel fuel is a key vulnerability and undermines many of the advantages introduced with ECVs and DEWs. This dependence is exacerbated by the continual increase in energy demands from the warfighter. For example, the U.S. Army's Integrated Visual Augmentation System promises to improve soldiers' situational awareness by integrating thermal and infrared imaging with digital communication systems in an augmented reality environment.[7] Portable radios, flashlights, targeting lasers, and many weapon systems such as the Javelin missile require portable electric energy. Soldiers also carry a suite of electric warfare, chemical, radiation, and biological agent detection devices. They are all powered using diesel fuel or disposable batteries. In their current form, military microgrids are simply not up to the task of supporting the electrification of warfare.

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The Ideal Military Microgrid

Improved military microgrids can address these current and emerging challenges. The conceptual improved microgrid

- would not require fuel resupply,
- would have a diverse selection of power generation assets,
- would have a high volume of energy storage,
- would provide or absorb high power levels on demand, and
- would feature resilient distribution systems, all while maintaining its mobility.

Many of these desired aspects are not technologically feasible today. However, there is much research and development into technologies to begin improving toward the ideal military microgrid. The required developments follow broadly into two categories: energy generation and energy transport.

Energy Transportation

One of the biggest challenges of transitioning from diesel fuel is transportation of energy to the warfighter. High-voltage transmission across large battlefields is not feasible, so this energy must be stored for transportation to the ECVs. The storage and transport of this energy may take many forms, such as portable batteries, hydrogen fuel cells, or energized fluids. Of these, batteries are the most mature technology. They can be either swapped or discharged to energize ECVs. Assuming a 96 percent efficiency, the charge-discharge-charge cycle required results in 88 percent of energy reaching the ECV. For comparison, today's diesel generators are typically about 40 percent efficient at converting the chemical energy contained in diesel fuel to electrical energy.

Another challenge for battery-based energy transfer is slow charging time. Today, battery charging times are relatively slow compared to a transfer of fossil fuels, but much research work is underway to develop rapid chargers. The energy density of diesel fuel is approximately 11,600 Wh/kg and the density of lithium-ion batteries is approximately 100 Wh/kg. Multiplying each by the percentage of energy converted to electricity at the point of use means diesel is about five times more energetic per kilogram. Thus, converting to a battery-based distribution system will require approximately five times as many "battery trucks" to replace today's fuel trucks. Other methods of transport, such as energized fluids for flow batteries or compressed hydrogen, will likely require less distribution support due to higher energy densities. However, these technologies require further research and development prior to widescale deployment.

Renewable Generation

Renewable generation is the most mature technology with potential to reduce diesel fuel dependency. However, the non-dispatchable nature of renewable generation, such as wind and photovoltaic, make it difficult to rely on these as the sole sources of energy for military operations. Military operations often occur in inhospitable climates that may not be consistently well suited to renewable generation. Using typical U.S. based capacity factors, every ten ECVs would require a 625-kW rated photovoltaic (PV) array, (covers approximately one acre of land) a 440-kW rated wind plant, (stands 70m high to the central hub with a 50m rotor diameter) or a 207-kW rated geothermal plant (requires about 250 square meters, similar to a nuclear power plant, and the proper geophysical conditions in the Earth's crust).[8] For now, the best use of renewable generation is small-scale integration into diesel-centric microgrids to reduce fuel consumption.

