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Large Scale, Lightweight Retractable Solar Photovoltaic Arrays for Military Base Microgrids

(April 23, 2009 – with 7 ½% Efficient PV)

There is a growing recognition within the military for the need to reduce fuel use, especially for ground forces at bases with difficult supply lines. The February 2008 Defense Science Board Report titled "More Fight, Less Fuel" highlighted this need and the potential for utilizing solar photovoltaic arrays to offset fuel use. It found that the fully burdened cost of delivering a gallon of fuel in the Iraqi military theater "was at least $20 a gallon, and for many missions went upwards of hundreds of dollars per gallon for ground forces."

The development of advanced batteries, electrification of vehicle drive systems, and the growing recognition of the advantages of a smart micro grid on bases will enable the use of large photovoltaic arrays that could significantly reduce military ground force fuel use. This paper has been prepared to introduce a concept developed by IPESsol, one of our EBO Group companies, focusing on "**I**nnovative **P**ower and **E**nergy **S**torage **sol**utions". Our concept for an easily deployed, large scale retractable photovoltaic array was initially introduced in a technical paper at the American Solar Energy Society 2007 Conference. (Excerpts are included at the end of this paper.)

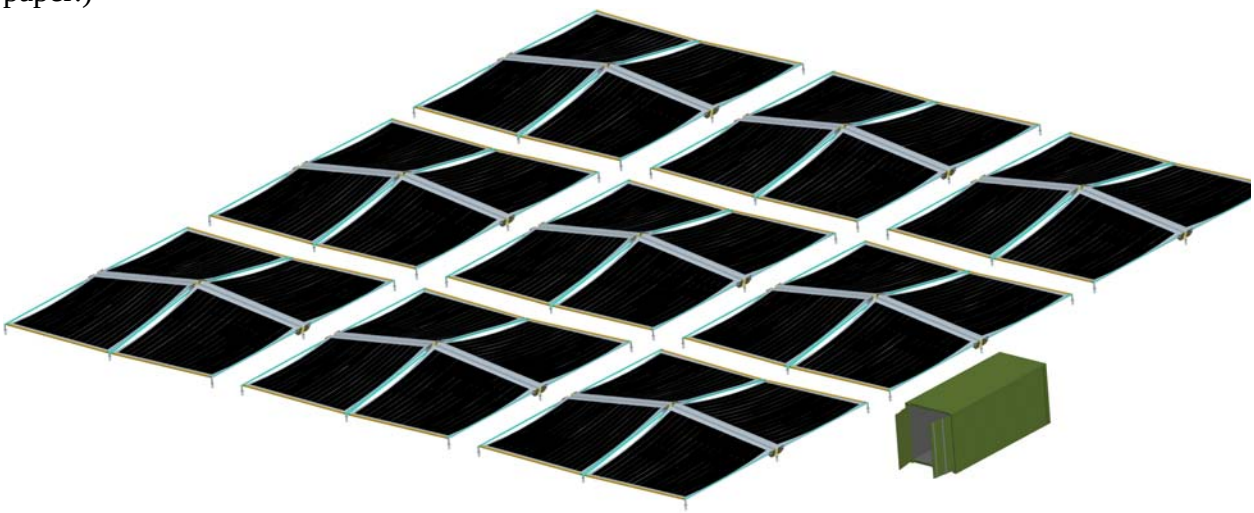

Figure A: Full Size IPESsol Array assembled from a single 20-ft. ISO Container

The IPESsol solar array is designed to fit into a standard 20-ft. ISO container. See Figure A. Thirty-six retractable solar roll assemblies can fit into a single 20-ft. ISO container (internal dimensions of 7'8" height x 7'8" width x 18'10" length). The peak power of this array could approach 75 kW with 7 ½% efficient PV cells. In locations with an equivalent average daily peak solar intensity of 5 hours, the system would generate 375 kWh of electrical energy per day. An array system from a single 20-ft. ISO container could eliminate the need to deliver 13,000 gallons of fuel per year. This data is based on 7 ½% efficient thin film PV cells on a plastic substrate. PV efficiencies are expected to increase to 9% to 10% in the next two to three years as the technology and manufacturing capabilities are further perfected.

