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Bamiyan 1 MWp Solar Mini-Grid (Afghanistan)

Robert Foster[1], Tony Woods[2] and Ian Hoffbeck[3]

[1] Winrock International, Arlington, Virginia (USA)

[2] Sustainable Energy Systems International, Timaru (New Zealand)

[3] Future Solar Industries, Beirut (Lebanon)

Abstract

One of the world's largest solar mini-grids was installed for the community of Bamiyan in central Afghanistan in 2013. The 1 MWp photovoltaic/diesel hybrid mini-grid was installed by a partnership led by Sustainable Energy Services International (SESI) for the Government of New Zealand as part of international donor infrastructure development for the country. This paper details system design, operation, and lessons learned.

Keywords: *Mini-grids, photovoltaics, Afghanistan*

1.0 Introduction

Bamiyan formed part of the ancient Silk Road in central Afghanistan and lies 230 km northwest of Kabul at an altitude of >2,500 meters. The ancient history of Bamiyan is witness to the invasions of Genghis Khan in 1221, who massacred every person and living thing in Bamiyan at the still desolate "City of Screams." Marco Polo visited Bamiyan in1271 and wrote of its splendor and famed Buddha statues (sadly destroyed by the Taliban in 2001). Today the community is largely comprised of the Hazara ethnic group, and is a relatively peaceful haven designated as a UNESCO World Heritage Site (Rakotozonia, 2011). Bamiyan is also the gateway to Afghanistan's first national park at the beautiful Band-e Amir Lakes.

Due to its remote location and rugged terrain, Bamiyan has never been connected to the national electric grid, and only a modest diesel plant was used to supply power to the main bazaar area. Prior to the arrival of the solar mini-grid in Bamiyan in late 2013, some of the 20,000 villagers used small solar panels to provide some basic electric lights and communications for their homes. Some also used generators and rented out power to their nearby neighbors at an approximate cost of 300 Afs (~US$4.68) per bulb per month for four hours a day. This equates to around US$1.95 per kWh.. In the Mulah Ghulam neighborhood, the Afghan government through Ministry of Rural Rehabilitation and Development (MRRD) had also previously installed a diesel generator, but it did not operate for very long as with most diesel similar efforts in Afghanistan since diesel fuel was difficult to truck in and unaffordable for the residents. The absence of power metering for billing purposes also adds to the inability for isolated systems to achieve financial sustainability.

The New Zealand Ministry of Foreign Affairs (MoFA) approved development of a one MW solar-diesel hybrid mini-grid system, called the Bamiyan Renewable Energy Project (BREP) in 2012. The system was divided into three smaller systems in order to reach a larger customer base. An additional smaller system was initially planned for connection to the generator for the Bamiyan Bazaar. This plan was later modified for technical reasons. The equipment allocated for this smaller 40 kW system was reallocated for a system to power a portion of the community in the nearby Folaadi Valley.

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The Bamiyan Renewable Energy Program (BREP) was contracted by the New Zealand Ministry of Foreign Affairs and Trade (MFAT) to provide power and built as a joint venture of Sustainable Energy Services International (SESI) and NetCon, both New Zealand registered companies. The BREP generation system provides high-quality, 230 V, 50 Hz electricity to about 1,800 households in several neighborhoods around the Bamyan City area. The installation began in August of 2012 with the system beginning operation in October, 2013. The total project cost was US$14.1 million, including all tranmission and distribution lines, capacity building and construction. After completion of construction, the system was given to Da Afghanistan Breshna Sherkat (DABS), the Afghan utility company who now wholly owns and operates the system. The BREP Project Developers included

- New Zealand Ministry of Foreign Affairs and Trade (MFAT)
- Sustainable Energy Services International: SESI (prime)
- DABS: Da Afghanistan Breshna Sherkat (national utility)
- NET Con (distribution)
- Stephenson & Turner Architects & Engineers
- Snowy Mountain Engineering Company: SMEC (review)

It should be noted that over the past four decades, several studies and falst starts have been made in Bamiyan to develop a small hydro-electric project. There exists sufficient hydro resource potential for developing a small ~750 to 1,000 kW hydro plant near Bamiyan in Topchi that could be implemented to help meet the growing energy needs of the community that will grow beyond the present solar mini-grid system. A complete feasibilty study and design for this proposed project was prepared by the USAID Afghanistan Clean Energy Program (ACEP) in 2010 by Winrock International (Winrock, 2010).