Nuclear Fission Generators

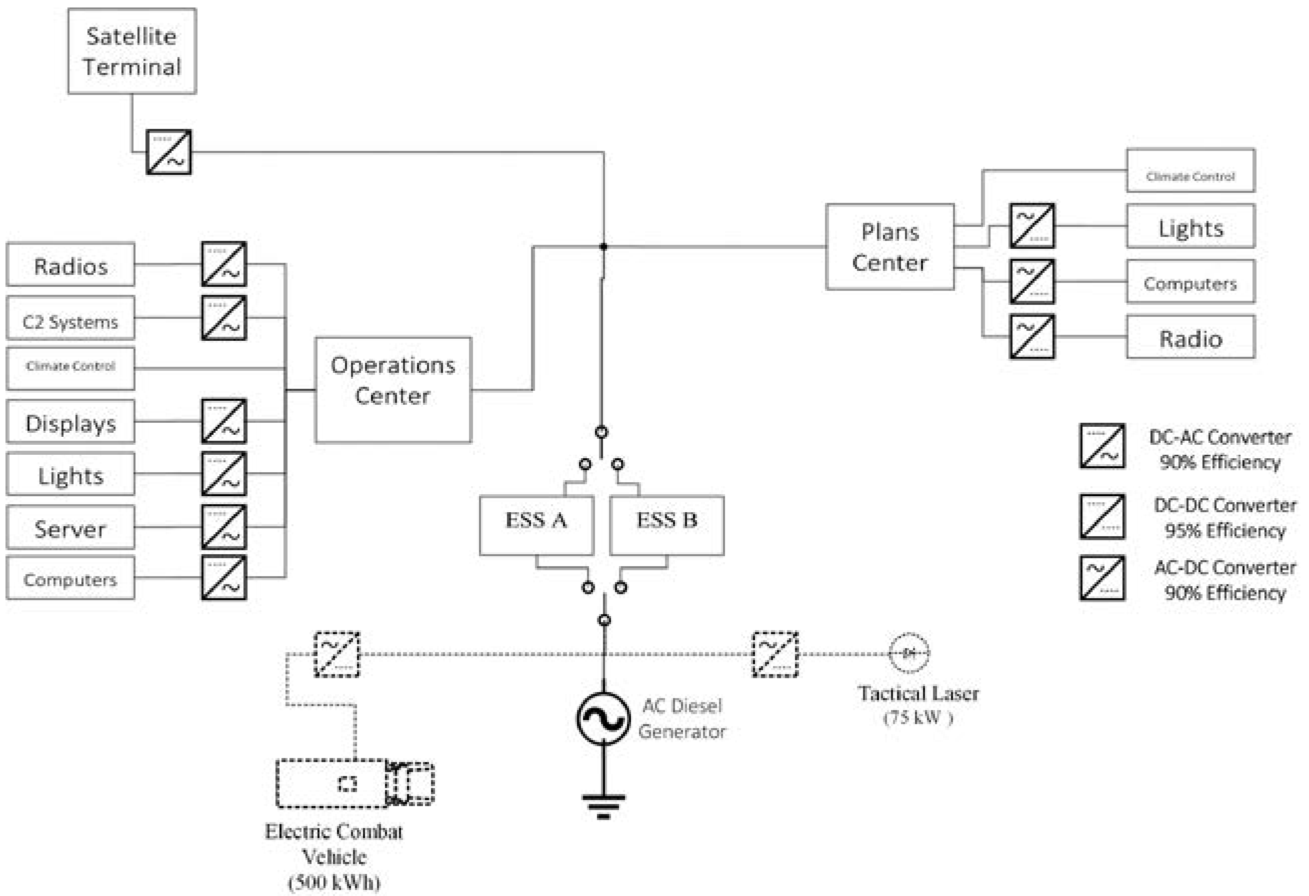
Modular nuclear reactors could provide a reliable source of energy for ECVs, and the Department of Energy has several modern designs under consideration. Project Pele has much promise to develop mobile nuclear power for future Department of Defense needs. The energy must still be moved to the ECVs, incurring the same limitations to electrical energy transfer and fossil fuel delivery. Assuming a continuing expeditionary nature for U.S. military operations, it is too dangerous to keep active nuclear power plants close to the front lines. Additionally, a nuclear power plant would require extensive protection from attack, committing valuable resources, as well as a team of highly trained technicians. Assuming a capacity factor of 92.5 percent, and with 88 percent of energy reaching the vehicles, every ten ECVs would require approximately 170 kW of rated nuclear generation, enough to power forty U.S homes.[9]

Space-Based Photovoltaic Energy

Space-based PV satellites in orbit could wirelessly transmit energy as radio waves to ground antennas for collection by energy storage systems and ultimate transfer to ECVs. Proper orbital placement and constellation arrangement can produce energy without weather or diurnal cycle impacts. The U.S. Air Force's Space Solar Power Incremental Demonstrations and Research Project attempts to develop the required technology.[10] However, U.S. military dominance in space is not yet guaranteed in future conflicts. Additionally, large ground-based antennas are required to convert the radio frequency energy transmitted from orbiting satellites to earth into electrical energy for storage and movement to forward vehicles. Assuming a capacity factor of 85 percent, due to interruptions from solar weather and heavy cloud cover, a satellite with a continuous ground power rating of 180 kW is required for every ten ECVs. If demonstrated at the proper scale, space-based PV will remain an expensive option for powering ECVs and is probably best reserved for special missions with low power requirements rather than mainstream ECV support.

Radioisotope Thermoelectric Generators

Radioisotope thermoelectric generators (RTGs) may offer one of the most effective solutions to this problem. U.S. Army Futures Command leadership recently alluded to RTGs as a possible power generation solution.[11] RTGs have long been used for power in space. NASA's latest RTG has an energy density of 2.4 electrical Wh/kg, compared to lithium-ion batteries, which have at least 100 Wh/kg. [12] If each ECV had its own internal RTG, with a capacity factor of 10 percent, a 96 percent



(Figure by author)

Figure 2. Improved AC Microgrid Electrical Diagram

charging efficiency for the battery, and a charging power of 20.83 kW (twenty-four-hour self-charge for a 500-kWh battery), each ECV's RTG would weigh approximately 8,700 kg. This is prohibitively large for a moving vehicle, and the temperature differentials required to produce that power level in space are not typically attainable on Earth. However, with increased research focus and funding from the Department of Defense, significant improvements are possible. Self-powering vehicles would not only eliminate the military's dependence on diesel fuel, but also significantly reduce support logistics requirements without the need for highly vulnerable energy production sites or energy transport infrastructure. Self-powered vehicles with DEWs could further reduce ordnance requirements.

Enhancing Today's Microgrids

While there is not yet a mature technology to completely rid the U.S. Army of its diesel fuel dependency, modernizing the military electrical microgrids is the pivotal first step to supporting the electrification of warfare. In the short term, intermediate modernization can be accomplished by integrating energy storage systems and adding small photovoltaic generators. This modernization drives the evolution of current command post microgrids into microgrids suitable for the incorporation of directed energy weapons and electric combat vehicles.

