CONF-9609210--1
SAND96-1867C

HYBRID POWER TECHNOLOGY FOR REMOTE MILITARY FACILITIES*

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ABSTRACT

The Department of Defense (DoD) operates hundreds of test, evaluation, and training facilities across the US and abroad. Due to the nature of their missions, these facilities are often remote and isolated from the utility grid. The preferred choice for power at these facilities has historically been manned diesel generators. The DoD Photovoltaic Review Committee, which was chartered in 1985 to support the implementation of photovoltaics within DoD, estimates that on the order of 350 million gallons of diesel fuel is burned each year to generate the 2000 GWh of electricity required to operate these remote military facilities (1). Other federal agencies, including the National Park Service and U.S.D.A. Forest Service use diesel generators for remote power needs as well (2,3). The generation of power from diesel generators is both expensive and detrimental to the environment. The augmentation of diesel generators with power processing and battery energy storage enhances the efficiency and utilization of the generator resulting in lower fuel consumption and lower generator run-time (4). The addition of renewables such as photovoltaics further reduces fuel use and run-time in proportion to the amount of renewables added (4). This hybrid technology can both reduce the cost of power and reduce environmental degradation at remote DoD facilities. This paper describes the expected performance and economics of photovoltaic/diesel hybrid systems. Capabilities and status of systems now being installed at DoD facilities are presented along with financing mechanisms available within DoD.

BACKGROUND

DoD relies on diesel generators to provide power at its remote test, evaluation and training facilities. Diesel generation is costly not only in the conventional terms of supplies and labor, but also in terms of damage to the environment. The cost for fuel, maintenance, and operators for reliable power from diesel generators typically results in electricity costs greater than $0.50/kWh (see section on Economics of Hybrid Systems). The costs of environmental degradation from air emissions and fuel spills are hard to quantify and are not usually included in economic analyses. However, these costs are real and can be severe. For example, several regions of the country require permitting of diesel generators and impose limits on generator use to control environmental degradation due to emissions (5). A single diesel spill of 200 gallons or accumulated leaks can costs hundreds of thousands of dollars in restoration. An analysis done for the National Park Service (using National Park Service values for air emissions and spill restoration) derived a cost of $3 per gallon of fuel consumed, including $2 for emissions and $1 for spills, for environmental degradation (6). An environmental cost of $3 per gallon of fuel can easily double the cost of electricity. Hybrid technology, which involves augmenting generators with battery energy storage, power processing, and renewables such as photovoltaics (PV), can reduce the conventional cost of electricity for remote facilities while reducing emissions and the risk of diesel spills.

DoD has long recognized the potential benefits of solar electricity generated by photovoltaics (PV). The Photovoltaic Review Committee (PVRC) was chartered in 1985 to foster the use of PV technology to realize these benefits. The PVRC, with technical support from the Department of

* This work was sponsored by the Strategic Environmental and Development Program project EN-046 and by the U. S. Department of Energy under contract DE-AC04-94AL85000 in partnership with the Department of Defense Photovoltaic Review Committee.

DISCLAIMER

Energy through the Design Assistance Center at Sandia National Laboratories, currently has thirteen photovoltaic hybrid systems under implementation. Table 1 lists some of the features of these systems along with their status. Two are operational, two are under construction, five are in the final design stages, two are in the procurement stage, and two are in development phase. Nine of the thirteen systems were required to be the least-cost power source to receive funding. These nine systems have an installed cost of $16M and are expected to save DoD about $50M over their 20-year life (based on economic analysis portion of the DoD 1391 project data packages submitted for these projects). This represents a net return of $34M from DoD's $16M investment.

The paper begins with a discussion of how the hybrid technology is expected to enhance the performance and economics of diesel generation. This is done by building an example hybrid system from a diesel generator power system. This is followed with a detailed description of three of the DoD hybrid systems: (1) Superior Valley, (2) Grasmere Point, and (3) Yuma. These three systems encompass the equipment and components available for hybrid systems as well as the functional capabilities of the technology. The paper ends with a discussion of funding and financing mechanisms that can be used to procure hybrid systems.

Table 1. Features and Status of DoD Hybrid Systems.

Project	PV Array (kWp)	Battery (KWh)	PPU[a] (kW)	Status
Superior Valley, China Lake, CA, Navy	344	3500	300	operational
Grasmere Point, Mt Home, ID, Air Force	80	700	90	operational
REWS, San Clemente Island, CA, Navy	94	2500	175	construction
Range 500, 29 Palms, CA, Marines	[70][b]	[1000][b]	[150][b]	procurement
Junction Ranch, China Lake, CA, Navy	126	2000	250	designed
Shipsite, China Lake, CA, Navy	35	750	250	designed
Nato Site, China Lake, CA, Navy	162	2000	250	designed
Kim Site, China Lake, CA, Navy	239	2000	250	designed
PTA ranges, Hawaii, Army	[1-30][b]	[50-500][b]	[1-30][b]	development
Yuma, Yuma Proving Ground, AZ, Army	450	5600	900	construction
WAM, Yuma Proving Ground, AZ, Army	225	3500	[150][b]	development
Mobile Power, Camp Pendleton, CA, Marines	3.8	50	6	designed
Comm site, Santa Cruz Island, CA, Navy	[120][b]	[2500][b]	[150][b]	procurement

[a] - Capacity of Power Processing Unit

[b] - Final sizes not yet determined

PERFORMANCE OF HYBRID SYSTEMS[A]

The synergism of combining diesel generators and PV with a battery and power processing results in energy costs less than possible from generators or PV alone. Figure 1 shows a block diagram for a typical hybrid system. When the generator is off, the power processing unit acts as an inverter and converts dc power from the PV and battery to ac power for the site load. When the generator is on, it serves the load and charges the battery. In this mode, the power processing unit acts as a rectifier and converts ac power from the generator to dc power for the battery. The battery charge rate is adjusted to maintain the generator at full output. The objective of this type of system is to minimize diesel run-time and fuel consumption. To achieve this, the generator only runs as needed to recharge the battery. It is started when the battery reaches a pre-set discharge level and is run at full output until the battery is recharged and then shut down.

