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13. ABSTRACT (Maximum 200 words)  Between 2000 and 2003 Transportable AC Systems (TACS) and Hybrids (HTACS) were developed and demonstrated to support the electrical requirements of Command Centers in the field. Primary power was provided by unbreakable, lightweight, flexible solar modules. Systems included battery bank, AC inverter, and backup generator. The HTACS added Windpower and higher-efficiency solar arrays, and a more ruggedized, modularized, and production-ized power control center. Demonstrated were held at six different Military bases in the U.S. and Europe.  The primary benefits of a TACS or HTACS system for the Military are driven by the Lightweight, Portable, nature of the Solar Energy Products with most advantageous features noted below: <ul style="list-style-type: none"> <li>• High Power-to-Weight ratios</li> <li>• Minimized Battery/ Fuel Transport</li> <li>• High Field Survivability (Silent, Camouflaged, Low angular or Thermal Signature)</li> <li>• Solves Targeted Energy Needs (Battery Recharging, Water Purification, Personal Electronics, PCs, Radios, Tools, Lighting, Transportable energy for command centers, medical, etc., survival kits)</li> <li>• Provides BOTH Cost-savings AND Improved Logistics</li> </ul> The result of these efforts is intended to provide the demonstrated, data-supported, basis for larger scale implementation of with solar powered tactical AC systems - - - Shown as economically superior to existing stand-alone Diesel generators.				
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# FINAL TECHNICAL PROGRESS REPORT

Report# FIN1

FOR ARO AND DARPA

UNDER #DAAD19-00-C-0118

FOR

## Transportable and Hybrid Transportable AC Systems

Submitted 11 July, 2005

BY

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**FINAL TECHNICAL PROGRESS REPORT (Report# FIN1)  
FOR ARO AND DARPA  
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**FOR Transportable and Hybrid Transportable AC Systems**

**FORWARD**

A two-phase program was created to design and demonstrate Transportable AC Systems (TACS) and Hybrid Transportable AC Systems (HTACS) for supporting the electrical requirements of Command Centers in the field.

Under Phase 1 of this contract, product demonstrations and collection of operating data were accomplished from three upgraded Transportable AC Systems deployed during 2001, 2002 and 2003 under DARPA and ARO funding. The collected data from four Military demonstration sites has provided data to support the suppositions of the "Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT) program through the Center for Army Analysis (CAA).

In addition, as part of a Phase 2 contract option, field deployment with follow-on data collection from 2 Hybrid Tactical AC Systems (HTACS) deployed at Military bases, was initiated to support the conclusions from the ADAPT and also from the REASR (Renewable Energy Analysis for Strategic Responsiveness) programs, both programs developed under the Center for Army Analysis (CAA).

The primary benefits of a TACS or HTACS system for the Military are driven by the lightweight, portable, nature of the solar energy products with most advantageous features noted below:

- High Power-to-Weight ratios (>2X Higher than Others)
- Minimizes Battery and Fuel Transport
- High Field Survivability (Silent, Camouflaged, Low angular or Thermal Signature)
- Solves Targeted Energy Needs (Battery Recharging, Water Purification, Personal Electronics, PCs, Radios, Tools, Lighting, Transportable energy for command centers, medical, etc., survival kits)
- Provides BOTH Cost-savings AND Improved Logistics

The result of these efforts is intended to provide the demonstrated, data-supported, basis for larger scale implementation of solar powered tactical AC systems - - - Shown as economically superior to existing stand-alone Diesel generators.

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# 1.0 PRODUCT BACKGROUND

## 1.1 Statement of Problem — Need for Reliable Portable and Transportable Power

Portable power for today’s electronically-laden military has become a critical aspect to deployment logistics. In an era where global positioning systems (GPS), real-time battlefield telemetry, secure communications, and coordinated battlefield deployment is the norm, electrical power has become a mission-critical requirement for attaining satisfactory Strategic Responsiveness. Furthermore, today’s conventional forms of portable, military power present logistical **fuel handling** problems, continuous **noise** issues, and **environmental** concerns.

As stated above, power generation and storage for portable and transportable applications are critical requirements for today’s military. Consequently, the U.S. Army is evaluating the use of PV power systems for their portable and transportable power needs. In data presented by the Center for Army Analysis in “Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT),” photovoltaic power systems have distinct advantages over other power sources in many applications. ADAPT provides a comparison between conventional portable power systems (e.g., diesel generators) and solar PV/diesel hybrid (80%/20%) systems. In terms of operation, where sun is a readily available resource, PV is much quieter, cleaner and requires less scheduled maintenance than a primary diesel generator (i.e. genset).

ADAPT includes a case study at Fort Bragg, where it was determined that soldiers in the field found PV maximized their efficiency and that the PV case enhances operational readiness ([Table 1](#)). In addition, by replacing 80% of the diesel-generated power with PV, the Army would realize a 200,000 pound reduction in pollution, primarily in global-warming gasses. Furthermore, 11,000 gallons of fuel would be saved, dramatically reducing cost due to material and fuel transport logistics.

