Design and simulation of grid-connected photovoltaic-diesel hybrid system

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Abstract. The availability of reliable electrical energy is essential in developing countries for functioning in modern economies such as in residential, industrial and commercial developments. The sources to produce electricity can be divided into two categories: renewable sources and non-renewable sources. Renewable energies are sources of clean and inexhaustible energies which can be produced from natural resources and they produce neither greenhouse gases nor polluting emissions. There are variety of renewable energy such as wind energy, solar energy, hydro energy, biomass and biofuel energy and etc. The photovoltaic-diesel hybrid systems are systems that combine photovoltaic system and diesel generators to generate electricity. There are many types of photovoltaic-hybrid system. They are series hybrid, switch hybrid and parallel hybrid. In the series photovoltaic-hybrid system, Photovoltaic generator or diesel generator is used along with battery bank to charge. In this paper, the sizing of photovoltaic-diesel hybrid system with grid connection is calculated for the electricity consumption of an industry. The study area of this paper is located in North Okkalapa township, Yangon division, Myanmar and at latitude 16°53'06.9"N and longitude 96°09'17.8"E. The load consumption of this garment factory is firstly collected. In this paper, a photovoltaic system was designed. The number of modules, the number of inverters, and the efficient techniques of connecting them together was stated. Also the area of the designed photovoltaic system was calculated, and a suitable location for the system was chosen. The sizing calculation of the system is designed by using HELIOSCOPE software and HOMER software.

Keywords: renewable energy, photovoltaic-diesel hybrid, stand-alone solar system, green design, photovoltaic devices, load demand

1. Introduction

Amongst wide ranges of renewable energy, solar energy is unique and one of the energy which has being commonly used both in industrial and residential sectors. Solar energy applies energy from the sun in form of solar radiation for heat or to generate electricity. There are two types of solar energy regarding the ways of using, active solar energy which uses mechanical devices and passive solar energy without using mechanical devices. Photovoltaic (PV) and solar thermal energy are two types of active solar energy. Photovoltaic system is a system which produces electricity from sunlight by using photovoltaic cells and solar thermal energy is created by solar energy into heat. Hybrid photovoltaic system is a system under the types of standalone system by the combination of solar energy and other energy sources such as wind, hydro, fuel cells to maximize the availability of power. Many hybrid systems are stand-alone system which operate off-grid that is not connected to an electricity distribution system. For the times when neither the wind nor the solar system are producing, most hybrid systems provide power through batteries and/or an engine generator powered by conventional
fuels, such as diesel. Some hybrid systems are grid-connected systems with or without battery storage added to allow power to be generated even if the electricity grid fails.

1.1. HelioScope
HelioScope, a new program introduced by Folsom Labs, includes all the features of PV System and adds the design functionality of Auto Cad, allowing designers to do a complete design with one package. With Google Ketchup integration and map, it is also easy to use. Using HelioScope software, the user enters the location’s address, selects the roof area for the array, specifies a PV module, and chooses an inverter model. It also provides a detailed wiring diagram, including the exact placement of panels, inverters, and other equipment and can select different components and run multiple simulations for the same location to compare the results and choose the best design configuration.

1.2. HOMER
HOMER, hybrid optimization model of electrical renewable software is the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid connected power systems for a variety of applications. Configuration of the system while designing a power can be made by using HOMER. This can provide to select the components of the system design and the size of the system. The main target of this paper work is to design a PV-Diesel hybrid renewable energy system that provides low cost electricity by comparing with other systems in order to get stability and reliability.

2. Configuration of PV Systems
Photovoltaic systems are solar energy supply systems, which supply power directly to electrical equipment or feed energy into the public electricity grid. The power range extends from tens watts to several megawatts. The photovoltaic system can be classified into stand alone and grid connected system.

2.1. Standalone PV System
Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads.

2.2. PV Hybrid System
In case of high-energy demand, the PV generator alone could not provide sufficient energy. The same problem occurs if a high reliability is demanded. For those reasons different generators are coupled, resulting in a so-called hybrid system. It can be categorized into three groups of configuration such as series hybrid, switch hybrid and parallel hybrid.