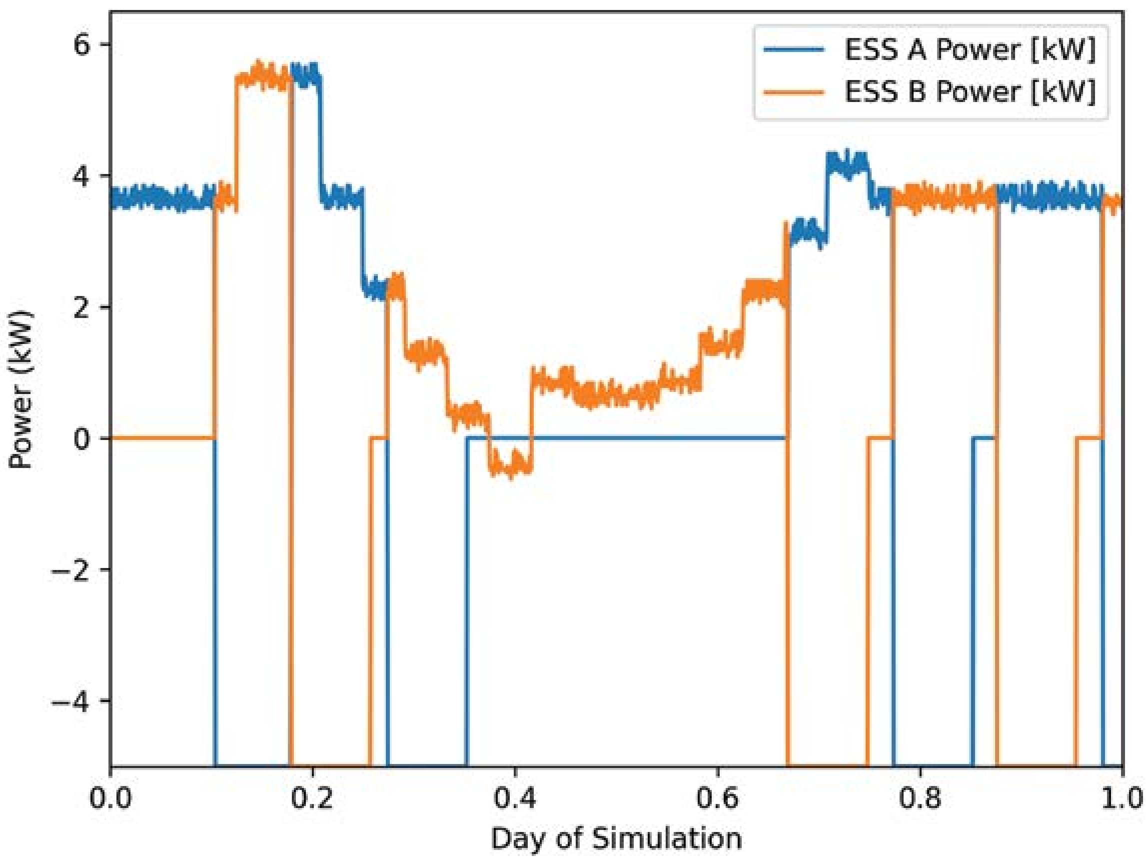
The integration of energy storage systems (ESS) has been proposed as an intermediate improvement. An ESS is a bank of batteries used to store energy. For command posts and combat outposts, ESS integration facilitates the elimination of wet stacking, the introduction of redundant generation, the ability to store renewable energy, and redundant, silent generation with a low thermal signature.[13] Generator and ESS operations can be coordinated to minimize signatures during threat windows. To modernize the command post microgrid, a dual unit ESS concept is recommended. This ESS stores energy which can power DEW rapid discharge or charge ECVs.

The addition of an ESS allows for the integration of PV generation into U.S. Army microgrids. A small array, 5 kW for example, can significantly reduce fuel consumption. However, there are numerous drawbacks to PV generation in tactical power systems worth mentioning. Array size is limited by mobility and set-up and tear-down time constraints under combat conditions. PV panels are highly reflective and easily detected using ground radar systems. Additionally, panel orientation is extremely important for achieving maximum PV generation, and the terrain and other tactical circumstances may not always allow optimal orientation. Solar radiation levels vary by location, climate, and weather. PV systems may not always be an effective power production source.

Intermediate Improved Microgrid Configuration

Figure 2 (on page 100) shows an improved AC microgrid configuration, with a 5 kW PV generator, and an ESS. It retains its functionality as a battalion command post but is postured for the emergence of DEWs and ECVs, which are shown as dashed lines. This microgrid could serve as the model for the power systems required to support ECVs and DEWs. For this initial analysis, a synthetic load profile for a battalion command post operating at the National Training Center is used. A subsequent analysis will include ECVs and DEWs.

To demonstrate the value of intermediate improvements, an evaluation analysis is conducted using OpenDSS to simulate fifty-six days at the National Training Center for the original microgrid (figure 1) and the improved AC microgrid (figure 2). OpenDSS



(Figure by author)

Figure 3. ESS Simulation Results, Showing ESS Power with a 10-kW System

Table. Analysis of the Microgrids with Intermediate Improvements

System	Fuel (Gal.)	Wet Stacking (%)
Original	307	24
Improved AC	199	0

(Table by author)

is an open-source electric power distribution system simulator. It is ideal for the complex analysis of unbalanced and multiphase microgrids. The analysis uses an ESS storage rating optimization algorithm, with an ESS one-way efficiency of 96.5 percent.[14] The ESS consists of two subunits, ESS A and ESS B.