**Table 1 Observations of Operational Readiness Comparisons Between Conventional and PV Hybrid Systems (CAA’s “Analysis of Deployable Applications of Photovoltaics in Theater (ADAPT)”)**

Security	Ops Friendly	Durability	Reliability
<b>Conventional Case: 100% Generator</b>			
<ul style="list-style-type: none"> <li>• Lower Visibility</li> <li>• Greater Heat Signature</li> <li>• More Noise</li> </ul>	<ul style="list-style-type: none"> <li>• Much Greater SOP Maintenance</li> <li>• More Labor Intensive</li> </ul>	<ul style="list-style-type: none"> <li>• Ruggedized</li> <li>• 10 &amp; 20 Year Life Cycles Depending on kW Rating</li> </ul>	<ul style="list-style-type: none"> <li>• Good Theoretical Reliability of 3 kW Generators</li> <li>• Less Than Planned</li> </ul>
<b>Photovoltaic Case: 80% PV and 20% Generator</b>			
<ul style="list-style-type: none"> <li>• Greater Trailer Height Visibility</li> <li>• Less Heat Signatures 80% of the Time</li> <li>• Noiseless 80% of the Time</li> </ul>	<ul style="list-style-type: none"> <li>• Much Lower Maintenance</li> <li>• Less Overall Labor</li> </ul>	<ul style="list-style-type: none"> <li>• Modules Ruggedized</li> <li>• Durable Lead Acid Batteries</li> <li>• 20 Year (+) Life Cycles</li> </ul>	<ul style="list-style-type: none"> <li>• PV System Has No Moving Parts</li> <li>• Reliable Electronics</li> <li>• More Sun is Better</li> </ul>

While a compelling case has already been made for PV, as noted above, an additional analysis from ADAPT looked at the quantity and type of on-hand power generation in today’s Army arsenal. [Table 2](#) illustrates the breakdown in genset size in terms of quantity for two divisions, namely the 82<sup>nd</sup> Airborne and the 4<sup>th</sup> Mechanized. While the operations and role of these two divisions are dramatically different, which is explained by the large discrepancy in the total number of generators from the 4<sup>th</sup> to the 82<sup>nd</sup>, both remarkably have 68% of the power generation provided by gensets of less than or equal to 5 kW. This power level is an easily manageable capacity for a portable PV system, provided that a sufficient area is available for solar collection. Furthermore, fully 36% of the 82<sup>nd</sup> and 48% of the 4<sup>th</sup> divisions require generators of 3 kW or less.

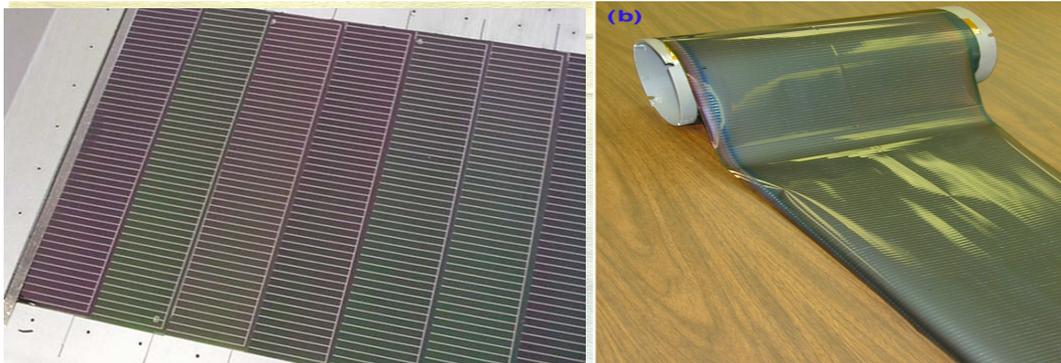
**Table 2 Breakdown of On-Hand Generators from the 82<sup>nd</sup> and 4<sup>th</sup> Army Divisions (Data from Current Year Equipment Holdings from Structure and Manpower Accounting Systems (SAMAS)).**

Division	Power Generation (kW)						Total
	3	5	10	15	30	60	
82 <sup>nd</sup> Airborne	322	290	189	46	32	16	895
	36%	32%	21%	5%	4%	2%	
	612 (68% of Total)			283 (32% of Total)			
4 <sup>th</sup> Mechanized	1115	447	444	138	120	46	2310
	48%	20%	19%	6%	5%	2%	
	1562 (68% of Total)			748 (32% of Total)			

## **1.2 PRODUCT DESCRIPTION**

### **1.2.1 GSE's Flexible Thin-Film Photovoltaics**

GSE has demonstrated expertise in producing flexible thin-film PV materials (*Figure 1*). This state-of-the-art solar product represents the culmination of a four year Defense Advanced Research Projects Agency (DARPA) effort and large investments by GSE to demonstrate production capability of a complex thin-film PV device over large areas. Our roll-to-roll process of manufacturing thin-film PV on flexible substrates results in low-cost, lightweight, and flexible solar modules.



**Figure 1 GSE's Flexible CIGS PV (a) Discretely Interconnected Cells using a Metallic Foil Substrate and (b) Monolithically-Integrated on a Polyimide Substrate.**

GSE's **Power Flex™** PV modules, when incorporated into a subarray, (*Figure 2*) offer a completely new solution for reliable solar energy. Weighing approximately 90% less than conventional PV modules and with a flexible physical form replacing fragile glass, the **Power Flex™** modules offer extensive usage, handling, installation and transport benefits.



**Figure 2** GSE's Power Flex™ Modules in a Subarray.

When combined into compact, foldable solar subarrays, as shown, these **Power Flex™** modules enable systems which will provide clean, quiet and fuel-free power with minimal maintenance required. Solar efficiencies have improved to a level where the area required to produce a 2.8 kW to 3.1 kW array is an easily deployable, stow-able, and transportable product.

Furthermore, an anti-glare surface treatment has been incorporated into various GSE products, and TACS0009 was supplied with an array incorporating this anti-glare surface. A comparison of two foldable solar modules in Figure 3 shows the visual difference between a module with and a module without such a surface treatment. The specular reflection is reduced on the treated samples from ~1% to less than 0.1%.