2.2.1. Series Hybrid System with both DC and AC consumers
Both of the PV generator or diesel generator is used to maintain to charge battery bank. When the electricity demand is low, load can be supplied from PV together with battery bank, converting to the desire output DC or AC and frequency by an inverter and is fed to the consumers. Charge controller prevents overcharging the battery bank when PV power exceeds the demand & batteries are fully charged. One of the disadvantages of this system is short battery bank’s life since it is cycled frequently.

2.2.2. Switched Hybrid Photovoltaic System with AC Load
In this system, either generator or the inverter as AC source is allowed but no parallel operation of main source is possible. Both generators can charge the battery bank. The generator can supply the load directly, improving the system efficiency & reduce the fuel consumption. Power is supplied to the load by the battery through the inverter during low load operating period. Switched hybrid photovoltaic system can be manual mode and if the automatic controller is added to this system, it will make the system complex.
2.2.3. Parallel Hybrid Photovoltaic System

This hybrid system (Figure 1) allows all sources supplying the load separately at low or medium demand, while supplying quick load from combined sources by synchronizing the inverter with the alternator output wave forms the bi-directional inverter can charge the battery bank.

![Figure 1. Parallel hybrid photovoltaic system](image)

2.3. Grid-connected Photovoltaic Systems

This system (Figure 2) is mainly composed of a matrix of PV arrays, which converts the sunlight to DC power, and a power conditioning unit that converts the DC power to AC power. The generated AC power is injected into the grid and/or utilized by the local loads. In some cases, storage devices are used to improve the availability of the power generated by the PV system. There are two types in grid-connected system: decentralize and centralize.

![Figure 2. Grid-connected PV system](image)

3. Designing Grid-connected PV-Diesel Hybrid System

3.1. Procedure to Design a System

Selection of design whether including battery storage or not for the selected site is important since the price for solar battery is expensive. Then the required load demand and size of diesel generator used in the garment factory is collected and thoroughly evaluated.

![Figure 3. System design process](image)

Also designing and sizing of PV arrays are processed by using HelioScope Software. After getting a suitable PV design, single line wiring diagram is evaluated and the cost data for each power system components will be estimated. The system design process is as shown in Figure 3. HelioScope, cloud-based sales and design software, can design any types of PV system on any location by using the google map. Helioscope determine the mechanical design and electrical design such as field segments, racking, azimuth and tilts, orientation, row spacing, module spacing and frame spacing as shown in Figure 4, Figure 5, and Figure 6.

![Figure 4. Field segments of mechanical design](image)
Figure 5. Row spacing, module spacing and frame spacing in mechanical design

Figure 6. Optimization of module shading

4. Simulation Results and Layout Diagram

For the first step, the loads of the factory are collected and the sizing of PV arrays, inverters and single line diagram of the system are calculated by software. Solar radiation data on a horizontal surface of the study area is shown in Table 1. As shown in table, April is the highest radiation month as in value of 6.34 kWh/m²/day and August is the lowest radiation month for the case study area as in value of 3.17 kWh/m²/day. Finally, the estimation cost of the proposed system is showed. According to the result, the annual average solar radiation is scaled to be 4.634 kWh/m²/day and the average clear index is found to be 0.483 shown in Figure 7.

| Months  | Radiation Data (kWh/m²/day) | Months  | Radiation Data (kWh/m²/day) |
|---------|-----------------------------|---------|-----------------------------|
| January | 5.13                        | August  | 3.17                        |
| February| 5.76                        | September|3.80                        |
| March   | 6.18                        | October | 4.42                        |
| April   | 6.34                        | November| 4.56                        |
| May     | 4.64                        | December| 4.85                        |
| June    | 3.44                        | Annual  | 4.634                       |
| July    | 3.42                        | Average |                             |