The improved AC microgrid has a 5-kW rated PV array, consisting of 14 x 360 W PV panels, each with a microinverter with a 95 percent efficiency. The analysis covers fifty-six days, containing two weeks of each season at Fort Irwin, California, to account for seasonal variations in PV production and climate control power demands. The solar radiation data and surface temperature data used in the simulation were observed data from 2018.[15]

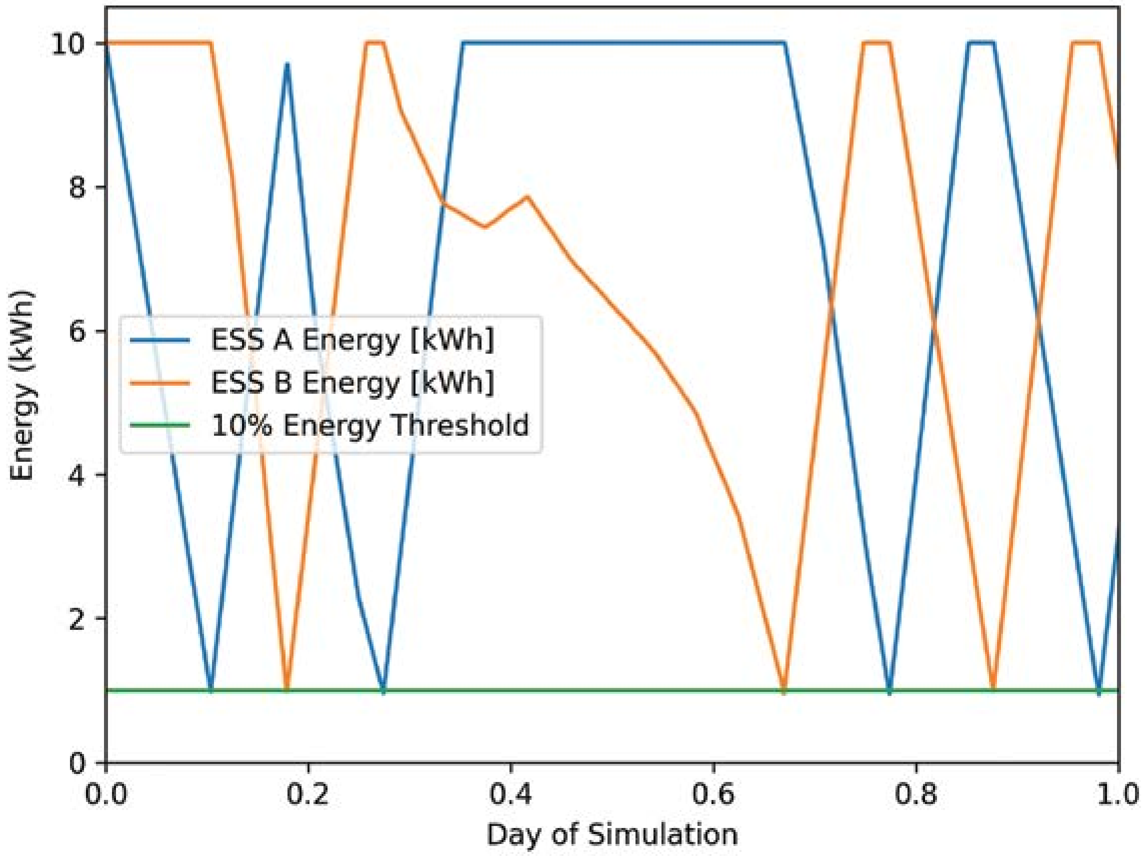
Demonstration of Intermediate Improvements

The table shows the results of the analysis of the microgrids with the intermediate improvements. In the original system (figure 1), the diesel generator wet stacked for 24 percent of the fifty-six-day simulation. Wet stacking occurs when diesel generators are underloaded, 30 percent of less of their rated power output in this simulation. The addition of the ESS allows the generator to run only at its most fuel-efficient operating point, its rated power. The generator can shut down during load loading as the ESS powers the microgrid along with the PV system if sufficient irradiation is available. This eliminates wet stacking and reduces engine wear and maintenance requirements. The AC improved microgrid (figure 2) eliminated generator wet stacking and created a 35 percent reduction in diesel fuel consumption from the current microgrid. With a fully burdened fuel cost in Afghanistan reaching to $400 per gallon in some locations, the cost savings could be considerable.[16] Much of that fuel consumption reduction is attributable to the integration of the PV generation.

Positive values show power provided by the ESS into the power system. Negative values indicate the ESS charging from the generator. Figure 3 (on page 101) shows the real power input and output for the dual ESS system for the DC microgrid over the course of one day of the simulation. At simulation initiation, ESS A and B were fully charged, as shown in figure 4 (on page 103). From figure 3, ESS B is initially idle from day 0.0 to day 0.1. During this same time, ESS A discharges, serving the load, until its energy is depleted at or below 10 percent of capacity, which can be seen at day 0.1 in figure 4. At day 0.1, ESS B comes online to meet load demand and the diesel generator switches on at its rated power and charges ESS A at its rated charging power. There is a time aligned increase in energy shown in figure 4. At day 0.18, ESS B is depleted, so ESS A switches to meet load demand and ESS B is charged by the diesel generator. The grid forming inverter on the ESS maintains grid stability and allows the maximum capture of PV energy. In all figures, negative ESS power values indicate charging and positive values indicate discharging.