1.1 Initial Design Stages

The design of the system was definied and constrained by two factors. The first determination was the overall size of the community and the demand for energy. Secondly the budget available to meet the demand. The design of the system was undertaken by Sustainable Energy Services International. Primary considerations were:

- The average demand from each household, and time of day of consumption.
- The population size, and expectations of growth in population and power demand.
- Socioeconomic factors influencing system operation and management
- Environmental and human capacity factors impacting component selection

Average loads of 200 watts per household were allowed, and 1.5 kWh per household per day were estimated based on previous experience with rural electrification, and allowing some room for future growth in demand.

The system design expects either additional solar panels to be installed as the population and/or demand for power grows, or for the use of the diesel generator to increase to meet demand if additional investment in solar PV is not made.

The system is also designed to allow the solar PV and transmission/distribution network to be merged into the wider Afghan power network in future, with all components constructed to international standards.

Component selection was designed to allow for modular components for inverters that could survive the dust and heat of Afghanistan, and also be installed and maintained by semi-skilled staff. This led the designers to favour the AC bus architecture of SMA (Germany) equipment, coupled with the flooded lead acid technology of Crown Batteries (USA).

Key to the long term success of the project was for financial viability to be built into the project. Pre pay power meters were installed at each household, on the pole outside to reduce meter tampering and power theft. This has been successful. The tariff calculation was undertaken by DABS, and set at US$ 0.25 for domestic use and US$ 0.70 for commercial use. The contractor preferred a single flat tariff for all consumers to avoid complication and more accurately reflect the cost of power for all consumers, but the split tariff was preferred by DABS.

To purchase power, consumers pay cash at the local bank into the DABS account, and then take the receipt to the DABS office who use an electronic dispensing unit to add power credits onto the consumer card. The consumer then takes the card back to their house and inserts the card into their meter to transfer the credit onto the meter. Consumers were required to purchase the prepay meter and consumer connection cable from DABS for the subsidised rate of US$30. DABS supplying the cable ensured that the correct cable quality was used. All household cables are buried, to reduce illegal temporary connections made to overhead lines.

2.0 Bamiyan Solar Mini-Grid Design and Components

The Bamiyan Renewable Energy Program (BREP) generation system provides 230 V, 50 Hz electricity to 2,400 households in several neighborhoods around the Bamyan City area. This 1,050 kW of power is divided between four generation sites: 400 kW at the Bamiyan New City site, 300 kW at the Hyderabad site, 300 kW at the Mullah-Gholam site and 50 kW at the Folaadi valley site. Each system has a main solar energy power plant and a backup diesel power plant. Each of the power generation sites is connected to a dedicated 20 kV transmission and 0.4 kV distribution system. These generation and distribution sites are not connected. The small site at Folaadi Valley connects directly to the distribution lines at 0.4 kV. A series of step down transformers reduces the voltages from the transmission lines and for supply into the distribution system. Each of the customer connections is 230 VAC and has a digital prepay electricity meter.

These provide energy to consumers 24 hours a day. For most of the year the solar energy system provides all of the power to the loads during the day while charging the batteries. During nighttime and times of poor solar insulation a diesel generator on site will automatically start and charge the batteries.

2.1 Power Generation

The solar modules provide the primary generation source, with the diesel as secondary source, and batteries for energy storage. Figure 1 below provides a visual representation of the generation system topography.