[A] Performance derived from computer simulations using the HYSIM model developed and verified by the Photovoltaic System Applications Department at Sandia National Laboratories.

The site load profile in Figure 2 is used to illustrate this concept. The peak power demand is 150 kW and would require a 150 kW generator. The total daily load is 1,043 kWh, which corresponds to an average load of only 43 kW. This generator would run 24 hours per day and the facility would only use 1,043 kWh of the generator's 3,600 kWh capacity (24 hours x 150 kW capacity). Figure 3 shows typical fuel-to-electricity efficiencies of a diesel generator. Based on these efficiencies, the generator would consume 137 gallons of fuel per day at an overall efficiency of 19%. Note that the peak efficiency of a diesel generator is approximately 30%.

With a battery and power processing unit, the generator would start every 2.5 days (145 generator starts/battery cycles per year), run about 22 hours per start, and consume 111 gallons of fuel per day. This performance is based on a 3500-kWh battery, a 150-kW power processing unit, and the battery and power processing efficiencies given in Figure 3. The generator was started to recharge the battery when the battery reached a 50% discharge level. At this discharge level, the battery can be expected to provide 10 years of service at 145 cycles per year.

Figure 4 shows the effect of adding PV. The reduction in fuel consumption and run time is nearly linear with the amount of PV until the point that the system cannot use all the PV energy. In this case, this point occurs with approximately 220 kW of PV and corresponds to a 95% reduction in fuel consumption and run time. The benefit of adding more PV decreases rapidly beyond this point. This effect shows how the generator enhances the performance of a stand-alone PV system. With only 3500 kWh of battery, an additional 470 kW of PV would be required to displace the last 5% contribution from the diesel generator.

ECONOMICS OF HYBRID SYSTEMS

In most cases, the cost of the mission itself far exceeds the cost of power at these remote military facilities. A single power failure can cost hundreds of thousands of dollars in slipped schedules and damage to sensitive test equipment. In addition to using redundant generators, DoD normally has at least one trained operator attend the generators continuously during operations to achieve an acceptable level of reliability. The high cost of $0.50/kWh for remote generators is driven primarily by the cost for the trained operator. The example developed to illustrate the performance of a hybrid system is also used to illustrate the economics of a hybrid system.

The generator-only system uses 50,000 gallons of fuel and runs 8760 hours to generate 381,000 kWh of electricity per year. Delivered fuel cost averages about $1 per gallon and costs for preventative maintenance are on the order of $3 per run hour (7). The fuel and maintenance total $76,000 per year, which represents an energy cost of only $0.20/kWh. The load profile in Figure 2 is based on operations 10 hours per day, 365 days per year. At a loaded cost of $35 per hour, the operator would cost $128,000 per year. The cost for the operator corresponds to an energy cost of $0.34/kWh, which brings the total operation and maintenance cost for the generator-only option to $0.54/kWh. Note that a cost of environmental degradation of $3 per gallon of fuel nearly doubles the cost of the generator-only option from $0.54/kWh to $0.92/kWh.

The cost of $128,000 per year for the operator is not unreasonable when compared with a single power failure that can scrap a mission costing $250,000 per exercise or cause $150,000 in damage to sensitive electronic equipment. The use of an operator has become standard DoD practice simply because the operator is less expensive than the power failure. The inherent reliability of the combination of redundant mechanical (generator) and electronic (power processing unit) power sources should be able to eliminate the need for operators, based on the track record of mature switching technologies used in motor drives and uninterruptable power supplies. In general, the power processing technology used previously in hybrid systems has not yet demonstrated this level of reliability. However, the experience thus far (as of the end of June 1996) with the Grasmere Point and Superior Valley systems has been encouraging. The Grasmere Point system experienced some initial software related control problems but has now been operating for four months at full capacity with 100% availability. The Superior Valley system has run at a low capacity with 100% availability

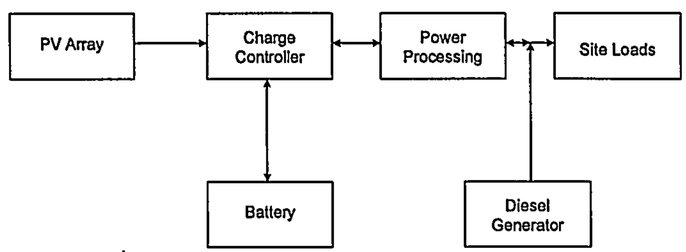


Figure 1. Block Diagram of a Typical Hybrid System.