Figure B shows the IPESsol array retracted. The total weight of the array is less than 6 tons and would offset nearly 40 tons of fuel per year for each container load deployed. The entire array covers a third of an acre and can be quickly assembled and deployed in a day or two with a small team of soldiers. The array can be assembled without the need for mechanized equipment or extensive training. Each roll assembly has four main parts that are easily connected together – a roll assembly, two side arm assemblies, and an end piece. The heaviest single part is the roll assembly, which weighs about 160 pounds.

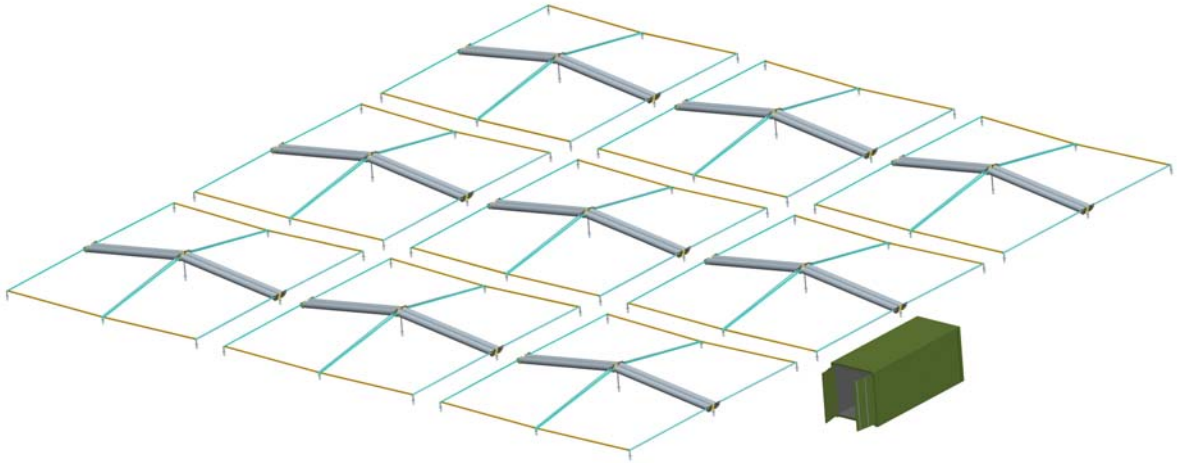

Figure B: IPESsol Array Retracted

A 2 kW inverter can be supplied for each roll assembly, or an 8 kW inverter can be used for each 4-plex. 8 kW of peak power could provide an average 40 kWh per day of energy, enough to effectively recharge two hybrid HMMWVs (Humvee) with their 24 kWh battery packs

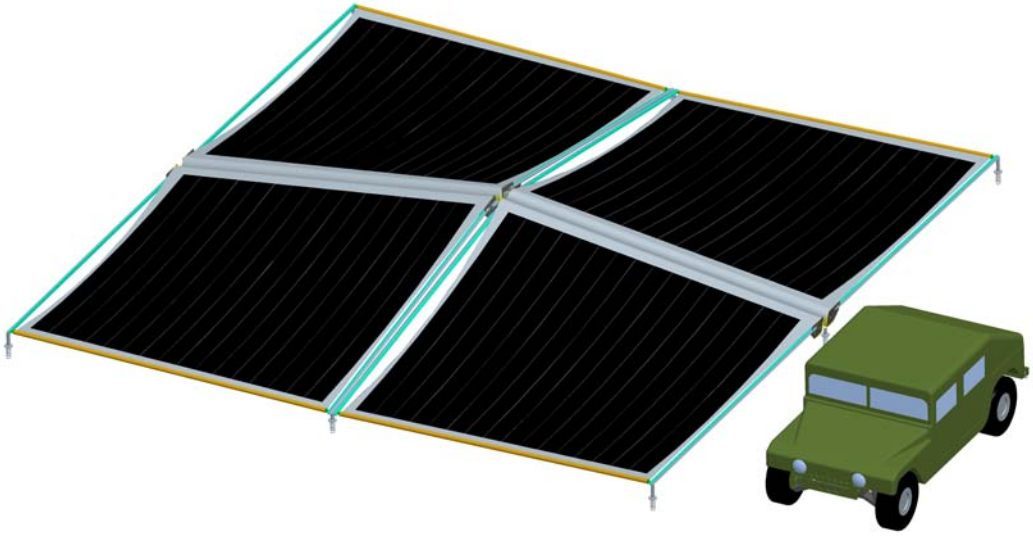

Figure C: IPESsol 4-Plex System Extended (Using 4 Retractable Rolls)

The IPESsol retractable roll assembly is designed with a slight saddle shape to create a tensile structure that stabilizes the PV material in winds up to 20 - 30 mph. At higher wind speeds, a control system senses excess wind speed or loading and automatically retracts the entire system in less than 10 seconds. This helps to reduce wind damage and dirt accumulation in

dust storms. It can also be retracted in rain or snow conditions. The system can be easily cleaned while it is being extended or retracted.