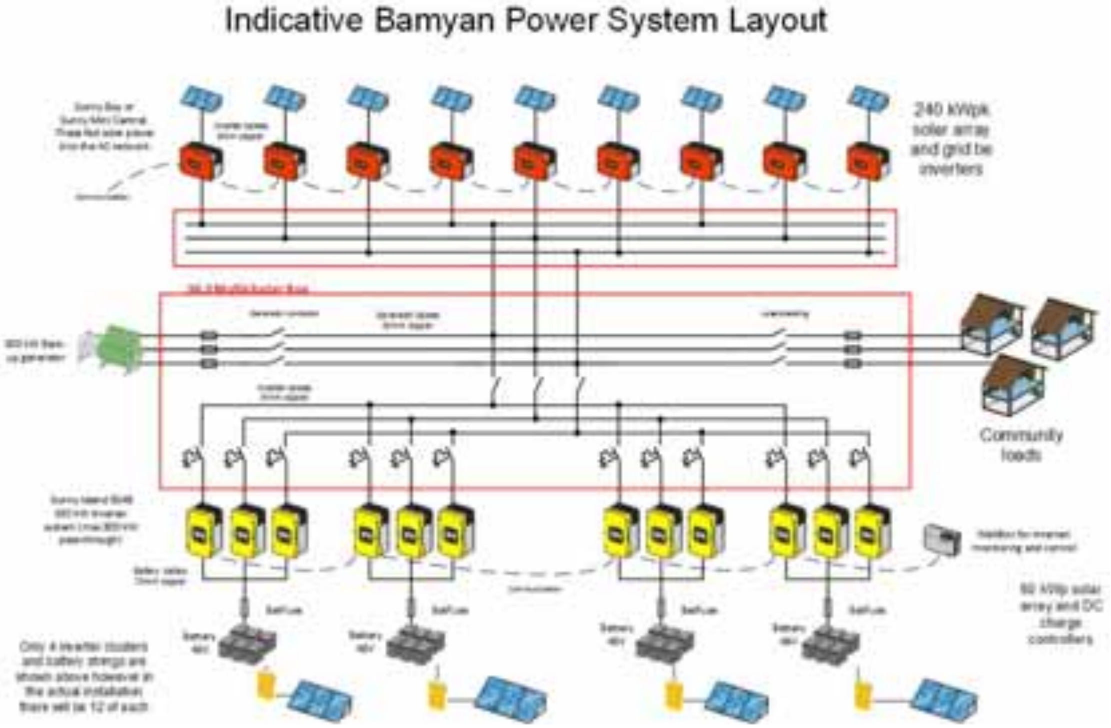

Fig 1: Bamiyan Renewable Energy Project (BREP) Solar Generation System Components

All components except for the solar modules, grid inverters, generator and transformer are contained within the powerhouse: an insulated, secured, weatherproof, and electrically grounded building on the grounds of the generation facility. All components are equipped with disconnects, allowing each component to be electrically isolated from any other component of the system. These disconnects variously include switches, fuses, relays and circuit breakers.

The primary power supply to the communities during daylight hours is directly from the solar arrays to the distribution network via the 3 phase AC inverters. Surplus power generation during the day is used to recharge the batteries, ready for use at night. The diesel generator is only used during bad weather or high demand periods.

2.2 Solar Modules and Inverters

Due to constraints of how much power can be sent to the batteries through the inverter/chargers, a small portion of the solar modules is directly connected to DC charge controller that uses the DC power to directly power the batteries. The battery inverters convert the DC power in the batteries to AC power that feeds to the grid. At the three large sites, the DC arrays consist of 288 modules; connected in arrays of 12 modules each to each charge controller. In total the system has 24 charge controllers, with two charge controllers each for the 12 battery banks. At Folaadi Valley, all 192 of the modules are connected to battery inverters. Each battery bank powers three battery inverters; with each of the three inverters providing one phase of power for the system. These 36 battery inverters all connect through the multicluster box that combines and controls power from the AC solar arrays, the diesel generator and also controls power fed back out to the grid.

The remaining solar modules are connected to the grid inverters. These are SMA three phase inverters installed at the site of the solar modules, and directly connected to the multicluster box. The site at Bamiyan New City has a slightly different configuration. It has 400kW of solar modules instead of the 300kW at Hyderabad and Mullah Gholam. This 100kW extra of solar modules is connected directly to the transformer. The Bamiyan New City generation site is connected to most of the high-power loads in Bamiyan City, including government buildings and large NGO offices. The design assumes that this portion of the city will experience higher day time loads from government offices and NGO's, thus the design is weighted towards higher day time power generation. The direct connection to the transformer bypasses the multicluster box and allows for the additional 100 kW of PV power to be supplied with minimal electrical losses.

The battery inverters are the "brains" of the power generation system. While all of the inverters are identical products, their software is configured differently to allow them to perform different functions. The 36 battery inverters are distributed into 12 clusters of three inverters each: one main cluster and 11 slave clusters. Each cluster has one master inverter and two slave inverters. The master inverter synchronizes the single-phase output of each inverter to create three-phase power output; controls the power draw from each of the two charge controllers for the cluster; and copies any changes in settings from itself to its two slave inverters. The main master inverter in the master cluster in turn controls these master inverters.