**Figure 3:** Foldable modules – Left with anti-glint; Right is without anti-glint

### 1.2.2 GSE's Solarized Transportable AC System

GSE's **Transportable AC System (TACS)** utilizes the **Power Flex™** modules to provide convenient and reliable electricity in nearly any location or situation. Each system is supplied with clean, silent power from a lightweight, flexible and durable solar array. Excess power from the solar array is stored in a battery bank for nighttime or cloudy day use, and backup power is supplied by a generator connected to the system's control unit ([Figure 4](#)).



**Figure 4** TACS Power Storage and Backup Generator System Deployed at Ft. Bragg, NC.

The fully integrated TACS readily supplies power to the Military loads with standard outdoor AC Power outlets while offering several other benefits, including: minimized environmental impact; reduced fuel transportation, storage and cost; predetermined generator runtime for mitigating generator noise; reduced generator maintenance; prevention of “Wet Stacking” by the ability to run generators at optimal loads, and transportability for use in any location. Under this contract, a typical TACS is comprised of the following items:

1. 2.8 to 3.1kW solar array
2. Power Management Center
3. Battery Bank (e.g. 400 A-hrs at 48VDC)
4. 4 kW AC Inverter (e.g. 30 Amps at 120 VAC)
5. 4 kW Backup Generator (e.g. 30 Amps at 120 VAC)

### **1.3 Performance Expectations**

The performance expectations for Tactical AC Systems to Support Field Command centers are discussed in this section.

#### **1.3.1 Loads at a Tactical Operation Center (TOC)**

Loads typically used at a Command Center include the following:

- Tent Lighting
- Portable Computers
- Coffee Pot
- Battery Re-Charging
- Copiers, Office Equipment
- Medical/Surgical Equipment
- Environment Control

Based on initial results from ADAPT, it was estimated that a typical command center will be supported by an energy source which supplies 6 Amps continuous at 120 VAC.

#### **1.3.2 TACS System Output Expectations**

The TACS system was designed for 6 Amps continuous at 120 VAC with a maximum demand capability for short periods of nearly 60 Amps at 120 VAC. Although the backup AC generator was capable of 30 Amps, when combined and synchronized with the 30 Amps of inverter AC from the inverter, a large dynamic range for available current was realized.

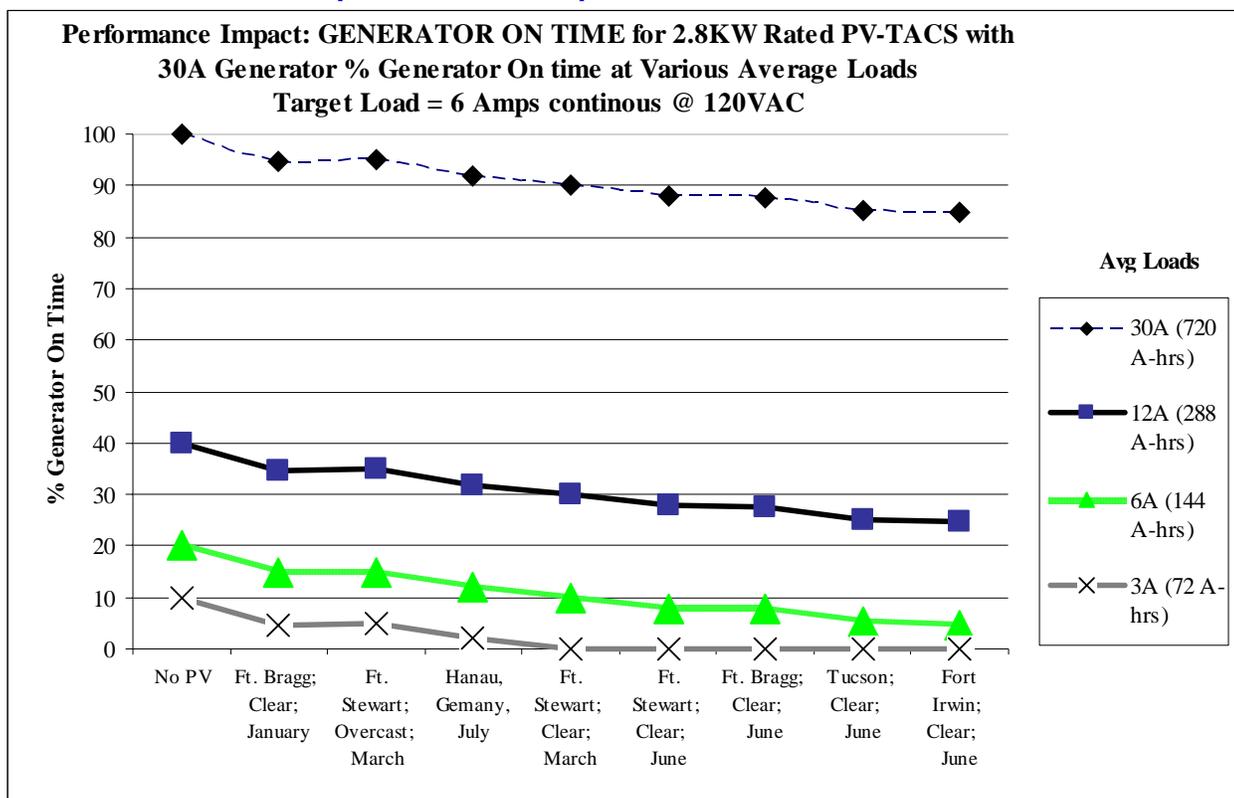
It is shown from the modeled performance in [Chart 1](#) that when the system is operated at its rated output of 6 Amps continuous at 120 VAC that the average system performance expectations are:

