HYBRID SOLAR POWER IN AFGHANISTAN WAR ZONE – UNIQUE ENGINEERING AND ECONOMIC FACTORS

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ABSTRACT

The war in Afghanistan required unique solutions using solar power due to absence of any electrical grid, absence of reliable and practical power generation. This presentation explains why and how a solar hybrid power approach was used for telecommunication sites and health clinics.

A major effort in any war zone is minimizing fuel convoys to resupply generators and minimizing field visits for generator maintenance. PV gradually came to replace generator power thereby reducing fuel consumption and fewer maintenance visits. This was done with a hybrid design employing PV as prime power source and one generator for occasional use. The PV design and load had to be carefully matched to optimize PV generation and minimize generator usage.

Solar power was chosen not because it was green or eco-friendly, but because it was the only approach based on economics and reducing risks to personnel in a war zone.

1.0 INTRODUCTION

Power production and transmission in Afghanistan has been devastated by the war in Afghanistan since the Soviet invasion from 1979 to 1989, the Mujahedeen conflict from 1990 to 1996, the Taliban from1996 to 2001, and the current war continuing since 2001. During this entire time, more than 33 years, electrical power generating station, dams, and all manner of electric power transmission and distribution systems have been targeted by insurgents and regularly destroyed. During these war years and continuing today, no electrical power generation or transmission equipment is safe from attack. Until peace is restored throughout Afghanistan, there is no expectation or hope that the situation for electrical power in Afghanistan will improve.

In order for the country to function, there must be some electrical power generation and distribution, and some adaption to the war zone. What has evolved is localized power production, diesel powered generators, and limited power distribution for local use, not extending beyond a distance that can be secured by the local Afghan National Security Forces (ANSF). A primary rule is that power facilities cannot be provided and maintained if they cannot be secured. A major result is there is no national grid or national infrastructure and major hydropower and wind projects have not been completed or even started because they are generally in rural areas with no security.

1.1 Local Power Generation and Distribution

The usual power generation and distribution in Afghanistan is some diesel generators powering a compound, a base, or a city. This is a very expensive system to operate due to the high cost of fuel in Afghanistan, expensive to maintain, and generally prone to outages due to lack of backup or connection to a grid. Regardless of the cost of this local power there are critical facilities that have to be operated such as health clinics, telecom facilities, banks, and related activities.

Beginning early 2000, as solar power equipment became known and available in Afghanistan, and people came to understand how to use solar power, it began to occupy a unique place in Afghanistan: providing power for critical facilities where there was no power available, and towards 2010 began to be used to displace diesel power. In both situations solar power was used to great success.

1.2 Early Solar Applications in Afghanistan

Examples of early solar applications in Afghanistan are listed. The genesis for all these efforts was a lack of electrical power
in almost all rural areas outside a city or major metropolitan area.

- Tube Wells: Similar to electric power there is no established water distribution, thereby requiring tube wells, all over Afghanistan. In 2010, modern for the Western world, there are still tube wells in Kabul, the capitol, with hand pumps used daily. Solar powered submersible pumps have been used successfully to replace hand pumps and allow a greater volume of water to be drawn.
- Village Electrification: Early attempts at bringing some electrical power to villages began in late 1990's by sending solar panels and batteries to villages to power a TV set and an outdoor lamp. This project covered thousands of villages and continues.
- Street Lighting: Solar powered street lights for villages erected in the center of a village, done in parallel with village electrification.

An example of a solar powered street light is in Figure 1.

Fig. 1: Solar Powered Street Light, Battery at Base

2. PROBLEMS

Electrical power cost, availability, and reliability (power problems) in Afghanistan are found in other poor, developing, agrarian countries. Due to the war in Afghanistan, ongoing since 1979, power problems are more intractable (not easily controlled or manageable; stubborn; obstinate) than in similar countries. I experienced the same problems in the war in Vietnam in the 1960's and by the generation before me in WWII.

Solving power generation and distribution problems in a war zone and in a country at peace are distinctly different. Power solutions in a peace time environment are often dominated by concerns for the environment (Green energy considered environmentally friendly and non-polluting). In a war zone, power solutions are dominated by physical security and casualties. Some considerations in a war zone are listed below. None of these are related to the environment.