The master cluster has the same master-slave topography of the other clusters. However, it additionally controls the master inverter of each cluster. The main master inverter synchronizes the three-phase power output from each inverter; copies settings from itself to each of the main master inverters; and has the ability to start up or shut down the entire generation system. Not only does it control the master inverters, but it also controls some other elements of the system. These include the relays in the multicluster box for connecting and disconnecting the grid inverters, the battery inverters, the generator, and the transformer; a relay that remotely starts and stops the generator; and a relay that starts and stops the powerhouse ventilation fan.

Fig. 2: One of the Large BREP PV Arrays: 300 kWp at the Mullahghulam site

2.3 Diesel Generator

Each of the three large sites is equipped with a 275 kVA diesel generator made by FG Wilson. The diesel generator will automatically start when either the demand from the loads is more than the battery inverters and solar inverters combined can provide; or when the demand might cause the battery state of charge to drop to a low level. The generator is equipped with an external 3,000 liter fuel tank. The Folaadi valley site has a smaller 30 kW FG Wilson diesel generator. The main master inverter controls the autostart for the diesel generator at each site.

2.4 Battery Storage

The system uses flooded lead acid batteries manufactured by Crown (USA) for backup. Tab. 1 below gives the key parameters for the batteries used in the system.

Tab. 1. Battery Bank Parameters for the Bamiyan Solar Mini-Grid

Parameter	Value	Unit
Capacity	3750	Ah
Nominal Discharge Rate	20	hours
Nominal Operating Temperature	27	°C
Battery Voltage	8	V
Weight	860	kg
Cell voltage	2	V
Number of Cells	12	
Depth of Discharge	40	%
Cycle Life	3800-4000	Cycles
Batteries per Cluster	6	
Cluster Voltage	48	V
Batteries per Large Site	72	
Batteries at Folaadi Valley	12	
Total Batteries	228	

Each battery bank is charged and regulated by the two charge controllers in each cluster. As vented lead-acid batteries, the batteries must periodically have water added to the cells. To facilitate this process, each battery has a hose system connecting all of the cells. Each powerhouse is equipped with an automated battery watering system. This system consists of a water tank, a water deionizer and a battery-watering cart with a pump. This watering cart connects to the hose and automatically fills each cell to the appropriate level. The system is designed for a 40% depth of discharge. Under proper maintenance the battery bank should have a lifetime of about 7 to 9 years of operation, or longer depending on how it is used and maintained. Figure 3 below shows the arrangement of the battery banks in the power house.

Fig. 3: Crown Battery Banks each at 48 V; 3,747 Ah at a C/20 Discharge Rate

2.5 Transmission and Distribution

The transmission and distribution system begins at the step up transformer at the generation site and ends at the customer connections. The three large systems produce 400V three-phase electricity at the generation site. A transformer at the generation site steps up the power from 400V to 20kV for transmission. At the interface between the transmission and distribution systems, another transformer steps down the 20kV three-phase electricity to 400V three-phase electricity. The network at Folaadi Valley has no 20kV portion due to the close proximity of the consumer loads, so no transformers are used.

Most of the loads in Bamiyan come from residential homes and hence are only single phase. Larger consumers, including government offices and businesses have a 3 phase supply and 3 phase meter. The distribution pole and lines used the original ACEP proposed distribution design for the Topchi hydro-power plant (Salinas, 2011). The transmission network was installed by NetCon, a New Zealand electrical lines company. The lines were built to New Zealand Standards and installed by professional NZ linesmen.

Each transmission and distribution network is equipped with a recloser that can automatically isolate the electrical lines from the generation source. In the case of faults on the line, the recloser will disconnect and reconnect the lines a few times to see if the fault opens. If the fault does not correct itself, the recloser will leave the lines disconnected until a technician can repair the problem.

Fig. 4: BREP electrical distribution system as installed by NetCon

Fig. 5: SMA Multi-cluster Hyderabad BREP Power House with Sunny Island Battery Charging Inverters

Fig. 6: SESI trained and utilized Afghan women technicians as part of the installation crew.