- On-Time of Generator 5-10% in sunniest areas and 15 to 20% in overcast areas
- Silent Running is therefore 80-95% of a day

Therefore, approximately 1/10th the fuel was used compared to generator alone. In addition, less than approximately 1/10th the maintenance was required compared to generator alone. This TACS system, compared to a generator alone, therefore has advantages over a system using only a generator, by providing:

- A Substantial Reduction of Generator:
  - Fuel
  - Maintenance (No Diesel “Wet-Stacking”)
  - Usage (Long Periods of Silent Running), AND
  - Pollution, and
- An Overall Improvement in Logistics by Incorporation of PV Power Source

**Chart 1- Performance Impact Chart – Comparison between TACS and GENSET**



### 1.3.3 Economic Payback Period Estimate

An in-depth comparison between the lifetime economics of a TACS and a Generator (GENSET) only was reported at the Tri-Service Power Expo, Norfolk, VA, 7/17/03, by Hugh Jones, Center for Army Analysis, Resource Analysis Division.

Given assumptions typical for a Tactical Operation Center (TOC), the primary results were:

- 1-2 year average payback vs. GENSET (For Deployed operations where real fuel costs, mostly transportation, are much higher - - Assumed \$13/gallon)
- 8 year average payback vs. GENSET (For Sustaining Base Operations Where Fuel Cost Low - - Assumed \$0.76/gal)

- Payback time does not include added advantages such as silent running, thermal signature reduction, pollution abatement, and labor opportunity cost, but does require 20 year solar array life.
- Further reduced payback times are expected in future from economies of scale and increased solar efficiencies.

## **2.0 SUMMARY OF THE MOST IMPORTANT RESULTS AND ACHIEVEMENTS**

An earlier DARPA agreement and an AFRL contract had resulted in 1<sup>st</sup> Generation models of TACS systems that were demonstrated at several Military bases (at Ft. Bragg, NC and later at Ft. Stewart, GA). Based on the considerable input and suggestions from participants in these earlier efforts and demonstrations, the upgrades associated with this ARO/DARPA contract were identified. The two phases of this ARO/DARPA effort are discussed in this and the next section.

### **2.1 Phase 1 (2001 and 2002): Transportable AC Systems (TACS)**

#### **2.1.1 Objectives**

To upgrade designs for Transportable AC Systems (TACSs) in order to demonstrate a power source with improved economics relative to a diesel generator alone.

The specific aims during Phase 1 were:

1. Evaluate the pre-existing TACS design
2. Develop upgraded designs for the Solar Array Structures
3. Develop upgraded designs for the TACS Power Control Center
4. Deliver completed systems to customers for demonstration, with follow-up.

#### **2.1.2 Primary Results**

Critical Results during Phase 1 (2001 and 2002) were:

1. Successfully incorporated multiple substantial performance upgrades into the Power Control Centers, the PV Arrays, and the trailer-mounted TACS systems.
2. Completed contractual fabrications of all Power Control Center.
3. Successfully demonstrated TACS systems at Ft. Bragg, NC; Ft. Stewart, GA; Ft. Irwin, CA; and Hanau, Germany.
4. To support this contract, Global Solar improved output performance of modules to greater than 50W average (2.8KW system)

#### **Challenges**

GSE had challenges in achieving the desired efficiencies on the solar arrays during 2001. GSE therefore also completed a hybrid array to ensure that sufficient solar power was supplied for a demonstration at Ft. Bragg, NC under the care of the 1<sup>st</sup> of the 504<sup>th</sup> PIR, 82<sup>nd</sup> Airborne Div. This hybrid array used silicon-based solar modules, designed to be as lightweight and unbreakable as possible, to enable the demonstrations to proceed in light of the scarcity of the desirable, high-efficiency, GSE flexible solar modules. It was delivered in October 2001 and was rated at 2.6kW, highest at that time. Responding to a specific request, one of the TACS deliverables was developed for use in Europe with 50 Hz power output and backup generator (TACS0007), finally delivered in December 2001 after considerable supplier delays.

All of the TACS power centers were ultimately supplied with upgraded solar arrays with the appropriate power output ratings during 2002 and 2003.

The following subsections contain further descriptions of the accomplishments noted above during Phase 1.

#### **1. Successfully incorporated multiple substantial performance upgrades into the Power Control Centers, the PV Arrays, and the trailer-mounted TACS systems.**

Building on what was learned from the field demonstrations of TACS systems, Global Solar identified various shortcomings of design that impacted operation and logistics of the unit. Table 3 shows the primary improvements incorporated into the prototype TACS products.

2. Completed contractual fabrications of all Power Control Center.

Three TACS units were intended to be fabricated under this contract. Power Centers for TACS0005, TACS0006, and TACS0007 were completed. An array with nearly twice the number of modules as originally planned was delivered for TACS0006 as an initial demo. A high performance, hybrid 2.8KW solar array was delivered to the 1<sup>st</sup> of the 504<sup>th</sup> PIR, 82<sup>nd</sup> Airborne Div in October 2001 and all three TACS systems were upgraded to the 2.8 kW rated subarrays before the end of 2003.

