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PV on the Battlefield

New Generators

Powering the Soldier

Military Perspective

Mr. Terry Yonkers

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Secretary of the Navy Ray Mabus observes an array of solar panels while receiving a tour of the Boldak Expeditionary Energy Patrol Base in Helmand province, Afghanistan. (Petty Officer 2nd Class Kevin O'Brien)

PV: TAPPING THE SOLAR SOLUTION

The U.S. military currently finds itself trying to understand the complexities of an insurgency with deep historical and religious roots. To do so, the DoD must also deal with the inevitable increase in the amount of energy (electrical energy to be more precise) needed to perform that mission.

By Steven Tucker, RFAST-C; Power and Energy SME/PoC

Steve Tucker is a senior engineer with the U.S. Army's Natick Soldier Research Design and Engineering Center (NSRDEC) where he focuses on alternative energy and micro-grids for both basecamp-level operational power and energy efforts, as well as soldier platform-level applications. Steve is currently deployed with RDECOM's Field Assistance in Science and Technology Center (RFAST-C) in Afghanistan in support of Operation Enduring Freedom.

Literally hundreds of applications—from handheld radios, vehicle-based frequency jammers, and incoming shot location detectors to large container scanners that can "see" inside tractor trailer trucks—all rely on the constant flow of electrons to make them work. As a result, the amount of power consumed on a daily basis to support the military mission is mind boggling, and it appears to be increasing all the time.

An Energy Paradigm

The electrical power at most Forward Operating Bases (FOB) is generated by dedicated large capacity generators, and that power is then distributed by a traditional electrical grid. However, some sections of these large bases still utilize smaller independent generator sets of approximately 60kW for their power, but that method, known as "spot generation," is typically minimized when the aforementioned established electrical grid is available for tie in.

Here's the catch. Once you move out of the FOBs to the smaller Combat Outposts (COPs), then move further out to Patrol Bases (PBs), and ultimately to the yet even more remote Village Stability Platforms (VSPs), the amount of power required typically drops off. Does that mean the amount actually generated drops off at the same rate? Not necessarily. Many of the outlying posts have both military and commercial generators that are loaded at levels far below their optimal run point and far beyond the electrical capacity that the location requires. This suboptimal loading of the generators results in a host of problems, including inefficient use of fuel, "wet stacking," and related maintenance issues. As a result, there is a push to upgrade the generators in the field to the latest version of fossil fuel-fired generators in an attempt to resolve some of those issues.

Generator issues at the established bases aside, what about the small unit, the dismounted soldier, or even the special operator who is in the field for an extended amount of time without the ability to utilize a fossil fuel-fired generator as an electrical source? What about energy for recharging batteries when resupply is not feasible due to location or the need to maintain a silent state of operation? That's where I see alternative energy, and especially photovoltaics (PV), continuing to make inroads into the military energy generation mix.

Location, Location, Location

The current conflict in Afghanistan and other instabilities currently happening in the Middle East (Syria, Iran, etc.) lead me to believe

that the military will be active in this part of the world for some time to come—and in my opinion, almost definitely over the next five years.

As a result of the high level of solar insolation (the intensity of incoming solar radiation) inherent to the geographical area of those current spots of concern, PV is in a prime position to be the energy generation method of choice for select mission sets if several issues can be resolved with further R&D investment:

First: The efficiency of electrical loads and the conservation of energy as a force enabler needs to be addressed. I believe that a combination of education and a reality check on the true cost of power in the field is needed here. Perhaps that starts with addressing energy efficiency of an electrical load at the contracting level, essentially requiring every new piece of military equipment to meet a threshold energy efficiency level with no loss in mission capability. Make it a Key Performance Parameter (KPP) so that the higher the efficiency of the military system, the higher it would rank in the proposal down selection process.

However, this is not only a technology-based issue. Every electron consumed by a device should provide some benefit to the soldier using the equipment, but that soldier should also be keenly aware that electrons (like bullets) need to be resupplied in the form of liquid fuel for the generator needed to recharge their equipment or in the form of new batteries for non-rechargeable devices. Much like a child learns the value of money by having to work for it, we should stress the true cost of fuel and electrical energy during a soldier's training in terms of time, effort, and security required to ensure that the power gets where it needs to be. This may create a shift from a mindset of "It's someone else's problem" to the realization that "If the power doesn't flow, it's everybody's problem."