2.6 Interconnection Requirements

The generation system of the power planet produces 230 V electricity at 50 Hz. While this does match the power output of the rest of the Afghan grid, the system cannot connect with the rest of the Afghan electrical grid as currently configured. In order to connect, the Bamiyan system would have to synchronize to the grid signal. However, the battery inverters determine their own synchronization and are not able to synchronize to an outside signal. If a utility operator would like to connect the Bamiyan system to an outside grid, the battery inverters and the batteries must be removed from the system. The grid inverters, however, can continue to be used after modifying the settings. This will allow the operator to reduce peak loads, but it will not allow them to store energy. As any outside system will likely have some manner of baseload power (e.g. hydro, gas) the system will not require the battery storage of the Bamiyan system. Ideally grid connection would occur before the lifetime of the batteries is completed. This will allow the solar modules to continue creating electricity without requiring the replacement of any energy storage equipment.

3.0 Community Development and System Operation

SESI maintained close contact with the community throughout the course of the project, soliciting their opinions and asking for support in construction and site monitoring. All of the local laborers were hired from communities nearby the power plant sites. In one community there was a problem with someone in the local community stealing grounding wires. The implementing partner worked with the local community to find the perpetrator and to prevent further theft in the future. Maintaining the support of the local community prevented members of the community from delaying the project or harassing the project staff.

The installation team encountered theft of system materials as a recurring problem. Specifically, some members of the local community would cut and steal the grounding cables used on the meter boxes in order to sell the copper for scrap. This problem persisted even when the issue was raised with the local leaders (shura). The project team was forced to delay livening the system in some communities for this reason. Operating the system is unsafe without proper grounding and so these communities had to wait until the theft stopped before they could be connected to the system. Most homes in Afghanistan on the national grid do not use grounding either and electrocution is a danger.

3.1 Metering and Tariffs

BREP uses a prepaid pay-as-you-go model for collecting revenue. This differs from the post-paid analog metered collection system common in the the rest of Afghanistan. Instead of the traditional analog electricity meter, each house is equipped with a digital meter that is charged by means of a charge card. The customer takes the card for their meter to the DABS office where they prepay for an amount of electricity. The DABS staff accepts their payment and adds value to their card by a dedicated charging machine housed in the office. The customer then takes this card back to the meter installed outside his or her home. They insert the card into the electrical meter, where the meter automatically subtracts the value from the card and adds it to it's own internal meter. The meter has a large backlit digital display that shows the current balance for the customer. When the balance reaches zero, the meter automatically disconnects the power.

Currently the electricity tariff is set at AFN 16 (USD $0.25) per kWh for residential customers and AFN 45 (USD $0.70) per kWh for government and business customers. However, the tariffs collected by DABS is not sufficient for the long term sustainable operation of the plant, which would require full depreciation of the batteries, solar PV and distribution lines to be deemed *fully sustainable*. This is actually much higher than the national tariff rate and represent as compromise. However, the cost of fuel alone for operating the plant on diesel backup is about 20 AFN (USD $0.30) per kWh. This means that any time the diesel generators are turned on, the plant is operating at a loss; even before taking into account costs other than diesel itself. The tariff should be high enough to pay for all of the fixed and variable operating costs of the plant as well as making extra money to replace equipment as it fails. The system currently covers all of its own operational and maintenance costs under the current tariff structure however as demands grow, and diesel consumption grows, the setting of the domestic tariff at a rate lower than recovery for diesel means that operating surpluses generated from running on solar PV will diminish over time.

There was some strong suggestions from development agencies to introduce load limiting systems in the supply to each household to *prevent households taking more than their fair share*. This was firmly rejected by SESI as it places a limit on growth, irresective of the willingness and ability to pay of consumers. Instead, our focus was on growing the system to meet demand and facilitate growth rather than the limiting of power and hence community development.

Gradually Bamiyan residents been signing up for the power system and willing to pay the interconnect fee. About 2,000 customers have signed up for BREP out of the 2,500 planned customers so far. Afghans often take a wait and see attitude to see if the system will work before signing up; they are also wary of the relatively high electric tariff as compared to their urban counterparts.

It is estimated that the system will be fully depreciated after 20 years, so the tariff would need to make, at least, 14 million dollars extra over the course of 20 years. As it stands, DABS are able to pay for variable costs of operation; including staff salaries, maintenance of equipment, tools and parts, but due to internal politics it heasitates to pay for fuel for the generators in winter. As of early 2015, DABS was requesting the government of New Zealand to still provide a diesel subsidy for the system operation and it has been shut down at times for lack of diesel fuel. Additionally, DABS must seek a capital injection or outside funding in order to replace equipment at the end of the equipment lifetime. This could be as early as 7 years from the date of installation in the case of the batteries. After parts start to fail, the entire system must be shut down until a new capital source is found.