Micro grids could also incorporate wind turbines to augment the solar electric input. Figure D shows the concept of a wind turbine integrated into the center of an IPESsol four-plex system. It could use the same anchor points provided for the solar array with guy wires to stabilize a pair of lightweight 18' long poles. This would provide a wind turbine height of 36' to better capture the wind energy. If the wind turbine was rated for 5 to 8 kW, it could share the same power electronics as the solar array and provide a much greater daily energy output. The wind turbine would supplement the solar generated electricity by operating at night and by supplementing the solar input throughout the day when the sunlight is not at its peak. In windy locations, the combined energy generated could exceed 100 kWh per day for each Four-Plex System

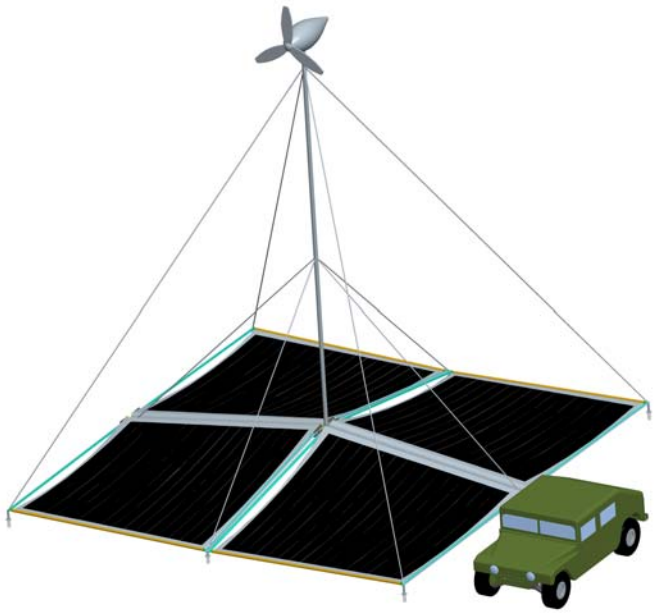

Figure D: IPESsol Four-Plex with Wind Turbine

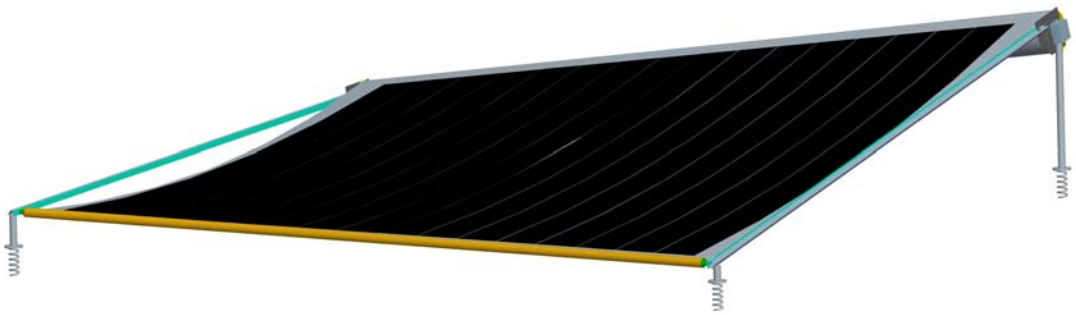

Figure E: A Single Retractable Roll Assembly Showing Saddle Shape

A 4-plex system is made up of four individual roll assemblies. Each roll assembly is supported above the ground to keep it clean and to allow air flow under it for cooling. See Figure E. A single roll assembly can effectively deploy about 275 sq. ft. of flexible thin film solar PV material. With a 7 ½% efficient PV material, it can produce a peak power of about 2000 watts (2 kW). The roll is made of a unique lightweight composite structure that is nearly 12" in diameter to prevent damage to the PV cells, wires, connectors and laminations.