Figure 7. Chart of solar radiation and clear index of study area

4.1. Load Profile for Case Study Area

Designing the PV-diesel hybrid system with grid-connected, it is necessary to undertake a load profile to determine the electricity cost of a factory. In case of energy consumption, data are collected by the factory records. The tables of electricity usage and diesel usage are shown.
Table 2. Average Load Usage of Study Area

| Descriptions                      | Value       | Unit   |
|-----------------------------------|-------------|--------|
| Energy Consumption on holiday     | 1332.95     | kWh    |
| Annual Electricity Usage(billed)  | 486.528     | kWh    |
| Annual Electricity Cost           | 58,321.249  | MMk    |
| Average Electricity Cost          | 119.87      | MMk/kWh|
| Average Monthly diesel            | 530         | liters |
| consumption                       |             |        |
| Average diesel price              | 860         | MMk/L  |
| Diesel consumption with solar     | 70%         |        |

Table 3. Annual Electricity Usage of a Garment Factory

| Month | Billed Consumption (kWh) | Actual Consumption (kWh) | Total (MMK) | Average price (MMK/kWh) |
|-------|--------------------------|--------------------------|-------------|-------------------------|
| Jan   | 40,568                   | 38,540                   | 4,867,100   | 119.973871              |
| Feb   | 30,096                   | 28,591                   | 3,558,100   | 118.2250133             |
| Mar   | 36,960                   | 35,112                   | 4,416,100   | 119.4832251             |
| Apr   | 33,440                   | 31,768                   | 3,976,100   | 118.902512              |
| May   | 47,784                   | 45,395                   | 5,769,100   | 120.7328813             |
| Jun   | 46,288                   | 43,974                   | 5,582,100   | 120.5949706             |
| Jul   | 39,600                   | 37,620                   | 4,746,100   | 119.8510101             |
| Aug   | 49,368                   | 46,490                   | 5,967,100   | 120.8697942             |
| Sep   | 39,651                   | 38,517                   | 4,752,517   | 119.8576761             |
| Oct   | 38,808                   | 36,868                   | 4,647,100   | 119.7459287             |
| Nov   | 44,880                   | 42,636                   | 5,406,100   | 120.4567736             |
| Dec   | 38,192                   | 36,282                   | 4,570,100   | 119.6611856             |
| Total | 515,467                  |                           | 61,718,089  |                         |
| Average Per day                    | 1,412        | 169,091 |                         |

Table 4. Annual Diesel Usage of a Garment Factory

| Month | Consumption (Gallons) | Cost (MMK) | Diesel cost (MMK/Gal) |
|-------|-----------------------|------------|-----------------------|
| Jan   | 200                   | 500,000    | 2500                  |
| Feb   | 200                   | 520,000    | 2600                  |
| Mar   | 200                   | 520,000    | 2600                  |
| Apr   | -                     | -          | -                     |
| May   | 200                   | 600,000    | 3000                  |
| Jun   | 200                   | 600,000    | 3000                  |
| Jul   | -                     | -          | -                     |
| Aug   | 200                   | 560,000    | 2800                  |
| Sep   | 200                   | 560,000    | 2800                  |
| Oct   | -                     | -          | -                     |
| Nov   | -                     | -          | -                     |
| Dec   | -                     | -          | -                     |
| Total | 1,400                 |            |                       |
| Average | 117          | 321,667 | 2,757                  |
| Average in litres                   | 530.37      | 606.50  |                       |
4.2. Helioscope Design

The roof top layout plan of Anita Garment factory is shown in Figure 8 and Figure 9.

![Figure 8. Anita garment factory roofing plan layout](image1)

![Figure 9. Array layout design by HelioScope software](image2)

In this design, field segment 1 which is facing to south, has 308 modules of 280W. The azimuth angle of this segment is 169.246 degree. In the field segment 2, which is facing to east, includes 23 modules of 280W. The azimuth angle is 79.5085 degree. Both of the segments have flush mounting racking system and portrait orientation. The tilt angle for both segments is 12 degree and total power output from segments is 92.7 kW. The simulation results are showed in the following figures.