Second: The conversion efficiency of alternative energy sources—and for this discussion, flexible thin-film PV in particular—needs to be increased. A very short list of potential avenues that could be pursued to accomplish this goal includes further R&D to capture photons in parts of the light spectrum not currently fully utilized, embedded nano-level conductors to increase device current, or perhaps even some form of embedded light concentration by texturing the top encapsulant layer. In short, the power levels need to increase without increasing the overall deployed footprint or weight of the PV itself.

Third: Durability, especially for non-rigid forms of PV, is another area for potential progress. This starts with a solid understanding of the military environment in which the PV will be deployed and the unique stressors of that environment, understanding the realistic level of maintenance (or lack thereof) that the PV will receive once it is deployed in a military setting, and then working backwards from there. There is an urgent need for PV manufacturers to engage their material suppliers with technical military support personnel who have actually lived and seen the environment. Blowing sand, high ambient temperatures, sustained and constant wind induced flutter, high UV loading, lack of maintenance due to mission pressure, and many other obstacles are all realities in the current area of operations.

Fourth: While many attribute the fully burdened cost of fueling military forward ops more to fossil fuel-fired generators with their inherent logistical fuel tail, the cost of procuring, shipping, installing, monitoring, maintaining, and ultimately disposing of or transitioning alternative energy sources to local use still needs to be considered. A focus on making sure that equipment will perform as advertised in the environment it will be deployed to, followed closely by reducing initial procurement cost, is most important. Without both of these factors initially considered, the rest is most likely a moot point.

Fifth: The weight/cube model applies to all military equipment, but with alternative power sources, it boils down to how much energy one gets for the weight/bulk they have to install or carry. In the case of PV, this is strongly influenced by the conversion efficiency. Yet, it is also a matter of the heavier component materials selection in the PV stack as well as external packaging. Small changes such as lighter-weight substrates and encapsulants, minimization of package materials, and miniaturization of application electronics all add up. While the reduction of weight and cube in soldier-borne alternative energy sources may not mean a corresponding reduction in soldier load, it does mean that some capability has been opened up for carrying other very important things such as food, water, and ammunition.

Sixth is pertinent application development. The application must take into account all five elements expressed above: maximized efficiency of internal electronics with no loss in mission capability; increased conversion efficiency of the alternative energy source; durability to survive field conditions; cost minimization of deployment; and minimized weight/cube. However, another element must be added: making sure that any application development-oriented alternative energy effort produces prototype items that match a need expressed or anticipated in the field and is also able to be evaluated and utilized at some level in that same military field setting so additional lessons can be learned and fed back into the development process.

Potential Areas for Application Development

As expressed earlier, electrical power at base camps—from FOBs all the way out to VSPs—appears to be managed and supplied by fossil fuel generators. Until alternative energy sources can match that ability to provide power 24/7 in a comparable size and weight or the price and availability of fuel drives a different operating paradigm, it is doubtful that outside of select mission sets alternative energy will make any appreciable market penetration replacing the installed generator assets at most base camps.

That said, I see at least three areas that show promise for increased alternative energy use.

First: The small unit/individual soldier will learn to use alternative energy more effectively. This platform has the "human element" benefit of being able to employ alternative energy intelligently and adapt the use of alternative energy to suit the operational environment at that moment. I also believe that training on how to do so properly—along with the realization of the benefit of

minimizing logistical resupply and realistic expectations management of what alternative energy can and cannot do—are all keys to long-term soldier acceptance and utilization.

Second: Within the special operations forces (SOF) is where thin-film PV, and most alternative energy in general, will ultimately gain full operational acceptance. Coupled with the ability of SOF troops to make do with what they have at hand, the very nature of typical SOF austere operating conditions closely matches the mindset required to live "off the grid" back in the United States. This "off-grid" and outdoor enthusiast market is the niche that small capacity PV systems are being marketed to on the commercial side.

Power for unattended sensor systems and unmanned transmission relay sites are two areas in which I can see PV being utilized at first, especially if combined with a concealed energy storage system. The very nature of the electrical load of these two systems—high "burst" energy utilization for short periods of time interspaced by long periods of dormancy when energy collection and recharge of the energy storage component would be performed—lends itself perfectly to alternative energy's ability to operate virtually continuously without operator intervention. Specialized applications in this area may require modification to the visual characteristics of the thin-film PV, whether in shape, perceived color, or texture. Essentially, how do we make PV not look like PV so that it blends into the background unnoticed?