3.2 System Operation and Maintenance

The largest capacity building need was educating the operator (DABS) about how to operate and maintain the plant. This including training DABS engineers and their participation in the installation of the system. In addition to the engineers, clerical and management staff was trained on how to properly manage an electrical system of this type, how to make customer connections, how to charge customer cards, and how to maintain an accurate accounting system. SESI-NetCon staff remained at the site to operate the system, allowing time to train DABS staff on the proper long-term maintenance of the system.

4.0 System Monitoring and Performance

Recognising the value of monitoring and evaluation to measuring long term project success or failure, Sustianable Energy Services International undertook on itself to perform detailed monitoring and evaluation activities with a professional social survey subcontractor to survey and record community attitudes and expectations on the project. These findings will be contrasted with a followup survey again to be undertaken by SESI and its subcontractor and a detailed report issued once 2 full years of operational data has been gathered.

Initial risks to public acceptance of the system related to the subsidy of other power networks elsewhere in Afghansitan, and the failure to use power meters on other smaller power networks in Bamyan prior to the BREP project. The lack of power metering and the reliance on the lightbuld basis of charging households for power menat that households were completely unaware of how much they actually paid for power. It was only with the introduction of power meters that they could compare their power costs with other cities, and then unfortunately they compared with subsidised power tariffs in cities like Kabul and Kandahar leading to incorrect perceptions that the people of Bamyan were being over-charged for power. This is despite the BREP solar installation reducing actual household power costs down from US$1.95 per kWh to US$0.25 per kWh. The willingness and ability to pay for power was clearly evident, and supported by the increasing demand for power measured over 2014/2015, however the public perception was based more on comparisons with other cities.

4.1 Online Monitoring

Each of the networks is monitored by a complete monitoring system that is web accesible via the local Bamyan cellphone network. The monitoring function allows online monitoring of error codes, power output, voltage and current, battery conditions and other core system parameters. This is extremely useful for troubleshooting and tuning the system to current needs, as well as additional support of DABS in the longer term. An example of the data gathered shown below in Fig. 1 below shows a typical operational period for the network in September 2015. The generator can be seen to have been required only once in this period, as shown by the green bars on the far left. The Total Multicluster Load Power (demand) can be seen shown by the red line, and power output from the solar arrays by the blue line. The surplus power generated (kWh) is stored in the batteries and meets demand in the night hours.

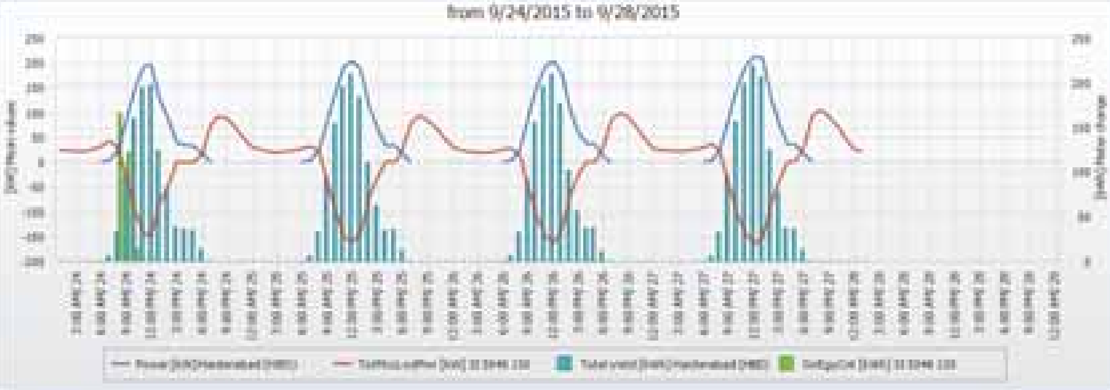

Fig. 1: Example System Power Output and Load Demand

Expectations of power demand from the community have roughly met expectations, and power demand grew sharply in 2014 once the system was accepted by the community as being real and reliable. This is shown graphically in Fig. 2 below from monitoring from the installation at Hyderabad, one of the three large installations; which shows power demands from 2014 and 2015, and the average demand in bold.