- Transportation: Fuel must be transported by military convoys in large tankers which are easy to target with an RPG. All fuel is transported overland by tankers, there are no pipelines for distribution.
- Storage: Fuel must be stored in protected areas and special tanks that are difficult to target and destroy.
- Delivery cost: Due to risk to fuel tankers and requirement for convoys and the long supply chain, the price of delivered fuel is extremely high.
- Rationing: When the supply chain for fuel is interrupted, fuel becomes scarce and is rationed.
- Theft: When fuel is rationed and the cost is extremely high, it is more likely to be stolen.
- Generator Operations: Many small generators requiring a lot of people for maintenance and operation.
- Generator Maintenance: Generator maintenance requires people, parts, lubricant, and a long supply train, operating in a hostile environment. Any interruption in generator maintenance will cause generators to be shut down.
- Site Security: Every location with a generator requires blast walls, and similar physical security.
- Site as a Target: Generators become targets for RPG's and small arms fire.
- Point of Use Production: Power generation is typically at point of use, a radio site, a health clinic, a support base, lot of small generators, typically with no backup. See Fig 2 for a typical point of use generator at a radio site.

All these items are a problem, in Afghanistan and previous wars, due to the risk of being blown up by a road side IED (improvised explosive device), kidnapping, shooting, rockets, and similar. This has a huge effect on how things are done in the field and the cost of generating, distributing, and maintaining power systems.

Fig 2. Point of Use Generator at Radio Site

3. SOLAR POWER AWARENESS

Solar power has been in use in Afghanistan for more than 10 years for unique applications such as water pumps, but not as a substitute for diesel fuel and generators. Only recently have the military forces, the Afghan Government, commercial organizations, and various nongovernmental organizations (NGO's) become more aware of the advantages gained from solar power for solving the fuel and generator problem. In other words using solar power as a replacement for conventional generators to the maximum extent possible.

The US Department of Defense (DoD) has various estimates for the cost of fuel delivered to a military base camp in Afghanistan as $300 to $400 per gallon. This has recently received more attention than in the past. One often cited statistic from the US military was the human cost in casualties in transporting fuel around Afghanistan, and how this could be reduced by using solar power. Some examples are listed. The goals in these examples are not to replace diesel fueled generators but to reduce as much as possible diesel consumption, reduce generator maintenance and replacements, and provide higher reliability (PV versus generators).

- Solar Backpacks: Self-contained backpack with PV, batteries, and controller, for battery charging without a gas generator.
- Base Camp Solar: Installing large solar arrays at base camps to reduce diesel fuel usage.
- Remote Radio Sites: Eliminate generators at remote radio sites by using PV only.
- Remote Sensors: Use PV to power remote sensors.

An example of PV panels at a radio site is in Fig. 3.

Fig 3. Radio Site Solar Power

4. SOLAR DESIGN CONSIDERATIONS

The primary design goals for solar power in Afghanistan are in two types of applications, each employing a different design approach.

- Fuel Consumption and Maintenance Reduction: Reduce diesel fuel consumption by offsetting generator power with solar power. This goal also works to reduce generator maintenance and engine oil consumption, and increases time between generator replacements.
- Prime Power Source: Provide power in locations that have no generator power and where it is not practical or possible to install and maintain generator sets.

To meet these two goals, solar power plant design in Afghanistan is generally of two types, hybrid and stand-alone. The hybrid design is based on economics. The stand-alone design is based on reliability and reserve.

- Solar Diesel Hybrid: Combined PV and diesel generator. Primary goal is to minimize fuel consumption and generator maintenance. This is done by harvesting as much PV generated power as possible, using battery storage, and operating the site generator as a backup. Applications are for radio sites, buildings, military base camps, residential units, clinics.
- Stand-Alone Power Generation: PV generated power is the only power available, there is no backup generator. The power plant (PV and batteries) design is to satisfy the load 24 hours a day with some reserve for reduced

sunshine and maintenance. Applications are for remote sites such as radio, security check points, remote sensors, observation points, border crossings, meteorological measuring locations.

The remainder of the discussion relates to solar diesel hybrid design, which is the focus for this material.

5. <u>SOLAR DIESEL HYBRID PLANT DESIGN</u>

The design is driven by using solar generated power to the maximum extent possible and minimizing diesel generator power. This minimizes fuel consumption, minimizes generator maintenance, increases overall power system availability, and maximizes time between generator replacement. Design considerations are listed below, some of which are unique to Afghanistan.