Third: I expect that specialty textiles for military applications will continue to develop. Prior work in the area of creating a PV "wire"—while a device low in conversion efficiency and of very short lifespan—showed that a fundamental shift from planar PV cells to a tubular format of this technology was indeed possible. I believe that additional work currently being done in this area will show that a similar pursuit of producing PV "tapes" can be successfully woven in a tarpaulin-like fashion to produce a working rough textile. Granted, this technology is still currently in its infancy, but with success at the original prototype level followed by visionary leadership providing additional funding to support R&D in this area, I believe we could see PV textiles of larger format that include inherent energy storage elements produced at pre-production levels in the next five to 10 years.

Conclusion

I am sure there are focus areas and efforts that others in the R&D realm could expand this discussion to include, and I would welcome them to do so. Solving the energy issues that our military faces will not happen overnight, nor will it happen with just one alternative energy solution, as there are simply too many platforms that need their own specific solution set. However, I submit that many aspects of the six points I raised earlier remain valid across most, if not all, platforms.

In closing, we can do better when it comes to the way we use and produce energy for the military mission. We owe it to the soldier—and the taxpayer—to do it now.

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PV: SOLAR ENERGY AS A REMOTE POWER SOURCE ON THE BATTLEFIELD

As the modern battlefield grows more challenging and our warfighters become increasingly technologically advanced, the U.S. military and its allies are identifying remote power as a capability gap that must be filled.

By Dr. Frank Jeffrey and Mr. Wes White, PowerFilm, Inc.

The U.S. military can attribute its success in battle to both the art of leadership, tactics and maneuver, and the science of weaponry and electronics commonly referred to as C4ISR—or Command and Control, Computers, Communications, Intelligence, Surveillance, and Reconnaissance. This combination of art and science has changed the character of warfare and with it the requirement for electricity in areas where no such electricity is available.

The more technologically advanced the force becomes, the more reliant it becomes on power. As Mr. Tucker correctly notes in his article, this electricity requirement appears to be increasing all the time. To meet this requirement while simultaneously mitigating the risks associated with being tethered to electricity, soldiers, and Marines, vehicles, and forward operating bases (FOBs) must be able to generate their own energy, otherwise known as remote power. Solar power is a lightweight, safe, secure, and sustainable renewable power source—which is also affordable and durable enough to use in the operational environment—and is one technology that is proving to be a viable tactical and operational power source.

The Remote Power Problem

Currently there are numerous solutions for getting remote power to the warfighter in areas where simply plugging into a nearby wall outlet is not an option. The two most common solutions are carrying batteries and turning on generators. However, these two answers come with their own problems. Batteries are heavy, and carrying more of them results in a loss of maneuverability and causes other equipment to be left behind. Generators, on the other hand, can be noisy and require fuel; transporting this fuel is expensive, personnel intensive, and often life threatening. Increased soldier weight and additional fuel convoys are both liabilities.

Solar power can reduce these two liabilities by cutting both the weight of batteries and the amount of fuel needed. However, there are some questions and misconceptions about solar that warrant discussion. Mr. Tucker's article has effectively set the stage for this discussion and is a perfect vehicle to use in addressing the future of solar power on the battlefield.

PowerFilm SOLAR

PowerFilm, Inc. is a flexible thin-film Photo Voltaic (PV) developer and manufacturing company that provides solar panels to the military in an effort to fill the military's remote power need. This article *(PV: Tapping the Solar Solution)* has been submitted in response to an earlier article written by Mr. Steven Tucker, RFAST-C, Natick and addresses points made by Mr. Tucker from an industry teammate point of view.

Discussion Points: Electrical Loads and Education (Training), Conversion Efficiency, and Durability.

Mr. Tucker has done an excellent job of laying out the benefits and challenges for PV, or solar, use in the field. He makes clear the need for cooperative work between military customers and industry suppliers in order to field the most effective solutions. Success requires a new way of looking at energy supply by commanders and a new way of looking at total solution products by the PV industry. It is, therefore, worthwhile to expand on some of the critical needs identified in the paper using the three discussion points below.