**Table 3: Listing of Upgrades for TACS0005, TACS0006, and/or TACS0007 designed in Phase 1**

#	Upgrade Description	Primary Advantage
1	Incorporated batteries with higher capacity to weight ratio.	Rather than 12 hours of silent running capacity (at 6A load) on a single trailer platform, this upgrade provides more than 24 hours.
2	Incorporated means for transmission of system operating data via cell phone to any secure computer via modem and phone lines. Tests continue to assure high performance of telemetry system.	Rapid identification of system problems. Rapid analysis of performance of properly operating system under various operating conditions.
3	Upgraded the operation manuals as well as the checklist sheets.	Helps assure proper operation and appropriate preventive maintenance of system in the field and when in standby storage.
4	Incorporated utility power input access for charging battery system.	In the field, it will sometimes be necessary or desirable to attach system to a utility service to charge the battery bank.
5	Upgraded cable connectors and cable wrap hardware incorporated.	Eases deployment and avoids potential for shorting when cables or PV are sitting in water or during rainstorms. Avoids haphazard stowage and eases deployment entangling.
6	Redesigned and strengthened rack for PV stowage.	Avoids bending of PV subarrays during transport (with high winds blowing through trailer).
7	Amended trailer layout to place generator on tongue side of Power Center and PV rack on tailgate side.	Weight balance with PV stowed or deployed is improved. Ease of stowing and deploying PV is drastically improved. Exhaust heat and noise from generator are considerably reduced.
8	Incorporated "stippling" of the front surface of the modules into the standard module-assembly process.	Avoids higher than reasonable surface reflections from PV surfaces at low sun angles. This issue appears to be important only between October and February when sun angles are low.

3. Successfully demonstrated TACS systems at Ft. Bragg, NC; Ft. Stewart, GA; Ft. Irwin, CA; and Hanau, Germany.

Demonstrations of various TACS were accomplished as follows:

1. January 2001 – Ft. Bragg, NC – 82<sup>nd</sup> Airborne, 1<sup>st</sup> of the 504<sup>th</sup>
2. March 2001 - Ft. Stewart, GA – 82<sup>nd</sup> Airborne, 1<sup>st</sup> of the 504<sup>th</sup> from Ft Bragg.
3. June 2001 - Ft. Irwin, CA – 82<sup>nd</sup> Airborne, 1<sup>st</sup> of the 504<sup>th</sup> from Ft. Bragg
4. July 2001 – Hanau, U.S. Army base, Germany, 127<sup>th</sup> Military Police Company

No power system failures were reported during these demos, even when the TACS was running above the rated load. The feedback from the soldiers in the field was quite positive from those who were made aware of

the economic and logistical benefits of the system. The specific measurements and summaries made for these demos can be found in Appendix I. Figure 4 from above shows a TACS system deployed at Ft. Bragg, NC. Figure 5 and 6 show deployed TACS arrays from Ft. Stewart, GA, and Hanau, Germany. No photos for the deployed Ft. Irwin, CA TACS are available.



**Figure 5** *Deployed TACS Solar Array at Ft. Stewart, GA*



**Figure 6** *Deployed TACS Solar Array and Power Center at Hanau, Germany*

#### 4. Improved output performance of modules to greater than 50W average (2.8KW system)

Initial demonstrations utilized more than 56 modules (4 subarrays) to meet the photovoltaic array performance expectation of 2.8KW per system. After many delays, and considerably more expense than originally anticipated, Global Solar was able to produce modules that met the original expectation of 50W per module. The arrays ultimately delivered to the field under this contract were therefore comprised of 4 subarrays, 56 modules each, at 50W or greater output at STC (Standard Testing Conditions – 25C, 1000W/m<sup>2</sup>) per module. The array ratings were all rated at or greater than 2800W at STC, the original specification within this contract. Future foldable arrays for TACS systems (and other GSE products) will continue to be reduced in overall size as efficiency of the PV modules continues to improve. Logistics for stowage and deployment will therefore also continue to improve.

#### **2.1.3 Lessons Learned**

GSE received considerable input and suggestions from participants in the demonstrations related to what can be done for next generation TACS units.

Several concepts for future potential design were suggested and pre-evaluated during this contract. During and after Phase 1 completion, the following upgrades were expected to be incorporated into many of the future TACS designs:

- Rugged-ization and Production-ization of the Power Control Center to meet the extremes of this Military application and to minimize overall system costs, respectively.
- Deep discharge, sealed, maintenance free batteries rather than the liquid electrolyte types utilized in TACS0005, TACS0006, and TACS0007. Logistics to be improved although at the expense of a somewhat reduced Capacity to Weight ratio.
- 4 separate battery bank cases (reduced weight) rather than a single one, in order to allow field removal from the trailer by soldiers without requiring additional, sometimes hard to locate, lifting equipment.
- Off-the-shelf enclosures for power center components rather than customized enclosures, to reduce overall costs.
- A low profile layout that fits M101, M105, and other trailers, with the power access available by opening the back tailgate. In its stationary, working condition, there would be room available atop the batteries for storage of other Military articles as necessary.
- Incorporation of a 24V power tap for operating 24V equipment in the field
- Improved methodology for estimating an accurate Level of Capacity of the battery bank.
- Incorporation of auto-start for existing Diesel generators
- Incorporation of Wind power to further extend silent-running capabilities of the Power Center.

#### **2.1.4 Phase 1 Summary**

This contract was enabling in that it provided a pathway to advance the TACS technology, using lightweight, unbreakable, transportable solar modules from GSE. A successful program was completed in spite of the delays due to various problems encountered including availability of sufficient high performance solar modules, availability of army trailers, and availability of appropriate 50Hz back-up generators.

The TACS system worked well in the field, under field conditions, without substantial system failures, often running above their rated load. The demos have provided keen insight into the directions that future advancements need to take. The opportunity to demonstrate these upgraded, yet still early versions, of TACS paves the way for future effort under Phase 2 and beyond.