Figure 4 shows ESS energy storage of the ESS set over the same one-day period of the simulation. ESS A initially discharges to serve the load until day 0.1, depleting its stored energy. ESS B is initially idle in both figures 3 and 4.

The impact of the PV generation is clear with the extension of ESS B's elongated energy depletion through the middle of the day. The PV generation extends this operation, allowing the generator and ESS A to sit idle from day 0.3 to 0.7. Figure 5 (on page 104) shows the generator is offline and idle during this time, reducing fuel consumption. For a brief period at day 0.4 the PV generation exceeds the microgrid power demand and charges the ESS serving the load, increasing its stored energy. The dual configuration



(Figure by author)

Figure 4. Simulation Results for ESS Energy versus Time

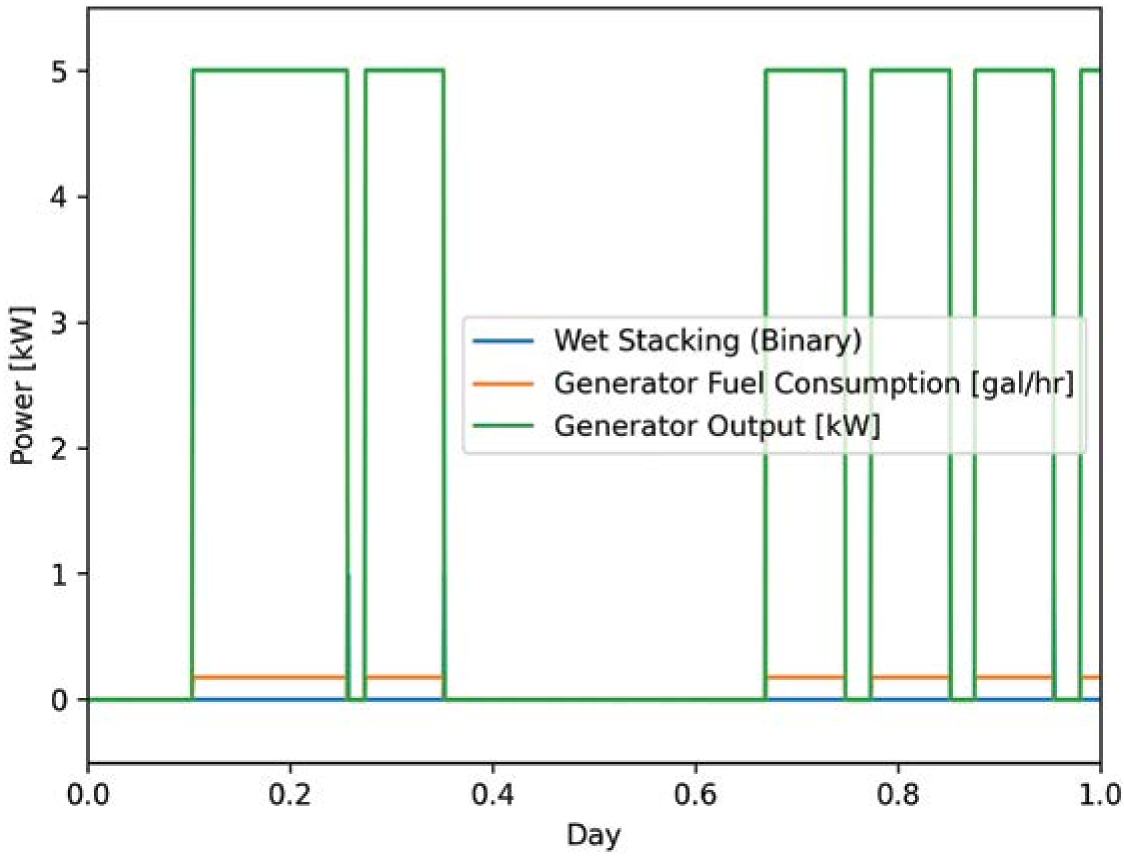
prevents the loss of any PV energy, should it exceed load demand at the time of generation. It also postures the power system for the integration of ECVs and DEWs.

Figure 5 shows the generator's real power output for one day of the simulation. The generator only comes on at its most fuel-efficient operating point, full-rated power. It rests idly in between, while the ESS meets load demand. There is a clear correspondence between figure 5 showing the generator operating at rated power and an increase in storage energy in the charging ESS in figure 4. As the generator only operates at its rated power, there is no wet stacking (blue line remains at zero). If the generator were to operate at less than 30 percent of its rated load, the chart would reflect that time step as a value of one for the blue line. The orange line shows fuel consumption, which corresponds to the generator's dispatch. At rated power, the generator consumes fuel most efficiently.

Stressing the Intermediate System with Emerging Challenges

The previous analysis clearly demonstrated the advantages of the improved command post microgrid system. Wet stacking is eliminated, and fuel consumption is reduced by 35 percent. Additionally, the system resilience is enhanced as the PV and ESS combination introduces a redundant generation source. If the generator is lost, the system can continue to function. The dual ESS also adds improved resilience through redundance in energy storage. Additionally, the energy storage creates the ability to produce energy for a limited time with no thermal or acoustic signatures. Load curtailment can extend this operation.