First: "The efficiency of electrical loads and the conservation of energy as a force enabler needs to be addressed." Mr. Tucker points out that a combination of education and a "reality check" on the true cost of power in the field is needed. Most in the solar industry would agree. While improving efficiency of electrical loads is a critical need, the necessity of understanding energy conservation and prioritization in a battlefield environment is vital. Effective energy use in a tactical situation is more than simply turning off a light when not needed; it's also about getting the most combat capability out of the limited power available. The first level of this is, of course, to improve efficiency of electronic devices as much is possible. Electrons are valuable, and an effort should be made to waste none of them.

1KW PowerShade solar shade. (PowerFilm)

A second critical requirement for effective use of alternative energy is development of intelligent systems marrying the electronics, rechargeable batteries, and PV as effectively as possible to minimize any use of back-up batteries or generators. Electronic systems intelligent enough to efficiently charge batteries using the constantly varying power level of solar are needed. Many of the current generation of such devices throw half the usable solar energy away because of poor understanding of the relationships. Rectifying this requires a new way of thinking for electronic designers.

Effective use of solar will also require a new way of viewing capabilities by our troops and leaders in the user world. It is inevitable that tactical field manuals and military education courses such as Basic Training, NCO courses, and Officer Basic Courses address renewable energy usage, much like they already do skills such as Basic Rifle Marksmanship, Land Navigation, First Aid, and Personal Hygiene.

Second: Mr. Tucker also points out that the conversion efficiency of alternative energy sources, and flexible thin-film PV in particular, needs to be increased; he offers a short list of potential avenues that could accomplish this, including further R&D to capture photons in parts of the light spectrum not currently fully utilized, embedded nano-level conductors to increase device current, and some form of embedded light concentration by texturing the top encapsulant layer. As discussed, improving conversion efficiency under field conditions, rather than laboratory conditions that may differ significantly, is a top-line need. This becomes a challenge as the standard physics rule applies: If something is easy to measure it's probably less meaningful, and what is most meaningful is probably hard to measure.

In the field, we need maximum conversion efficiency under a wide range of temperatures, light intensities, spectral distributions, and shading effects. How a specific PV module responds to these variables is governed not only by the semiconductor chosen but also by the cell interconnect scheme. In the end, there will be no substitute for field experience. This experience should be the guide used for selecting a technology for any specific field application for two reasons: Different field applications will require different technologies, and lab results don't always match field results.

Soldiers using 120 watt panels during NIE 12.2 at Ft. Bliss, TX. (PowerFilm)

Third: Durability is another area for potential progress and is accurately addressed by Mr. Tucker, who points out that this starts with a solid understanding of the military environment and the unique stressors of that environment. This includes understanding the realistic level of maintenance (or lack thereof) that the PV will receive once it is deployed in a military setting. As with conversion efficiency, durability assessments must be based on field experience: A higher conversion efficiency is useless if the module fails in the field.

Mechanical durability is principally determined by the required thickness of the semiconductor itself and by the interconnect method. Thin semiconductor layers are quite flexible and capable of absorbing a lot of damage with minimal power loss, while thicker semiconductors, such as crystalline wafers, are subject to breakage and complete failure if not adequately protected. Interconnects are probably a larger source of failure than cells themselves. A heavily parallel monolithically interconnected module can take significant damage without power loss, while a module using a simple series connection of cells can be killed by a single broken wire. In general, the more prone the semiconductor or interconnect is to breakage, the heavier the encapsulation required to protect the devices. Highly durable semiconductor layers (e.g., amorphous silicon on plastic) with monolithic interconnects can be extremely durable with a minimal addition of encapsulation plastics. Thus, the intrinsic durability of the semiconductor and the interconnect scheme directly impact the weight and cube of a finished module.

Concluding Thoughts

Significant progress has been made in developing PV for use in the operational environment, though further development will require continued cooperation between industry and the military, improvements in education, and constant testing. As squad and platoon level energy requirements only trend upward, the advantages of solar as a lightweight, durable, and affordable remote power source are clear. Powerfilm believes getting these benefits to the soldier is critical to improve his combat effectiveness.

Dr. Frank Jeffrey is the Founder, President, and CEO of PowerFilm with a Ph.D in Physics. Wes White is a retired Army LTC with seven years on the DA Pentagon G3 and G8 staffs.

More info: powerfilmsolar.com