## **2.2 Phase 2 (2003 and 2004): Hybrid Tactical AC Systems (HTACS)**

### **2.2.1 Objectives**

The overall objectives of the program were to develop a Hybrid TACS (HTACS) to be used to explore and analyze the value of adding a wind power system to the Transportable AC System (TACS). The specific aims during 2002 were:

- Evaluate earlier TACS designs against lessons learned.
- Start incorporating upgraded designs into a Hybrid TACS Power Control Center:
- Improve the efficiency of the Solar Array Structure (3.1kW rather than 2.8kW), and
- Provide an anti-glint surface reducing specular reflection in the field.

### **2.2.2 Primary 2002 and 2003 Results**

- Solar-Wind Hybrid Option contract initiated.
- The following upgrades were evaluated and included into the two HTACS fabricated under this contract:
  - Incorporated Wind Power
  - Ruggedized Selected Components (Inverters and charge controllers)
  - Modularized to Fit trailers M101 and larger
  - Productionized to ultimately Lower Costs
  - Further Minimized the Battery Bank Weight
  - Improved solar array performance to meet 3.1kW goal for the same size array as was used in Phase 1, and
  - Incorporated an anti-glint coating onto the 3.1 kW array at the same time
- Completed delivery of HTACS units to Ft. Lewis and Yakama Training Center in Washington in March-April, 2003
- GSE and SunWize Technologies, Inc (lower-tier subcontractor for redesign, fabrication, testing, and field deployment) also provided initial field training and data-collection capability support for the 2 HTACS as follow-up after delivery to Ft. Lewis and Yakama Washington sites.
- SunWize accomplished a field upgrade for incorporating a more ruggedized inverter, released by manufacturer after initial assembly of HTACS.
- All contractual items were completed.

The motivations for these strategic upgrades are described in further detail in the following subsections. In all cases these upgrades were relatable to improved logistics or improved survivability

#### **1. Improved Logistics**

- Although 2.8 kW of rated PV powers a substantial portion of the load, an untapped additional source of power in many applications is WindPower. The improved capacity factor enabled by the addition of Windpower can contribute to improved logistics by further reducing fuel requirements.
- Ruggedized Inverters and charge controllers clearly extend the useful life and minimize maintenance issues.
- Modularization and weight reduction of battery Banks allows transport by teams of people rather than heavy moving equipment.
- Avoiding liquid electrolyte batteries reduces weight and minimized the logistics of environmental waste handling at end of life.
- The modularization and productionization of the system under this effort supports lower cost goals. For large quantity orders in the future, the upgrades here form a strong baseline for cost reduction.

#### **2. Survivability Improvements**

- Reflection from surfaces of PV modules was noted as a concern. GSE had developed an anti-glint surface that minimizes spectral reflections. Incorporating these anti-glint capabilities can clearly improve survivability of the users in the field.
- Rapid deployment and stowage of a transportable system was also considered a survivability advantage.
- Solar module breakage is clearly avoided by using the flexible solar products in this case, increasing system uptime.

### 2.2.3 Lessons Learned

Although the feedback from the two HTACS systems was less than for the previous TACS tests, a number of thoughts related to future advantages are listed:

- The added advantages of windpower are clearly location-dependant. Windpower will be a good tool to have available for various specific site applications.
- Stowing and deploying the solar arrays and windmill were both straightforward. The deployment of the windmill took less than approximately 20 minutes.
- The modular system incorporated for the batteries and the power center made the HTACS much easier to transfer to and from trailers, an important field-logistics opportunity.

**Figure 7 Deployed TACS Solar Array**



**Figure 8 Deployed TACS Power Center**



## 2.2.4 Phase 2 Summary

Feedback from the field regarding these 2 HTACS units was minimal. The follow-up and analysis of these fielded units was not executed beyond the training of the teams at the Yakama and Ft. Lewis sites.

However, it is clear that these 2 HTACS systems were substantial upgrades from the earlier TACS units provided and evaluated in Phase 1. Clearly they exhibit better overall designs than previous units. These systems are much more modular and durable than their predecessors, and these designs therefore form a solid platform for solid designs for future TACS and HTACS opportunities.

## 2.3 Last Known Status of All Fielded TACS Units Built By GSE

Table 4 below indicates the last known status (late 2003 was last update) of the fielded TACS and HTACS units fabricated by GSE under this contract vehicle and others.

**Table 4: Last-known Status of TACS and HTACS**

<b>TACS Power Center</b>	<b>Contract Vehicle</b>	<b>Location of Power Center</b>	<b>PV Array Status</b>
TACS0002	AFRL Contract	AFRL, Tyndall AFB, FL	2.4KW array for Temper Tent delivered in Q4 of 2002.
TACS0003	DARPA Agreement	Ft. Bragg, 82 <sup>nd</sup> Airborne, 1 <sup>st</sup> of 1 <sup>st</sup>	Hybrid Array, delivered Q4, 2001 (Folding Silicon modules – CIGS hybrid) 2.6KW
TACS0004	DARPA Agreement	Ft. Bragg, 82 <sup>nd</sup> Airborne, 3 <sup>rd</sup> of 1 <sup>st</sup>	Fully Operational – 2.8KW
TACS0005	ARO Contract	Germany- 60 Hz system	Fully Operational – 2.8KW (Which replaced the low efficiency, earlier 10 Subarray PV, ~2.5KW, supplied initially)
TACS0006	ARO Contract	Ft. Bragg, 82 <sup>nd</sup> Airborne, 1 <sup>st</sup> of 1st	Fully Operational – 2.8KW
TACS0007	ARO Contract	Germany – 50 Hz system	Fully Operational – 2.8KW
TACS0008-0009	ARO Contract – Hybrid TACS Option	Ft. Lewis and Yakima Training Center	Fully Operational 2.8 and 3.1kW one with anti-glint surface

### **3.0 FUTURE EFFORTS**

The solar-powered transportable AC system has proven its value in the field demonstrations. Although the earlier versions of the TACS worked well, most of the upgrades incorporated in the second phase of this effort performed very well during system evaluation. These designs therefore form the platform for future designs of transportable power systems.