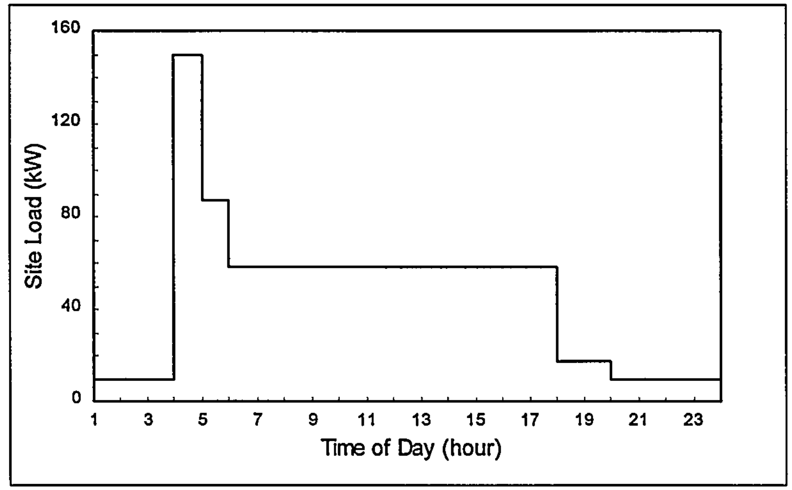


Figure 2. Load Profile of the Example Hybrid System.

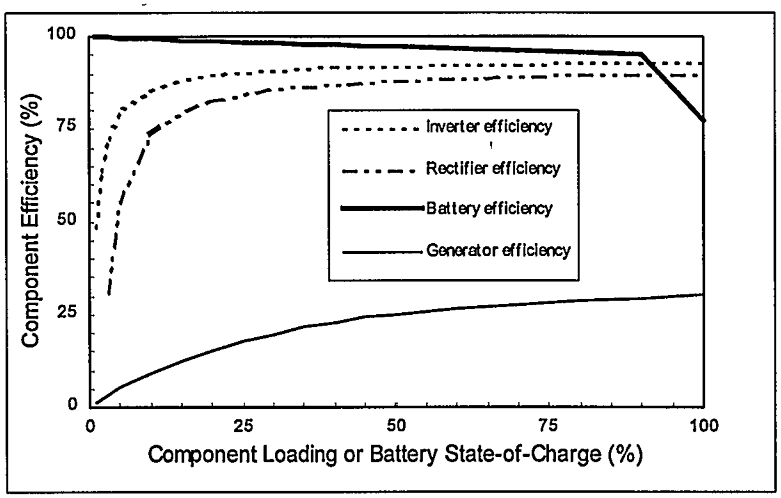


Figure 3. Component Efficiencies used in the Example Hybrid System.

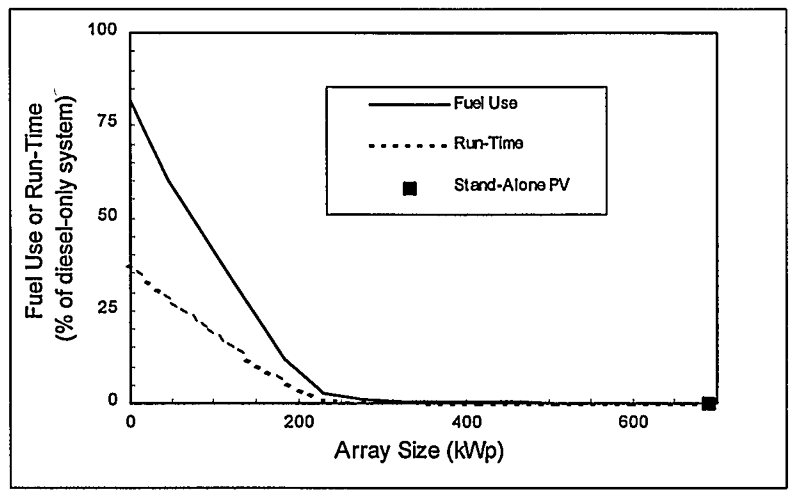


Figure 4. Predicted Performance of the Example Hybrid System.

for five months. (The low capacity was the result of limited mission activity and not the result of any problems with the hybrid system.) The expectation is that these initial DoD systems will advance the maturity of this technology through field operating experience. These systems will be closely monitored, and any required improvements will be incorporated into the future units to achieve the high reliability that the technology is capable of providing.

A turnkey battery and power processing system for this example would cost on the order of $500,000. It would save about $26,000 per year in fuel and preventative maintenance and $128,000 per year in operator cost. Maintenance for the battery and power processing system is estimated at approximately $5,000 per year. The simple payback for the battery and power processing system would be about 3 years. A turnkey 184-kW PV array would cost on the order of $1.1M and would save $35,000 per year in fuel (35,000 gallons per year) and $8,000 per year in preventative maintenance (2,800 run hours per year). Maintenance on this array would be about $2,500 per year. The simple payback for adding PV to the battery and power processing system is about 27 years. The expected service life of the PV array is 25-30 years.

Clearly the battery and power processing option offers the best economic benefit based on fuel, maintenance, and labor. However, the battery and power processing option does not have nearly the impact on emissions or fuel spills as adding PV. If the environmental cost of $3 per gallon of fuel is included in the analysis, the payback for the battery and power processing option is only reduced from 3.2 years to 2.5 years, whereas the payback for adding PV is reduced from 30 years to less than 9 years. Note that PV will be economical whenever the fuel cost is high. The fuel cost of $1 per gallon used for this example is typical, but it represents a minimum cost as well. Diesel costs do not go much below $1 per gallon. On the other hand, fuel costs of $2-$3 per gallon (because of high delivery costs) are not uncommon at remote sites. The point is that this example represents a worst-case economic scenario for PV. Even so, PV offers a substantial economic benefit compared to the real cost of diesel generation, which includes the cost of environmental degradation.