The dual ESS system offers maximum flexibility for the microgrid. Having two independent units allows the simultaneous charging and discharging of energy storage, doubles available storage volume, and ensures



(Figure by author)

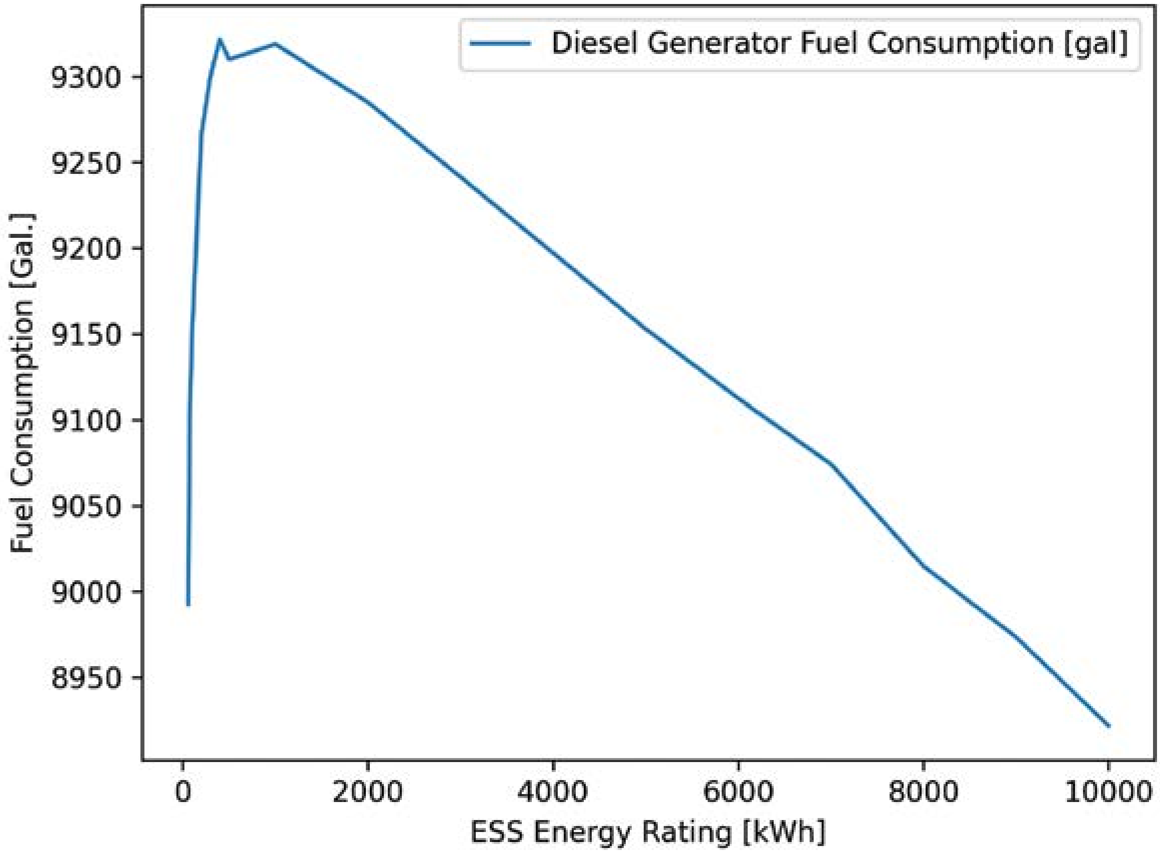
Figure 5. Generator Power Output During Simulation

the maximal capture of PV energy. Additionally, it postures the system to have double its rated power discharge in preparation for the expansion of high-power consumption devices such as DEWs and ECVs. For example, one ESS unit can meet command post demand, while another discharges to charge an ECV.

The tactical laser system under development by the U.S. Navy is modeled as the DEW for this analysis.[17] It produces a 10-kW laser beam, effective for air defense against small munitions, unmanned aerial vehicles, and small boats or vehicles.[18] The fiber laser's power requirement is 75 kW. In this simulation, the laser is directly connected to the microgrid's ESS and has a 1/256 probability of discharge at each time step, equating to about six shots a day. Its primary purpose is to destroy projectiles and small aircraft launched against the command post. This number derives from the assumption that a peer adversary's artillery battery has six cannons that shoot one salvo at the command post daily.

In this scenario, there are ten electric combat vehicles that support the command post. The charge rate for the ECVs was assumed to be 200A at 600V and each vehicle has a 500-kWh storage capacity. It is also assumed that one half of the ECVs required charging every twenty-four hours. That leads to an expectation of 16.67 charging hours per day, with a 70 percent chance of a vehicle starting charging at each time step (if no other vehicle is charging), if only one vehicle charges at a time. There is an 85 percent probability that a vehicle will complete charging once it starts. These probabilities were introduced to create some uncertainty in the models to improve realism.