- Space: Sites in Afghanistan are always designed with consideration for security resulting in concrete blast walls, razor wire enclosures, and limited space for PV panels. Typically there are no large open spaces or fields that can be secured for installing PV panels. See Fig. 4 that shows a typical cell site outside Kabul, and Fig 5 that shows a typical radio site. The goal is to install as many panels as possible in the space available. Due to high walls and shelters panels are typically mounted on pedestals to minimize shadowing. The pedestals require additional mechanical design.
- Load Voltage Design: In order to maximize plant efficiency (minimize wasted power) the load is designed for all DC power consumption, and only one DC load voltage, for example 48VDC for an outdoor cell site. Inverter use and DC to DC converter use is avoided to the maximum extent possible. This results in the PV array and the batteries being matched to the load.

Fig. 4: Typical Cell Site Kabul Area

Fig. 5: Typical Radio Site With Solar Power

- Capitol Cost: Capitol cost is typically not a major constraint because most PV plants are constructed for government and military sites, and the power and minimization of fuel consumption is frequently more important than the capitol cost of the equipment and the land.
- Climate: Many sites in Afghanistan are in rural areas, difficult to access, resulting in fuel and generator maintenance being extremely difficult and costly to provide. Therefore the plants are designed for the day of the year with the worst weather and least sunshine. This appears to be an over-design by a factor of 3x or more for panels and batteries, but is necessary in order to provide 24 hours a day, 365 days a year operation.
- Solar Irradiance: The solar irradiance in Afghanistan is uncertain due to lack of field data. Our best estimate is below in Fig 6.

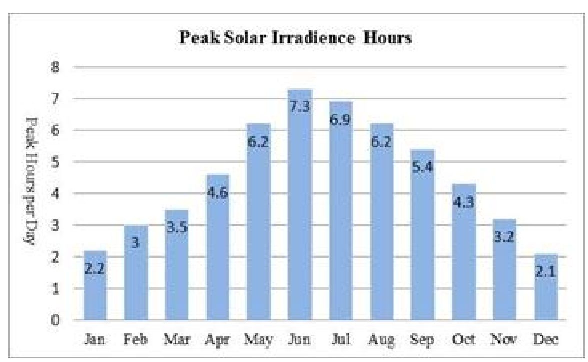

Fig 6. Peak Solar Irradiance Afghanistan

- Site Monitoring: Except for cellular radio coverage, in the major Afghanistan cities, there is no national telecommunications infrastructure as found in Western Europe and the USA. Therefore there is limited site monitoring, except by the cellular network using the GSM General Packet Radio Service (GPRS) or similar services.
- Equipment: Standard off the shelf PV panels, controllers, batteries, and similar equipment may be used, but with attention to upper temperature rating.

A typical solar diesel hybrid design is shown in Fig 7. The solar power equipment is setup and operated as listed below.