DoD HYBRID SYSTEMS

This section describes three of the DoD systems: (1) Superior Valley, (2) Grasmere Point, and (3) Yuma. These three systems encompass the equipment and components available for hybrid systems as well as the functional capabilities of the technology. The Grasmere Point system has been in operation at full capacity since March, 1996. The Superior Valley system has been in operation at a reduced capacity since February, 1996. The capabilities of the Superior Valley system were verified during thorough testing of the power processing and controls at Sandia's power processing test facility (8). The Yuma system is actually a grid-support hybrid where the conventional power source is the utility as opposed to a diesel generator. This system, which is now under construction, is the most advanced of the DoD hybrids. It is discussed in this paper because these advances are as applicable to generator hybrids as they are to grid-support hybrids.

Superior Valley System. Photocomm Inc. recently completed the installation of a 300-kW photovoltaic/diesel hybrid system for the Navy's Superior Valley Tactical Air Combat Range at China Lake, California. The system includes 344 kWp of ASE-300-DG/50 PV modules, 3500 kWh of C&D motive power batteries, a 300-kVA Abacus bimode power processing unit, a National Instruments Labview system controller run from an IBM pc, and a 300-kW Detroit diesel generator. This system currently represents the largest stand-alone photovoltaic system in the world.

When fully operational, this system will reduce diesel run-time and fuel consumption by 90%. The system was funded by DoD's Strategic Environmental Research and Development Program (SERDP) and was selected to advance power processing technology to serve specific remote power needs within DoD. The Abacus unit "gangs" two 50-kW units per phase to achieve the required 300 kVA three phase capacity and uses the same power elements to both generate ac power to serve the site loads (inverter mode) and to generate dc power from the generator to charge the batteries (rectifier mode). This advance enables DoD to serve facilities of any power demand by ganging standard building block power processing units.

Figure 5 shows a block diagram for this system. The load is served by either the bimode units (in the inverter mode) or the generator. In other words, the bimode and generator cannot serve the load in parallel. The bimode serves the load as long as the battery state-of-charge (SOC) is above 60%. The system controller monitors battery SOC (based on accumulated current in and out of the battery) and starts the diesel when the SOC drops to 60%. After the generator has stabilized, the bimode monitors the generator voltages and phase locks itself to the generator when the two waveforms match. Solid state contactors then connect the generator to the ac bus and the bimode stops generating ac current. This effects an instantaneous transfer of the site load from the bimode to the generator. After a short delay, the bimode begins charging the battery. The battery charge load on each phase is adjusted to maintain the generator at full power regardless of the instantaneous site load.

The instantaneous load transfer from the bimode to the generator will cause voltage and frequency transients if the magnitude of the site load is close to the generator capacity at the time of the transfer. Testing on the Detroit diesel showed that it cannot maintain frequency and voltage during a full 300-kW block load. A similar test on a 300-kW Caterpillar diesel at Sandia actually caused the engine to stall. At Superior Valley, this problem is avoided by manually locking out load transfers when the magnitude of the site load is high. In addition, the battery charge is implemented one phase at a time to gradually increase the load on the generator from the site load level to the full generator capacity.

This approach may not be practical for all situations. For this reason, all DoD hybrids procured after Superior Valley were required to include a "soft" load transfer where the power processing unit and generator momentarily parallel while the load is gradually transferred from the power processing unit to the generator. The battery charge load is required to gradually ramp up as well. This function has been demonstrated in both the AES unit at Grasmere Point (see below) and in a Kenetech unit during testing at Sandia. Abacus is also developing this capability under a Small Business Innovative Research contract with the Department of Energy.

The generator is run until the battery reaches an 85% SOC. The generator is also started each Sunday night and is run until the battery is overcharged by 20% to equalize the battery. The Superior Valley bimode cannot taper the battery charge current. This type of equalization charge would not be suitable for valve-regulated-type batteries with a limited volume of electrolyte.

The PV modules are configured into 12 source circuits and are connected to the dc bus through 12 Abacus maximum power trackers (MPTs). These devices maintain the PV source circuits at their maximum power voltage point independent of the battery voltage. The MPTs also function as the battery charge controller for the PV array power. When the battery reaches its float voltage, the MPTs limit the array current to hold the battery at its float voltage level.

The primary functions of the system controller are (1) to monitor and display the status of the PV array, battery, bimode, and generator subsystems, and (2) to determine when to start and stop the diesel generator. All critical functions are embedded in the various subsystems. For example, the system controller monitors the battery SOC and decides when the generator should be started, but the actual generator start-up is handled by its auto-start unit, and the load transfer and bimode switch from inverter to rectifier mode is handled by the bimode. This distribution of control functions allows the system to be run manually as well as automatically.

Grasmere Point System. The Grasmere Point system, installed by Idaho Power during the summer of 1995 for Mt. Home Air Force Base, became fully operational in February 1996. This system, which was funded through the Energy Conservation Investment Program (ECIP), includes 75 kWp of Solarex MSX-120 modules, 700 kWh of Hoppecke flooded lead-acid batteries, and a 90-kVA Advanced Energy Systems (AES) static power pack power processing unit. The system interfaces with two 160-kW Caterpillar Diesel generators and controls that were part of the existing generator power plant. The array is wired directly to the dc bus through an Ananda Power Technology array control unit and does not rely on a maximum power tracking device.

Figure 6 shows a block diagram of this system. The AES static power pack uses the same power elements to both invert and rectify and has several advanced features including the ability to operate in parallel with the generator to serve the load. The Grasmere system is designed to use this feature. The normal demand at Grasmere peaks between 100 and 120 kW, requiring the generator to turn on during peak demand periods. The static power pack controls all generator operations. The controls will start the generator if either the load is increasing at a rate that will likely exceed the power capacity of the static power pack or if the battery SOC drops below 60%. The battery SOC is estimated from the battery voltage. The static power pack controller also displays the system status, archives system performance data, and provides manual control of the system.