First, A DEW was added the improved AC microgrid and analyzed with a 15-kW generator and 20 kWh capacity ESS. The lack of an ESS in the original system significantly undermines the effectiveness of the DEW, as a capacitor bank would be used to charge the weapon. This capacitor bank acts as a buffer to store sufficient energy to



(Figure by author)

Figure 6. Fuel Consumption versus ESS Energy Capacity for the Improved AC Microgrid with the Addition of Ten ECVs

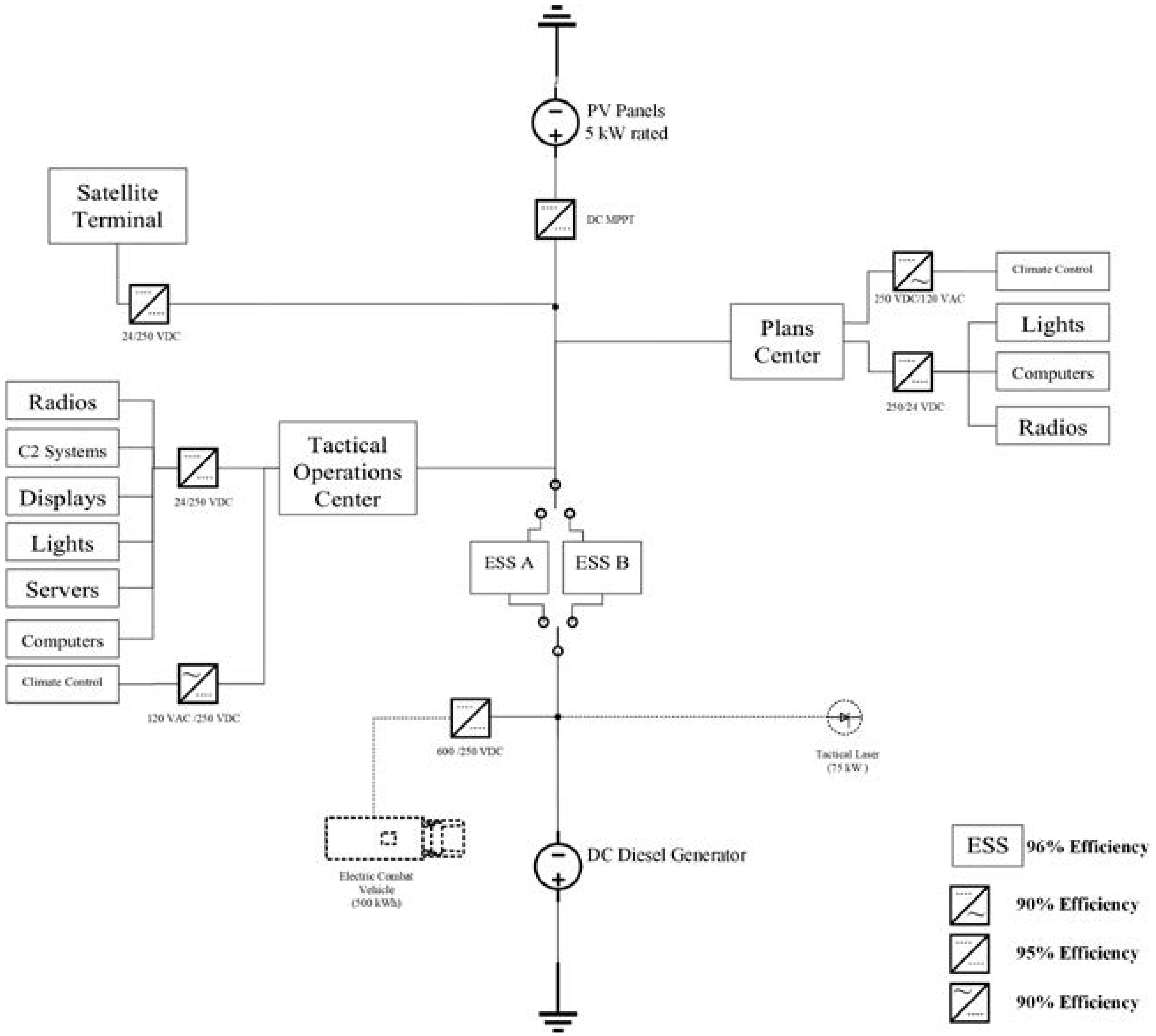
fire the DEW at its rated power, which exceeds the generator's rated power. This charger would take time to build up the energy required to discharge the device, limiting its rate of fire and increasing its vulnerability to massed fires. For example, the 10-kW fiber laser will require approximately ten minutes to charge at 650 W.

$$75\ \text{kW}\ \times 5\,\text{s} = \frac{375\ \text{kJ}}{10\ \text{mins}} = 625\ \text{W}$$

The fifty-six-day simulation previously introduced was repeated with the addition to the DEW into the improved AC microgrid. The simulation calculated that the fuel consumption increased to 278 gallons from the 199 gallons without the DEW. This is a marked increase in fuel for inclusion of the DEW from the previous simulation. The addition to the ESS provides the power for a rapid firing of the DEW, a requirement for projective defense.

Next, the improved AC microgrid received a fleet of ten electric combat vehicles. The power consumption for these is orders of magnitude higher than that of the command post microgrid. For this analysis, the improved microgrids are assigned a fleet of ten electric combat vehicles as well as powering the battalion command post. The improved microgrids were updated with a 150-kW rated diesel generator and a 500-kWh energy capacity ESS (same as the ECVs) to equip them for powering the ECVs.