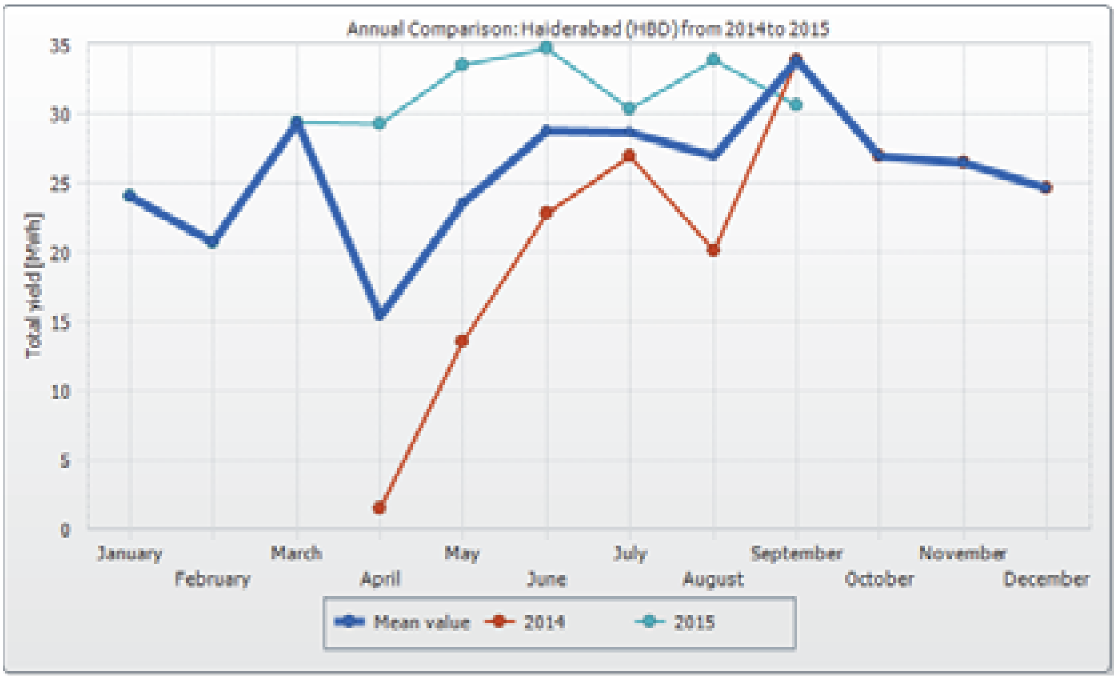

Fig. 2: Year to Year Energy Output Comparison at Hyderabad

5.0 Bamiyan Solar-Diesel 1 MW Mini-Grid LCOE Analysis

Markets currently serviced by diesel generators represent the largest potential market for many kinds of RE, especially solar energy which shares diesel's deployability across much of Afghanistan. To better understand the economics of solar-diesel mini-grids, an economic comparison between off-grid solar systems and diesel systems is considered for a real installed project in Afghanistan. This analysis compares the US $14 million (with T&D) 1 MW Bamiyan solar-diesel hybrid mini-grid energy system to an equivalent diesel only system. The diesel system considered is the same as the diesel backup generators powering the Bamiyan solar energy system, however they are operated more hours per day. The analysis assumes equal annual electricity sales for both systems.

5.1 Methodology and Assumptions

Two calculations are compared in this analysis. The first is the levelized cost of energy (LCOE) for both systems and the second is the net present value (NPV) for each system given an average sale price of the electricity generated. The LCOE calculation first considers the net present value of all costs associated with production of the system over its lifetime. This levelized cost is divided by the estimated energy production over the lifetime of the system, yielding the LCOE.

To assess the financial viability of the systems, a NPV calculation were performed. The profits for each year of the 20 year lifetime were calculated. Then all of these profits were discounted to present dollars, yielding the value of the system in today's dollars.