After the generator has stabilized, it parallels with the static power pack to support the load. Because the 160-kW generator will always exceed the demand, the static power pack will always switch to battery charging mode after the generator is connected to the ac bus. The load is gradually transferred to the generator to avoid voltage and frequency transients. The static power pack provides a taper current battery charge. The generator will always run until the battery has reached its float voltage and the charge current has tapered off to a preset level. The generator will then be turned off provided that the demand does not exceed the capacity of the static power pack. The controls also provide for a periodic equalization charge at a float voltage that is higher than the normal charge cycle float voltage. The user can select both the frequency and duration of the equalization charge.

The battery charge from the PV array is regulated by the Ananda control unit. The array is configured in 6 source circuits with a mercury relay between each circuit and the dc bus. When the battery reaches its float voltage, the Ananda control unit removes source circuits from the dc bus (by opening the mercury relays) as necessary to keep the battery voltage at its float level.

Yuma System. Utility Power Group recently started construction of a 900-kVA utility-tied PV power station for the Yuma Proving Ground. The system, which was funded in phases through ECIP and SERDP, includes 450 kW of Siemens M-55 modules, 5600 kWh of C&D motive power batteries, a 900-kVA Kenetech power processing system, and an Orion system controller. This system is designed to supply power in parallel with the utility to help manage the utility peak power demand, and to service a water treatment plant independent of the utility during utility outages.

Figure 7 shows a block diagram of the Yuma system. The 900-kVA power processing system consists of two identical 450-kVA subsystems. Each 450-kVA subsystem consists of two 225-kVA inverter/rectifiers; a master and a slave. Each 225-kVA inverter/rectifier includes a 225-kVA PV maximum power tracker (MPT) and a 225-kVA bi-directional dc/dc converter for the battery. The MPTs and the battery dc/dc converters allow the inverter/rectifiers to operate at a higher voltage than the PV array and battery. In this case, the inverter/rectifiers operate at 750 Vdc while the PV array operates at a nominal 375 Vdc and the battery operates at a nominal 432 Vdc. The higher inverter/rectifier voltage increases both the efficiency and capacity of the inverter/rectifiers. The PV array and battery are divided into two halves. One half of the array and battery feed the master MPTs and battery dc/dc converters, and the other half feeds the slave MPTs and battery dc/dc converters. The operational mode determines which MPTs, battery dc/dc converters, and inverter/rectifiers operate at any one point in time.

The Yuma system has three basic operating modes: (1) daytime utility-tied, (2) nighttime utility-tied, and (3) stand-alone. Whenever utility power is present, the system is either pumping power from the array and battery into the grid (daytime utility-tied mode), or drawing power from the grid to charge the battery (nighttime utility-tied mode). The amount of power pumped into the grid is governed by either the available power from the PV array or by a power level defined by the user, whichever is greater. The user defines power levels via a programmable power profile. This concept is illustrated in Figure 8.

The white bars in Figure 8 show an example of an array power profile for a summer day in Yuma. Note that this profile is the ac power that can be derived from the available dc power from the array. The bold line in Figure 8 shows an example of a user power profile. For this example, the user power profile is zero for hours 14 through 24 and hours 1 through 5, 450 kW for hours 10 and 11, and 750 kW for hours 12 and 13. This profile is used to tailor the output of the system to the site's demand characteristics. As stated above, the power delivered to the grid is the greater of the available PV power and the power profile defined by the user. For our example case, the power delivered to the grid is defined by the available PV power (white bars) before hour 10 and after hour 13. The power level and power source also determine the operating mode of the power processing system. Figure 9a shows the operational mode for these periods where only array power is delivered to the grid (the inactive components are removed from the block diagram to show the operational mode of the power processing system). Note that all battery dc/dc converters are inactive and only one 450-kVA subsystem is active (could be either master/slave pair 1 or 2). The 450-kVA subsystems are dispatched according to the delivered power level. Each subsystem can process the entire array output. Both subsystems are activated only when the user power level exceeds 450 kW. This is done to maintain a reasonable loading, and a reasonable efficiency, of the power processing system (see Figure 3 for typical inverter and rectifier efficiency curves).

During hours 10 and 11, the user power profile calls for 450 kW. Figure 9b shows the operational mode for this period. Still only one 450-kVA subsystem is active but the battery dc/dc converters (of the active 450-kVA subsystem) are now activated to supply enough power to make up the difference between the available PV power and 450 kW. The gray bars in Figure 8 illustrate the power drawn from the battery. Note that all array power is delivered to the grid and only the shortfall is drawn from the battery. This direct use of the array power realizes the maximum possible benefit from the array.

The user power profile calls for 750 kW during hours 12 and 13. Figure 9c shows the operational mode for this period. Note that both 450-kVA subsystems are now active. One subsystem processes the array power (the battery dc/dc converters are disabled), and the other subsystem processes the battery power. In this mode, one 450-kVA subsystem can deliver up to approximately 375 kVA from the array and the other 450 KVA subsystem can deliver up to 450 kVA from the battery for a total of 825 kVA delivered to the grid.

The battery is then recharged from the utility at night. Figure 9d shows the operational mode for this period. Note that both 450-kVA subsystems and all battery dc/dc converters can be activated to charge the battery. The system is designed to provide a full battery recharge each night. The power processing system is designed to provide a taper current charge once the battery reaches its float voltage level.