| Field Segments | Description | Racking | Orientation | Tilt | Azimuth | Interframe Spacing | Frame Size | Frames | Modules | Power |
|----------------|-------------|---------|-------------|------|----------|-------------------|------------|--------|---------|-------|
| Field Segment 1| Rush Mount  | Portrait (Vertical)| 12°   | 169.246° | 8.5 m   | 2x1          | 493        | 308   | 86.2 kW |       |
| Field Segment 2| Rush Mount  | Portrait (Vertical)| 12°   | 79.5085°  | 8.5 m   | 2x1          | 26         | 25    | 6.44 kW |       |

![Figure 10. Field segments by Helioscope](image3)
### Annual Production

| Description                        | Output | % Delta |
|------------------------------------|--------|---------|
| Annual Global Horizontal Irradiance| 1,723.0| 5.3%    |
| PDA Irradiance                     | 1,826.0| -5.3%   |
| Shaded Irradiance                  | 1,591.8| -9.9%   |
| Irradiance after Reflection        | 1,750.1| -3.3%   |
| Irradiance after Shading           | 1,710.6| -2.9%   |
| **Total Collector Irradiance**     | 1,710.7| 0.0%    |

### Energy Yield

| Description                        | Value   |
|------------------------------------|---------|
| Output at Irradiance Levels        | 1,517.83|
| Output at Cell Temperature Decrease| 1,712.83|
| Output After mismatch              | 127,476.1|
| Optimal DC Output                  | 127,297.4|
| Converted DC Output                | 127,295.6|
| Inverter Output                    | 124,817.0|
| **Energy to Grid**                 | 124,817.0|

**Figure 11.** Result of annual production

**Figure 12.** Condition set

| Description                        | Condition Set 1 |
|------------------------------------|-----------------|
| Weather Dataset                    | TMY, 10km grid, meteonet (meteonorm) |
| Solar Angle Location               | Meter LatLong   |
| Transposition Model                | Perez Model     |
| Temperature Model                  | Sandia Model    |
| **Temperature Model Parameters**   |                 |
| Rack Type                          | a      b       Temperature Delta |
| Fixed Tilt                         | -3.5%  -0.07% | 3°C                     |
| Flush Mount                        | -2.81% -0.045%| 0°C                     |
| **Seeding (%)**                    | J       F       M       A       J       J       A       S       D       N       D       |
| S 5 4 3 2 1 0 0 0 0 0 0 0 0 0 0 0 0 |
| Irradiation Variance               | 5%                 |
| Cell Temperature Spread            | 4°C                |
| Module Bending Range               | -2.5% to 2.5%     |
| AC System Deterize                 | 0.5%               |
| **Module Characteristics**         | Module | Characterization |
| EN1850-00-280 (Correct)            | Spec Sheet Characterization, PAN |

**Figure 13.** Shading by field segments

### 4.3. Layout of Rooftop of a Building with PV Arrays

The rooftop with PV arrays layout is shown in the following Figure 14 and Figure 15.

**Figure 14.** Rooftop Layout with PV Arrays
4.4. Electrical Results for PV-Diesel Hybrid System

According to HelioScope simulation, PV array generates 124.8MWh per year and performance ratio of the system is 73.8% as shown in Figure 16.

5. Conclusion

After evaluating the load profile by using a collected data from Anita Asia Garment factory, 331 numbers of Econess polycrystalline 280W photovoltaic solar modules, three 75kW and one 5kW SMA inverters were selected for photovoltaic-diesel hybrid system with grid connected. The proposed design can reduce the electricity and fuel consumptions of a garment factory. A 92.7 kW photovoltaic-diesel hybrid system which is roof-mounted design is proposed with respect to technical and design aspects. A rooftop solar system on Anita Asia garment factory will synchronize safely and automatically with the government (YESC) grid. The proposed system is designed and sized to minimize export of electricity to YESC grid while maximizing solar for Anita Asia’s self-consumption. From the collected data, it was determined that Anita garment factory’s average daytime load is 162 kW. During low loads time when a factory cannot fully consume the solar electricity either during holidays or non-production days, the solar system is designed as the inverters automatically reduce solar production and no feed-in to the grid occurs. During a blackout, the proposed solar photovoltaic-hybrid system will supply up to 20% of the factory’s load with the remaining power supply coming from the existing diesel generator system which will create savings for the factory on diesel fuel costs.

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