Electricity sold is considered instead of electricity generated because diesel generators often operate at only a proportion of their highest-efficiency loading. Because the solar system has battery backup, nearly all of the electricity produced can be sold. An exchange rate of 57 AFN per USD was used. A mid-range diesel price of 66 AFN per liter was used reflecting the Central Statistics Organization Q3 2014 data (however, current diesel prices in Bamiyan have recently come down to only 48 AFN per liter but can be expected to go back up in the future). DABS Bamyan currently offers a two-tiered tariff system: 16 AFN per kWh for residential consumers and 45 AFN per kWh for commercial consumers. This analysis assumes that 90% of the energy sold will be to residential customers, giving an average revenue of 17.9 AFN per kWh. Horizontal solar radiation was conservatively estimated at 5.0 kWh per square meter per day from a 2007 NREL estimates discussed in the solar resource section.

This analysis also assumes proper operation of the system. The battery depth of discharge is currently set at 40%, which the vendor (SESI) estimates will allow for a 12 year operational lifetime of the battery bank (depending on user operaiton and battery abuse, it could only be half of this lifetime). There will be some short-term incentive to set the depth of discharge lower (eg. 50%-80%). This will dramatically reduce the operational lifetime of the batteries and necessitate several replacements over the operational life of the system. A discount rate of 10% was assumed for the investments.

5.2 Life Cycle Cost of Energy (LCOE) Analysis

The table below shows key values determined by the analysis for both the solar and diesel systems. The LCOE of energy for the diesel only case was calculated at US$0.32 /kWh, while that for the solar diesel was calculated at US$0.46/kWh (about mid-range). The solar system may actually cost more depending on battery replacements. The LCOE for the solar system without batteries would be about half of this estimate.

Tab. 2. Bamiyan 1 MW Solar-Diesel Mini-Grid Analysis

Parameter	Diesel	Solar-Diesel
LCOE	$0.32	$0.46
NPV at Current Tariff	-$4,550,152.85	-$10,338,220.81
Average Tariff Needed for Profitability	AFN 48.4 (USD $0.61)	AFN 74.4 (USD $1.31)
NPV Sensitivity to Diesel Prices (Per dollar change)	$4.29 million	$0.26 million

Neither the solar-diesel nor the diesel only system is profitable at the 90% residential sales ratio. The solar system achieved a positive revenue flow, but was never able to make up for it's capital outlay if full cost recovery is desired. The diesel system never attained a positive cash flow. The solar system requires a somewhat higher tariff in order to reach profitability. It is likely that future projects similar to the Bamiyan project will be able to be completed with a lower capital outlay as PV prices continue to decline. The Bamiyan project was the first of it's kind in the region, and one of the top three largest solar-diesel mini-grids in the world. The solar system is much less susceptible to fluctuations in diesel prices. Because of the volatility of petroleum prices, this analysis assumed a constant price of diesel fuel as it is difficult to predict what the future costs will be. Such a scenario is unlikely and diesel prices will likely increase and decrease over the 20-year analysis timeframe. The solar system will be much more able to maintain a long-term profitability in this respect. At current tariffs, DABS will have to subsidize future battery bank replacements for the DABS solar-diesel mini-grid if the wider national grid does not extend into Bamyan before the battery banks require replacement.

6.0 Key Success Factors

Three key factors contributing to the project's success are technical operation, safety, and long-term financial viability. Successful technical operation was completed after livening of the system, providing power to the customers, and demonstrating that the design goals of the system are met. Risks to the long-term successful operation of the system focus mainly on the technical capacity of DABS to operate the system and retain the trained staff needed to support it. This includes the need for DABS to invest in the system to cope with the inevitable growth in demand that can be expected with any commercial power supply network.

Success in safety will be partially determined by the proper operation and maintenance of the system. This could be jeopardized if the system is damaged, improperly maintained, or if public awareness and education about the system flags.

Future risks to the long term viability of the project in future include:

- Potential lack of access to qualified support staff, both commercially and inside DABS
- Potential lack of support from DABS Kabul to respond to needs of the local Bamyan DABS office
- Reduced consumer support if the system reliability is not maintained.
- Inability to perform scheduled maintenance and maintain an adequate depreciation account for future parts replacement and upgrade.
- Employee graft reducing financial viability of the system.
- Theft of system components.
- Over-subscription of electricity services inducing system failure.
- Encroachment of the ongoing conflict in Afghanistan to the area.

The long-term financial viability will determine if the system is operated adequately to arrive at the end of its useful design life. Proper financial management will play a key role in this success. This will include setting and maintaining proper electricity tariffs, preventing theft and fraud, as well as proper operation and maintenance to ensure correct system function long term.

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