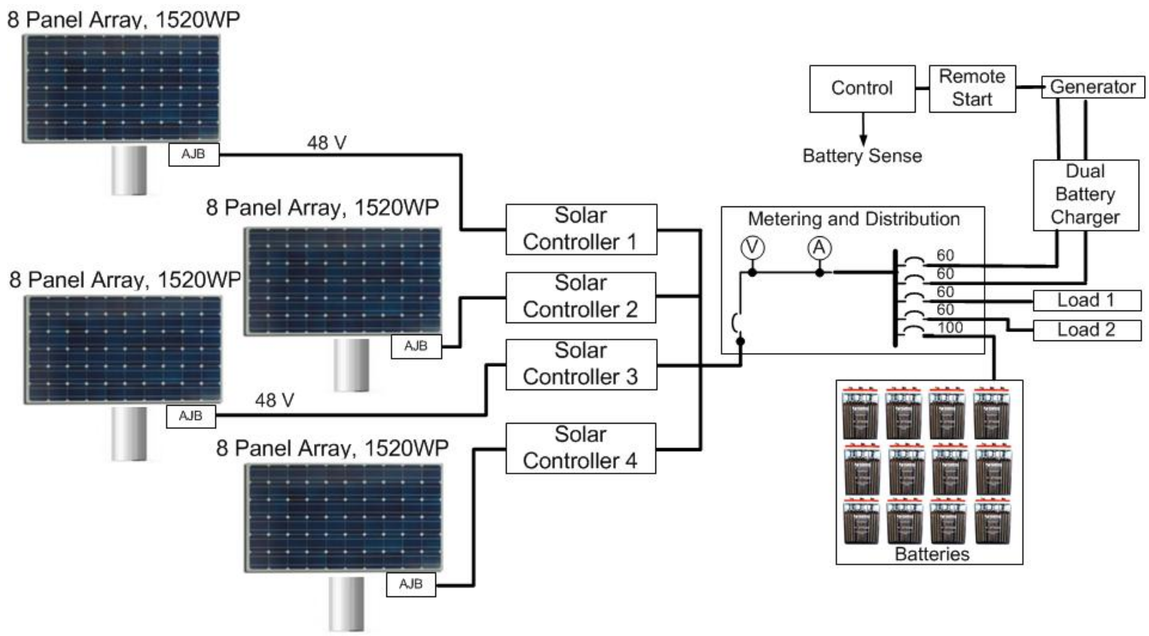

Fig. 7: Solar Diesel Hybrid

Figure 7 equipment configuration:

- The primary power source for battery charging and running the site, with generator as a backup.
- Designing for the winter time provides site power 24 hour a day by solar only, for approximately 9 months of the year.
- Generator serves as a backup power source and for battery charging, only during 3 winter months as needed.
- Design allows use of an automatic transfer switch and employing two generators if desired.
- Design includes power metering and alarms.
- Includes load control to prevent discharging batteries lower than a preset voltage. This can extend battery life.
- Includes antitheft fasteners to prevent loosing PV panels.
- Battery sizing is critical to prevent excessive depth of discharge which shortens battery life time.

6. FIELD RESULTS AND SAVINGS

The hybrid design has been installed, as a pilot project, at five commercial cell sites in Afghanistan that employ out door BTS equipment, therefore no air conditioners. See an example of one site in Fig. 8.

Fig. 8. Example PV Installation Afghanistan Cell Site

The hybrid solar system operates as designed, except, the total days of the year and hours per winter day for operation without generators exceeds the prediction. This indicates that the solar irradiance model, Fig. 6, used for latitudes of the sites underestimates the irradiance.
A summary of some aspects of the hybrid design and operation in Afghanistan are shown in Table 1.

Table 1. HYBRID SOLAR OPERATING DATA

Description	Units	No Solar - Two Generators	Solar Hybrid - One Generator
PV Power Installed Capacity	PWatts		4,200
Load, variable depends on traffic	Watts	750	750
Energy Consumption	KWHrs	18,000	18,000
Capitol Cost PV Plant With All Parts	US$		30,000
Financing Cost for PV Plant, per Month	US$		250
Capitol Cost Generators and Fuel Storage, 13.5 KVA generator	US$	21,000	11,000
Financing Cost for Generators, per Month	US$	175	92
Generator run time per day winter	Hours	24	4
Fuel Consumption per Month	Liters	1,100	183
Fuel Reduction per Month	Liters	0	917
Fuel Cost per Month	US$	1500	250
Reduction in Fuel Costs per Month	US$		1,250
Fuel Delivery Trips per Year for Generator	Trips	6	1
Generator Maintenance per Month	US$	750	125
Maintenance Trips per Year for Generator	Trips	6	1
Generator Overhaul, 3 Times every 5 years, Cost Prorated per Year	US$	3,600	1,800
Operating Costs per Month Including Financing Costs	US$	2,725	867
Savings per Month	US$		1,858
Payback Period for PV Plant	Years		1.8

7. CONCLUSIONS

The hybrid solar diesel design shown was installed as a prototype at five, commercial cell sites in Afghanistan. The system operates as intended by substituting solar power for diesel generator power. This design and installation is significant because it is the first time this was done in Afghanistan. The major advantages of the design for the operators and military applications are listed. For military applications the primary focus would be reducing casualties by reducing fuel delivery trips.

- Reduction in fuel delivery trips
- Reduction in maintenance trips for generators
- Improved power system availability
- Reduced operating cost
- Solar equipment payback in less than two years

NOTES:
All photos shown in document were taken by the author in a public location, with no restrictions.