The power processing system will automatically switch from the utility-tied mode to the stand-alone mode in the event of a utility outage, and it will automatically switch back to the utility-tied mode when utility service is reestablished. In the event of a utility outage, the power processing system shuts down while the water treatment plant is electrically isolated from the utility grid. The power processing system restarts in a stand-alone mode with the component configuration shown in Figure 9b. Only one of the 450-kVA subsystems can operate in the stand-alone mode at a time. If

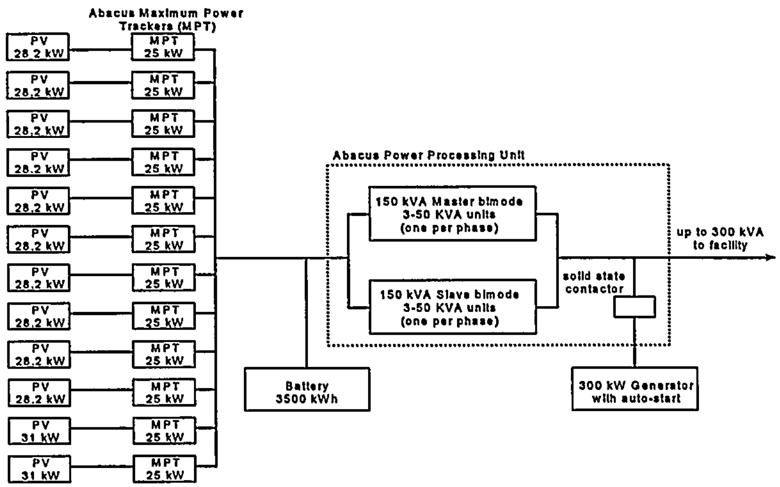


Figure 5. Block Diagram of the Superior Valley Hybrid System.

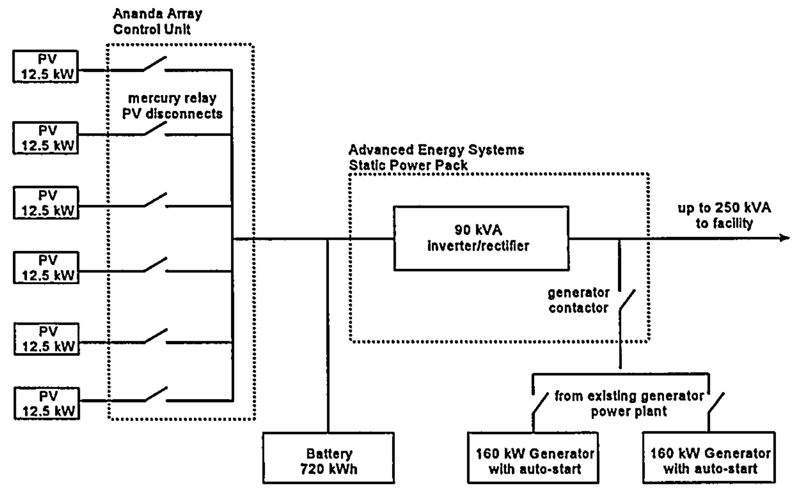


Figure 6. Block Diagram of the Grasmere Point Hybrid System.

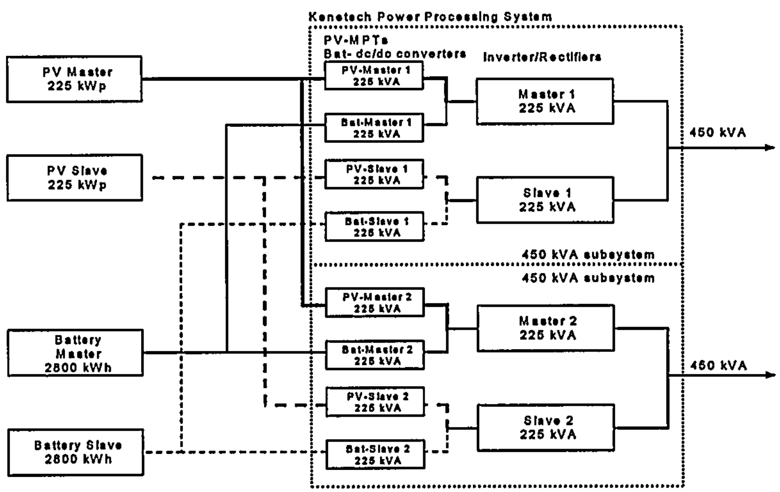


Figure 7. Block Diagram of the Yuma Hybrid System.