The simulation again covered the same fifty-six-day simulation period. During that time, the improved AC microgrid did not incur any wet stacking, the ESS incurred less than two hundred charge-discharge cycles,



(Figure by author)

Figure 7. Preliminary DC Improved Microgrid

and generator operated only at its rated power. The improved AC microgrid consumed 9,310 gallons of diesel fuel over the fifty-six-day simulation period.

Military generators have standard sizes, but battery power and energy ratings are more flexible. Figure 6 (on page 105) shows the impact of varying ESS energy capacity on fuel consumption in the improved AC microgrid. Since the batteries do not have 100 percent efficiency, there are losses in each charge and discharge cycle. Ignoring generator constraints and only considering the ESS capacity, an 8,500 kWh ESS is the smallest capacity to break even with the same grid configuration without an ESS. With current battery technologies, this is prohibitively large for a mobile microgrid.

Requirements for an Intermediate Improved Microgrid

This section introduces general guidelines to shape the design of military microgrids to support the ongoing electrification of warfare. Total diesel generator rated output should equal coincident peak demand. This can be determined by summing the nameplate rating of all connected devices if no detailed load data is available. This ensures that the generator can meet demand should the ESS be unavailable. The PV array is limited by setup time and transpiration constraints. A 5-kW system was used as it is possible to setup or take down fourteen PV panels on the ground within one hour. Since units move primarily at night, this allows ample time to set up and take down without loss of generation. The ESS power rating should match the largest of the expected peak demand, PV rated power, or generator rated power. To ensure maximum efficiency of the generator, redundancy in power supplies, and minimize degradation due to battery cycling, the ESS energy rating should be approximately two times the rated power. In addition to reducing fuel consumption, the intermediate improved AC microgrid scales to meet the developing demands for DEWs and ECVs.

Preliminary DC Improved Microgrid

U.S. Army command posts are modern command-and-control nodes. They contain a high density of computers and communications equipment that consume electricity. These devices all require direct current (DC) electrical power. The diesel generators produce alternating current (AC) electrical power. For end use in electronic devices, AC power requires conversion to DC power. Typically, an AC-to-DC or DC-to-AC conversion is 90 percent efficient and a DC-to-DC conversion is 95 percent efficient. With today's systems, the efficiency improvement of a DC transition is hardly worth the investment required. However, DEWs and ECVs are fundamentally DC devices, with significant power demands. Thus, conversion to a DC-based distribution system becomes economical. The U.S. Army uses a standard twenty-four-volt DC voltage for most equipment and vehicles; however, such a low voltage is not well suited to power transmission over hundreds of feet across a command power system. So, a DC distribution and generation voltage of 250 volts is proposed with a DC-DC conversation stepping it down to twenty-four volts at the point of use. This voltage is high enough for efficient transmission, but still low enough to relative safe handling for rapid connection and disconnection. Future devices such as ECV chargers can use DC-DC converters to achieve the desired voltages.

There are two limitations to this proposal. The first is that it would require a significant retrofit of the diesel generators to produce DC power or the design and fielding of new generators. Secondly, not all devices commonly found in U.S. Army command posts are DC. Climate control units are typically AC devices, as they have a compressor that requires AC power. A DC-AC converter can accomplish this for this load. The portion of energy used for climate control is orders of magnitude smaller than the portion of energy required by DEWs and ECVs, both of which operate on DC power. Native generation, distribution, and consumption in DC could reduce fuel consumption by as much as 5 percent. The concept of a DC microgrid is preliminary and requires further study. Figure 7 (on page 106) shows a preliminary design for a DC improved microgrid.

Conclusion

The electrification of warfare will continue at an accelerating pace, improving efficiency while reducing the logistical requirements of warfighting. An immediate transition away from diesel fuel and disposable batteries is not technologically feasible today, but improvements to military microgrids can reduce their operational risk. U.S. Army Futures Command is already providing tremendous momentum to improving energy security by investing in and coordinating research to simultaneously improve energy efficiency and capabilities.

In the near term, the power demands of electrical combat vehicles and directed energy weapons will disrupt the U.S. Army's current electrical infrastructure. The tactical battalion command post can serve as the kernel of the mobile military microgrids needs to integrate ECVs and DEWs in brigade combat teams for multi-domain operations. Integrating energy storage and limited renewable energy generation is essential to supporting these emerging technologies and capabilities. The power and energy ratings of these devices impact their operation and require careful analysis and design. The inclusion of these innovations can significantly reduce fuel consumption and improve electrical resilience while also preparing to incorporate the emerging power demands of ECVs and DEWs. Reductions in fuel consumption lower logistical demands. The mobile nature and reduced thermal and acoustic signatures of mobile military microgrids improve survivability. The elimination of wet stacking improves fuel economy and reduces generator maintenance requirements. Improved mobile military microgrids give commanders flexibility to integrate diverse energy sources and storage, providing the energy flexibility needed for modern conflicts with near-peer adversaries. ■

Notes

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2. *Powering an Electric Vehicle Infrastructure for the U.S. Army* (Austin, TX: Army Applications Laboratory, February 2021), accessed 21 July 2021, https://aal.army/assets/files/pdf/whitepaper-power-transfer.pdf.

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