Advancements to the basic solar technology (not part of this contract) have been substantial during and after this contract period. GSE demonstrated a 3.1 kW rating for a solar array made up of 4-subarrays under this contract. Present day (2005), GSE achieved ratings that would produce over 4 kW on the same dimension of solar array. So, there has been an increase of 29% in solar conversion efficiency in the last 2 years alone on portable solar products by GSE.

The proper sizing of a TACS or and HTACS system is still an optimization that should be evaluated. That is, the logistics advantages and the overall return on investment (compared to running a generator alone) are almost certainly improved for systems sized somewhere between 25 to 67% of the size utilized under this contract.

Future design improvements and large quantity procurements are expected to make this system a viable, economically superior, high-performance, transportable power system.

### **4.0 BIBLIOGRAPHY**

Hugh Jones, “**A**nalysis of **D**eployable **A**pplications of **P**hotovoltaics in **T**heater (ADAPT)”, Center for Army Analysis, Resource Analysis Division, Internal Report.

Hugh Jones, “Renewable Energy Analysis for Strategic Responsiveness (REASR 2)”, Center for Army Analysis, Resource Analysis Division, Tri-Service Power Expo, Norfolk, VA, 7/17/03]

## 5.0 APPENDICES

### 5.1 APPENDIX I: Measured Data And Summary Of Results For 4 Demonstrations Under Phase 1

#### Ft. Bragg Demonstration

**U.S. Army, XVIII Airborne Corps, 82<sup>nd</sup> Airborne Division,  
1<sup>st</sup> Brigade, 1<sup>st</sup> Battalion TACS Demo  
January 19<sup>th</sup> through 24<sup>th</sup>**

	19 <sup>th</sup> (1/2 day operation)	20 <sup>th</sup>	21 <sup>st</sup>	22 <sup>nd</sup>	23 <sup>rd</sup>	24 <sup>th</sup> (1/2 day operation)	Avg.
<b>PV (KW-hrs) @ 120V</b>	Not Deployed	.456	.511	1.34	1.57	2.05	1.19
<b>Load (KW-hrs) @ 120V</b>	24.9	52.0	29.4	12.0	16.9	7.6	23.8
<b>Generator On Time</b>	24.8%	71.2 %	38.0%	17.0%	26.3%	14.3%	32%
<b>Maximum Silent Running Period Per Day (hrs)</b>	4.7	3	16.4 Hrs	@ 4.1 Amps	6.2	6.1	7.3
<b>Avg. Load Current (Amps)</b>	17.4	18.1	10.2	4.1 A	5.9 A	5.2 A	10 ± 6
<b>Peak Load Current (Amps)</b>	33.6	39	27	14.3	13.6	12.57	23.35
<b>% of Load Powered by PV</b>	N/A	.9%	1.7%	11%	9.3%	27%	10 +- 10

#### **Summary and Conclusions for Ft. Bragg Demonstration**

The overall results from the demo showed:

- Average Generator On Time was 19% when loads on TACS were near 6A rating; 32% overall
- Load covered by PV input was between 0.9 and 27% (10% average).
- Silent Running time would have been more than 12 hours, if it had been decided to draw the battery bank down to the minimum rather than to run in auto-start mode.

These demonstration results are in line with the system ratings considering the loads used, and the seasonal and geographical conditions during the demo.

## Ft. Stewart Demonstration

Performance summary of the TACS003 during “Marne Force”  
U.S. Army Airborne Corp, 82<sup>nd</sup> Airborne Div., 1<sup>st</sup> Brigade, 1<sup>st</sup> Battalion  
March 22, 2001 through March 27, 2001

	3/22	3/23	3/24	3/25	3/26	AVG
PV (KW-hrs) @ 120V	1.16	3.06	2.04	0.012	2.69	1.79
Load (KW-hrs) @ 120V	19.36	18.38	18.05	18.80	19.48	18.81
Generator On Time	36.39%	22.64%	30.42%	27.78%	30.83%	29.61%
Avg. Load Current (Amp.)	6.45	6.13	6.02	6.27	6.49	6.27
Peak Load Current (Amp.)	20.70	20.38	18.67	21.11	27.46	21.66
% of Load Energy by PV	12.82%	16.66%	11.28%	0.06%	13.81%	10.92%

### Summary and Conclusions for Ft. Stewart Demonstration

During a 140-hour period beginning 3/21/01 at 18:44 hours (6:44 PM EST) the TOC average AC load was 6.4A with a peak load of 27.5A. Daily performance is shown in Table 1: Daily TACS Performance. The average performance during this period is summarized as follows

- 26.6 % Generator On-Time. [See Note 1]
- 12.5% of Load Powered by PV [See Note 2]  
(PV energy/AC load energy = 13.4/107.0 KW-Hr.)
- 12.56 hours of Silent Running time with no PV or generator operation.

These demonstration results are in line with the system ratings considering the loads used, and the seasonal and geographical conditions during the demo.