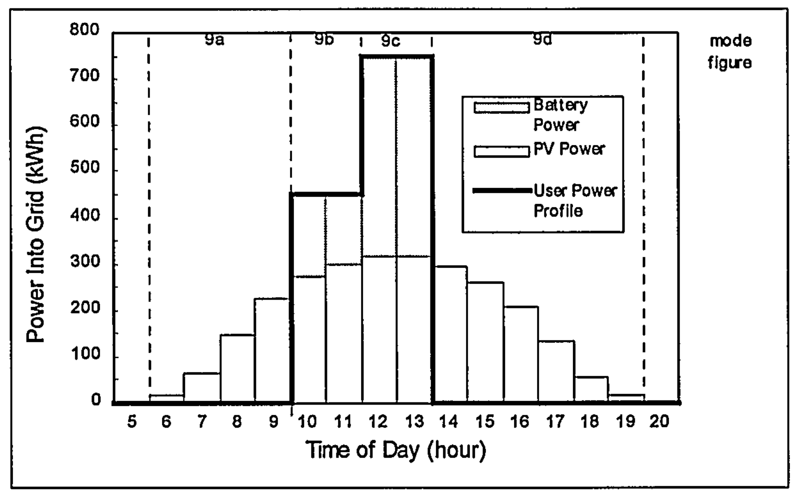
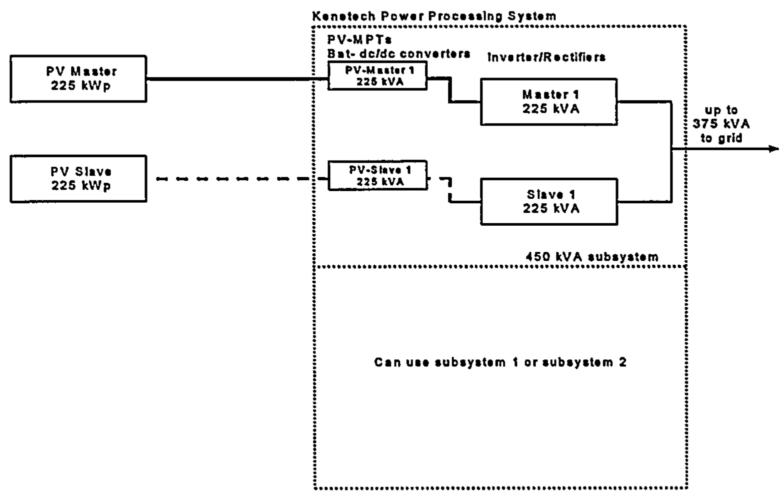
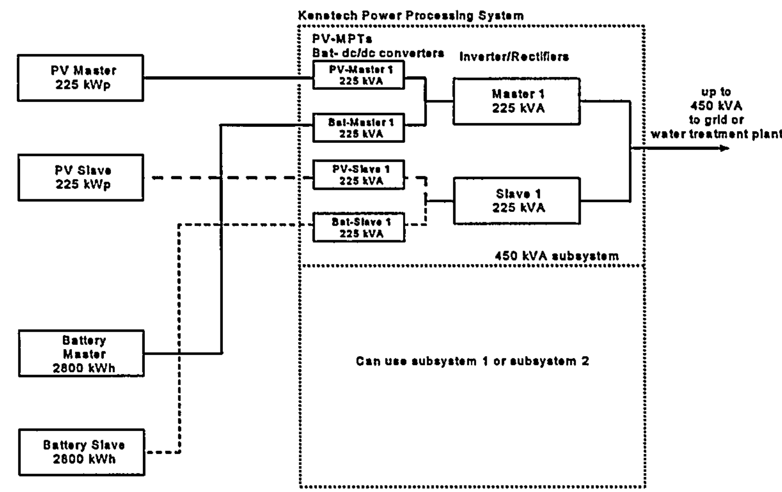


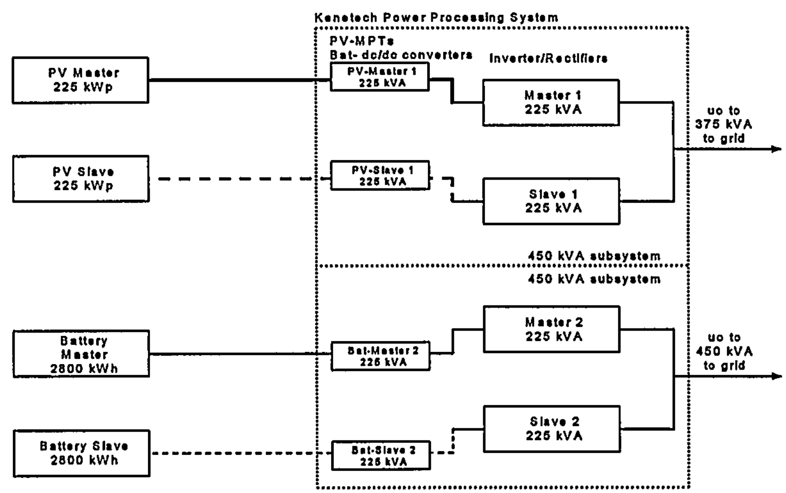
Figure 8. Power Delivered to Grid for Various Operating Modes of the Yuma Hybrid System.



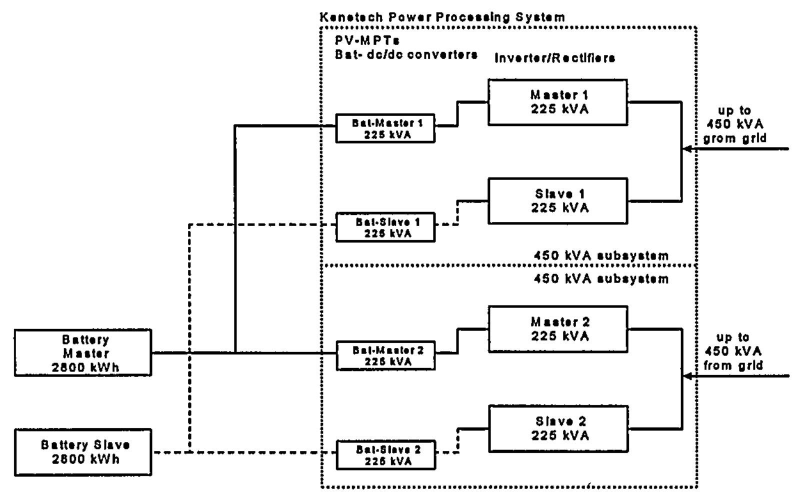
(a) daytime utility-tied mode with PV power greater than user profile.



(b) daytime utility-tied mode, with user profile (less than 450 kVA) greater than PV power, and stand-alone mode.



(c) daytime utility-tied mode with user profile (greater than 450 kVA) greater than PV power.