Figure F: U.S. Army Truck Equipped with a Palletized Load System to handle a 20-ft. ISO Container.

Figure G: A 4-plex system could also be transported on top of a Humvee to camps inaccessible to shipment of 20' containers.

EBO Group has several patents pending on IPESsol retractable solar array concepts. For more information, please contact:

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The following are excerpts from a Technical Paper presented at The American Solar Energy Society's Solar 2007 Conference on July 8-12, 2007, covering the development of IPESsol's lightweight retractable PV array. For a copy of the complete paper, visit www.ipessol.com.

1.2 A Pre-Packaged, Retractable, Flexible, Thin Film PV Array with Integrated DC Components and Wiring

Some thin film PV technologies have the potential to be fabricated onto flexible substrates, allowing them to be rolled up. Such materials could be integrated into a retractable system that could provide both shade and PV power. This is a new form of BIPV that combines an entire photovoltaic array with a lightweight shade structure that could be easily retrofitted over patios or parking areas. Such a system goes beyond most BIPV products; it could be manufactured with DC wiring and components integrated, eliminating junction boxes, intra-array wiring, and more. At least ten U.S. companies are working on or making thin film PV products that potentially could be adapted: Nanosolar, Miasole, DayStar Technologies, Uni-Solar, Iowa Thin Film (now PowerFilm Solar), Global Solar, ISET, Konarka, First Solar and Ascent.

Perhaps the most compelling advantage of a retractable thin film PV array is the potential cost savings of the resulting lightweight materials and structures. The reason for this assertion is as follows:

All permanent structures must be designed to withstand the maximum wind speed expected in a 50-year period. Figure 1 shows a U.S. map denoting maximum wind speeds utilized for building purposes. In most parts of the U.S., this maximum is 90 mph (40 meters per second), with parts of the Gulf and East Coasts as high as 150 mph (67 meters per second).

Fig. 1: Maximum 50-year Wind Speeds in the United States Based on International Building Code Data.

Most of the time, the wind speed is far below the maximum. Figure 2 shows the percent of time the wind exceeds various wind speeds for a typical region that has a maximum wind speed of 90 mph (40 mps). Note that the wind reaches 1/3 of maximum speed, 30 mph (13 meters per second), less than 5% of the time.

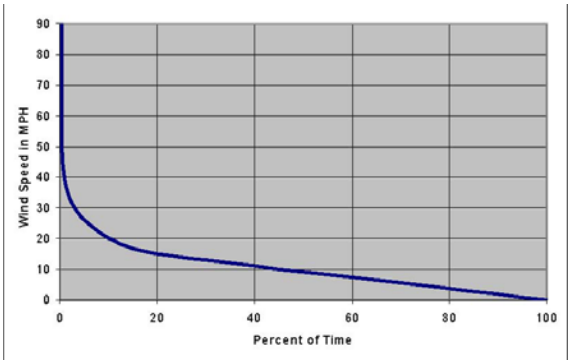

Fig. 2: Graph of Percent of Time the Wind Exceeds Various Wind Speeds for Typical Region with Maximum Wind Speed of 90 mph (40 meters per second).

Consequently, a PV system designed to automatically retract when winds exceed 25 mph (11 mps) would typically lose no more than 10% of available solar power. Note that the wind load force is proportional to the square of the wind speed: if the wind speed at retraction were 28% of the maximum speed, the wind load force would be less than 10% of the maximum load. Therefore, the retractable PV system, along with

structure supporting it, could be designed to withstand 10% to 20% of maximum wind load, compared to 100% for a permanent structure. This has great potential for reducing the cost of materials and structures, and the cost of PV power.

The combination of a lightweight shade structure with a retractable system that can deploy flexible thin film PV material, DC wiring, and components is an innovative concept. But there are numerous technical hurdles that stand in the way of making this concept a reality. It is not a matter of just adding PV cells to a retractable shade awning. If the technical challenges can be solved, it would provide a new cost-effective method of deploying PV arrays on existing homes.