## Ft. Irwin Demonstration

Performance summary during NTC at Fort Irwin, CA  
U.S. Army Airborne Corp, 82<sup>nd</sup> Airborne Div., 1<sup>st</sup> Brigade, 1<sup>st</sup> Battalion  
June 14, 2001 through June 17, 2001

	6/14	6/15	6/16	6/17	AVG
PV (KW-hrs) @ 120V (Note 2)	0	1.13	0.169	0	0.325
Load (KW-hrs) @ 120V	7.955	8.05	17.36	4.361	9.43
Generator On Time (Note 3)	15.4%	17.1%	14.5%	14.0%	15.25%
Avg. Load Current (Amp.)	2.76	2.8	0.6	1.51	1.92
Peak Load Current (Amp.)	12.61	11.69	2.38	6.04	8.18
% of Load Energy by PV (Note 3)	0%	17.41%	12.06%	0%	7.37%

### Summary and Conclusions for Ft. Irwin Demonstration

- 13.1% Generator On-Time shows the advantage of the TACS during light AC loads.
- The TOC was powered in Silent-Run mode for 86.9% of the time.
- The longest Silent Running period at typical loads exceeded 16.0 hours

These demonstration results are in line with the system ratings considering the loads used, and the seasonal and geographical conditions during the demo.

## Hanau, GERMANY Demonstration

**Performance Summary (TACS 0005) at Hanau, GERMANY  
127th Military Police Company at Hanau US Army base, Germany,  
July 25, 2001 and Ending July 30, 2001**

	7/25*	7/26	7/27	7/28	7/29	7/30*		
<b>PV (KW-hrs) @ 120V (Note 1)</b>	<b>3.36</b>	<b>1.88</b>	<b>1.66</b>	<b>1.01</b>	<b>1.54</b>	<b>0.74</b>	<b>10.19</b>	<b>Total Period</b>
<b>Load (KW-hrs) @ 120V</b>	<b>7.12</b>	<b>1.1</b>	<b>3.49</b>	<b>0.0</b>	<b>0.0</b>	<b>4.61</b>	<b>16.32</b>	<b>Total Period</b>
<b>Generator On Time</b>	<b>0.0%</b>	<b>0.0%</b>	<b>3.1%</b>	<b>0.0%</b>	<b>0.0%</b>	<b>19.2% (4.1%)</b>	<b>1.4%</b>	<b>Total Period</b>
<b>Avg. Load Current (Amp.)</b>	<b>2.93</b>	<b>0.38</b>	<b>1.21</b>	<b>0.0</b>	<b>0.0</b>	<b>7.48 (1.6)</b>	<b>1.02</b>	<b>Avg.</b>
<b>Peak Load Current (Amp.)</b>	<b>13.2</b>	<b>13.15</b>	<b>13.13</b>	<b>0.0</b>	<b>0.0</b>	<b>13.1</b>	<b>13.2</b>	<b>Max.</b>
<b>% of Load Energy by PV</b>	<b>47.2%</b>	<b>172%</b>	<b>47.6%</b>	<b>N/A</b>	<b>N/A</b>	<b>16.0%</b>	<b>51.3%</b>	<b>Total Period</b>

### **Summary and Conclusions for Hanau, Germany Demonstration**

During a six-day period beginning 7/25 at 11:46 hours the average AC load was 1.02A with a peak load of 13.2A. The average performance during this period is summarized as follows

- 1.4 % Generator On-Time.
- An Average of 51.3% of Load Powered by PV.  
(% of Load Powered by PV = PV Energy at 120VAC / AC Load Energy)
- Up to 50 hours of Silent Running from PV and battery storage only.
- Generator On-Time shows the advantage of the TACS during light AC loads.
- The AC loads was powered in Silent-Run mode for 98.4% of the time.

These demonstration results are consistent with the system ratings considering the loads used, and the seasonal and geographical conditions during the demo.

## **5.2 APPENDIX II: Additional Impacts Resulting From This Contract Effort**

### **6) Listing Of Publications And Technical Reports Supported Under This Contract**

#### **a) Papers published in peer-reviewed journals**

No papers related to this subject were published in peer-reviewed journals

#### **b) Papers published in non-peer-reviewed journals or in conference proceedings**

Albright, Scot P., "Lightweight Portable Power by Global Solar"; [3rd Tri-Service Power Expo & Conference](#), July 15-17, 2003, Norfolk, VA (DTIC – external site)

#### **c) Papers presented in meetings, but not published in conference proceedings**

#### **d) Manuscripts submitted, but not published**

No papers related to this subject were submitted other than those listed elsewhere

#### **e) Technical reports submitted to ARO**

Monthly status reports were submitted to ARO as well as a 2001 Interim Progress report. No other technical reports were submitted to ARO

### **7) Listing of "Scientific personnel" supported by this project and honors/awards/degrees received**

Significant portions of the following were supported under this effort.

- Working Program and Technical Manager – Scot Albright, MAS
- Engineering Vice President at Subcontractor (SunWize Technology) – David Panico, BS
- Working Program Technical Manager – Jim Chaney
- Electrical Design Engineer – Steven Groff
- Mechanical Design Engineer – Eric Kanto, Edward Goodwin
- Electro-Mechanical Technician – Daniel Hawkes
- Draftsman – Val Shishkin

No honors, awards, or degrees were received on behalf of efforts under this contract during the period of performance

### **8) Report of inventions**

No patent-able inventions were conceived within the scope of this effort during this contract period by either Global Solar Energy, Inc. or its subcontractor SunWize Technology.