(d) nighttime utility-tied mode for battery charging.

Figure 9. Operating Modes for the Yuma Hybrid System.

the available PV power exceeds the power demand of the water treatment, the excess PV power is used to charge the battery through the battery dc/dc converters.

The Orion control system is based on a system of industrial-quality microprocessors. Distributed processors monitor and interface with the subsystems, while a supervisory processor collects and analyzes the system status data and then determines the appropriate operating mode for each subsystem. The implementation of the actual subsystem operation of the PV power station is internal to the Kenetech power processing system. (The isolation of the water treatment plant is implemented by a remote pole-mounted isolation switch.) For example, during battery charging the Orion controller will collect the battery temperature, current, and voltage, determine the appropriate charge current at that point in time, and then instruct the Kenetech power processing system to charge the battery at that current. The Orion control system also displays the system status and archives performance data. Manual control is available from a keypad on either the Orion controller or the Kenetech system. A local computer interfaces with the Orion controller to modify the user power profile and system operation set points, access system status information, and download archived performance data. Performance data can be downloaded from a remote computer as well.

FINANCING MECHANISMS

Eight of the thirteen existing projects were funded by DoD's Energy Conservation Investment Program (ECIP), four were funded by DoD's Strategic Environmental Research and Development Program (SERDP), and one was funded in two phases through ECIP and SERDP. ECIP funds are subject to Military Construction Regulations and can only be used to procure complete turn-key facilities. All ECIP projects must be justified as the least-cost solution to the problem. However, ECIP funds are long-term monies and can be obligated and expended 7 to 9 years after appropriation. SERDP funds are research and development monies with little restriction on their use. SERDP funds must be obligated and expended in the same year that they are appropriated, which can create problems with a competitive procurement of a large system. Unfortunately, SERDP is not funding energy related projects at this time.

Another possible funding source is DoD's Facility Energy Management Program (FEMP). FEMP funds are operation and maintenance monies and have little restriction on their use but, like SERDP funds, must be obligated and expended in the same year that they are appropriated. In addition, FEMP projects, like ECIP projects, must be justified as the least-cost solution to the problem. Facilities can use their installation's operation and maintenance accounts or project accounts for renewable energy projects when appropriate. However, these accounts are normally under-funded, making investments in renewable energy a lower priority.

Since 1992, DoD has earmarked about $10M per year through ECIP for renewable energy projects. The potential applications far exceed this funding level and, as a result, the PVRC is working to develop alternative financing mechanisms. With alternative financing, the system supplier or third party investor provides some or all of the capital investment, which is repaid through a monthly fee. The terms and conditions of these types of procurements can be tailored to the needs and requirements of both the customer and supplier. Some utilities have established off-grid tariffs, where the utility installs and operates the system and the capital investment and operating expenses are paid per the rate structure of the tariff (9). Utilities, as well as private investors, can offer power-purchase agreements, where the monthly fee is based on a negotiated cost for the delivered power and energy over some period of time.

There is also Energy Savings Performance Contracting (ESPC), where the capital investment and operating expenses are paid through savings from the lower energy costs provided by the renewable energy system (10). A unique advantage of these alternative financing mechanisms is that they can be combined with operation and maintenance monies or project monies (not military construction monies) so that DoD need only finance a percentage of the system cost. The Yuma WAM project will most likely be the first test of alternative financing. This project was only partially funded up-front through SERDP. The PV modules and batteries were procured with this up-front funding, and the project must now be completed through other funding or financing mechanisms. It will most likely be completed through a combination of project funds and ESPC. The project will probably take advantage of an Indefinite Delivery Indefinite Quantify (IDIQ) mechanism now being developed through DOE's Federal Energy Management Program. The IDIQ allows federal agencies in western area states to procure energy services from pre-qualified suppliers through a simple delivery order. The IDIQ mechanism greatly streamlines the procurement process, making it relatively easy to implement cost-effective renewable energy projects without up-front funding.

SUMMARY

DoD consumes on the order of 350 million gallons of diesel fuel each year to power its remote test, evaluation, and training ranges. Electricity from diesel generators is both expensive and detrimental to the environment. As derived in the example, conventional costs for a generator-based power system are $0.13/kWh for fuel, $0.07/kWh for generator maintenance (including overhauls, and replacements), and $0.34/kWh for operators for a total electricity cost of $0.54/kWh. Adding the cost of environmental degradation nearly doubles the cost of electricity from $0.54/kWh to $0.92/kWh. Augmenting diesel generators with power processing, battery energy storage, and PV can reduce this cost through enhanced performance and reliability.

The example hybrid power system showed that the power processing and battery option has substantial economic benefit based on conventional savings from avoided fuel, maintenance, and labor. At a fuel cost of $1 per gallon, adding PV had only a marginal environmental benefit. However, when the real costs of diesel generation were used, which includes the cost of environmental degradation, adding PV had a substantial economic benefit as well.

The Photovoltaic Review Committee is actively implementing hybrid power technology to realize these economic and environmental benefits. DoD currently has 13 hybrid system under implementation. Details on hardware and operation were provided for three of these systems: (1) Superior Valley, (2) Grasmere Point, and (3) Yuma. These three system encompass the range of available hardware and operating capabilities of hybrid technology. DoD continues to invest on the order of $10M per year for renewable energy projects through ECIP. This $10M per year is not enough to implement even a fraction of the potential projects throughout DoD. As a result, the PVRC is looking to alternative financing mechanisms to realize PV's full potential. The Yuma WAM project, which was only partially funded up-front, will most likely be the first system installed with at least partial alternative financing.

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