2. TECHNICAL CHALLENGES AND TECHNICAL APPROACH

The proposed retractable PV system could be made light enough that it could be pre-packaged and UL (Underwriters Laboratories) listed, just as retractable shade systems are today. But PV cannot simply be added to the popular, articulated arm retracting shade awnings. The problems in doing this include the following:

- The extended awning fabric sags, forming a catenary curve that tends to flap and flutter in even moderate 10 to 15 mph winds. The fluttering of the awning fabric could damage PV cells, printed metallic wiring, ribbon wiring, and connectors.
- Such systems generally must be retracted when wind speeds reach 15 to 20 mph, and thus the solar power would be lost during sunny, moderately windy days.
- These systems require power to retract, whereas a retractable PV system should be capable of automatic failsafe retraction without power. The articulated arms on the shade awnings are spring-loaded, providing a small, but constant, tension on the lightweight awning material. Although they can be provided with wind detection for automatic retraction, power must be available to retract against the spring-loaded arms. A power outage would present a safety and reliability problem for a retractable PV system that is integrated into these awnings. Because power outages when storms are approaching are not unusual, such systems could remain extended and be subject to damage by high wind.
- These systems have no provision for wiring the PV modules or the rotating roll.
- Wrapping around the small 3-inch aluminum roll diameter, which is traditionally used, could damage the solar cells, wires, connectors, and laminations.

Therefore, if flexible PV modules and wiring are to be provided on a retractable awning-type structure, a new approach must be taken.

Non-retractable lightweight tensile structures solve the flutter problem by tensioning the fabric in the down, as well as the up direction to stabilize it. The simplest approach uses a 4-point saddle-shape structure (see Figure 3). Any three points define a triangular plane. A 4-point saddle places the fourth point far enough out of plane to stabilize the catenary curve in the fabric. A 4-point saddle can be achieved with rigid beams at the edges, or catenary edge shapes, but 4 points are the absolute minimum number of anchor points for a tensile structure.

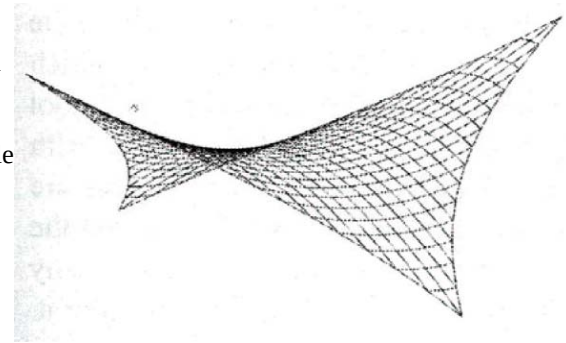

Fig. 3: Typical Permanent 4-point Saddle Tensile Structure.

Permanent 4-point tensile structures must have a significant saddle to provide stability against the expected 50-year maximum wind speeds. Such structures are not well suited for PV because a significant saddle would, in turn, cause significant variation in the solar intensity across the PV array. Such variations can

adversely affect efficiency of PV cells that are series-connected. (PV cells are wired in series to achieve the required system voltage; cells in the series that are subject to less solar intensity can affect the efficiency of the entire module or array.) In addition, permanent tensile structures tend to be expensive because they must be engineered for high wind loads.

The challenge is to develop a cost-effective retractable structure that has sufficiently high wind tolerance and resistance to flutter, yet is suitable for attaching or integrating a flexible, thin film PV array with DC wiring and components. Our proposed approach is to provide a pre-packaged PV system, big enough to meet residential power needs, in a lightweight tensile saddle structure that retracts at high wind speeds (20 to 30 mph). The saddle shape for our system will be gentle enough to minimize the efficiency problems described above. The reduced saddle will be feasible because the system will not have to withstand the maximum wind loads required of permanent structures. To successfully accommodate a PV system, the structure must be designed with an optimum saddle shape – enough to minimize damaging flutter, but not so much as to degrade PV efficiency. A retractable saddle shape is an innovative idea even for non-PV shade structures. In fact, retractable tensile structures of any type are rare, and none developed so far are suitable for PV. The combination of a retractable lightweight 4-point saddle tensile structure with a PV array and wiring is a very innovative concept.

Therefore, the primary goal is to devise a retractable, saddle-shape tensile structure that can remain extended more than 90% of the daytime without PV damage due to wind stress or fatiguing flutter, and that will safely and reliably retract without PV damage when wind speeds exceed the threshold speed or cause excessive flutter. The secondary goal is to achieve this result with a simple, cost-effective system that could accommodate the DC wiring and components, and potentially could be UL listed.

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