Optimization towards cost effective Solar Mini Grids in Bangladesh

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Abstract:

People living in remote rural areas e.g. islands of Bangladesh don't have access to electricity due to financial and technical challenges. Solar Photovoltaic (PV)-Diesel based hybrid mini grids can be a way to electrify remote rural areas of Bangladesh. However, solar energy is costly compared to conventional energy sources. Hence, optimization is essential to ensure success of solar mini grids in remote rural areas. Optimization of mini grid plant capacity based on demand is discussed. Diesel consumption and excess electricity from plant are the key optimization parameters. A case at Paratoli, Narsingdi, Bangladesh is taken into consideration to validate the optimization. Data is further analyzed to find out the future requirements and effects after optimization.

Introduction

Bangladesh with its growing economy is considered to be one of the emerging eleven economies (also known as N-11) around the world. However, the country will surely face challenge in ensuring energy security for its humongous population of around 160 million with respect to the area of the country. In addition, global energy demand is increasing quickly. It is said that the global energy demand will rise up to 33% by 2020 where it will increase to estimated 218 billion MW with increase rate of 49% by 2035[1]. Bangladesh will have to rely mostly on its natural resources e.g. coal, gas. The main source of energy in Bangladesh is natural gas (24%) which is likely to be depleted by the year 2020 [2]. Hence, Bangladesh is trying to emphasize on renewable energy. Bangladesh government has a target to meet 10% of the total demand from renewable energy by 2020 [3]. According to the World Bank database [4], only 59.6% of the people in Bangladesh have access to electricity. The rural electrification is one of the areas where the government needs to focus in the days to come. However, electrification in remote areas of the country e.g. islands is quite difficult due to the technical and financial challenges associated with it. Solar PV based mini grid project can of one of the possible solutions since possibility of grid expansion is remote in near future.

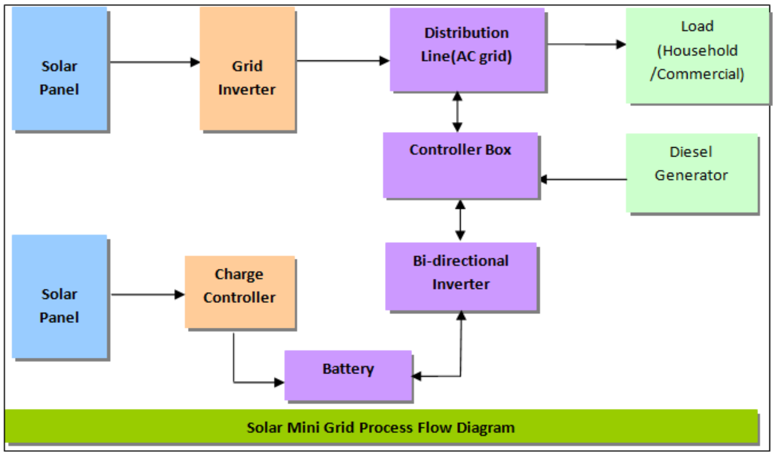
Solar mini grids in Bangladesh

Hybrid PV-diesel based electrification projects have already been done in many countries around the world. Bangladesh also is having high hopes on solar energy to give grid quality electricity in rural households. The first solar mini grid of the country came into operation in 2011, a 100 kWp plant in Sandwip, an island in the south eastern coast of Bangladesh [5].As of now, seven solar mini grid plants have been installed over the country with a capacity ranging from 100 kWp to 177 kWp. Another nine such projects are under construction. All these projects are being implemented under financing of Infrastructure Development Company Limited (IDCOL), a government owned financing organization with financing support from the World Bank, KfW, GPOBA, JICA, USAID, ADB and DFID. Along with financing into these projects, IDCOL is also associated with sector development, project development, project implementation and proper monitoring of the projects. IDCOL has a target to finance 50 solar mini grid projects by 2018.

Technology used in Solar PV based solar mini grid projects

Solar PV based mini projects refer to 100 to 250 kWp small PV plants providing electricity to 500-1000 customers including households, shops, clinics, schools, rice mills, irrigation pumps etc. The distribution line normally is within one to two kilometer radius of the plant whereas total distribution line length is about five to seven kilometers. Solar Photovoltaic (PV) module is normally the main source of energy in these projects. Diesel generator is normally kept as back up for the rainy and foggy days when solar irradiation will not be adequate. Solar mini grids can be designed in different ways. Designs considered in this paper are centralized PV plants. The process flow diagram of the solar a solar mini grid project is shown Fig 1. It can also be designed with no dedicated panels for charging the batteries. System designer prefers this earlier one to ensure the proper charging of the batteries. DC output from the PV modules is converted to AC output through grid connected inverters. Excess energy from the inverters is converted again to DC by bidirectional inverters (can convert DC to AC and AC to DC) to charge the batteries for night time load. During nighttime, AC output is generated through bidirectional inverters from the battery storage. Battery banks will be consisted of 2V low maintenance lead acid type batteries, each of 1540 Ah capacity. 24 numbers of 2V batteries will be connected in series to form 48V DC bus. Notably, electricity will be supplied to the customers at 230V (AC).

Fig. 1: Solar Mini-grid Process Flow Diagram



In emergency or inadequate energy storage, diesel generator will be switched on to meet the demand. Without any back-up generator, the battery bank can be damaged because of prolonged deep discharge and insufficient charge during rainy and foggy days. The generator is turned off when the batteries are fully charged. The consumption of the diesel generator is optimized when it supplies electricity to the loads and charge the batteries with the surplus. The diesel generator can also work in parallel with the battery bank to supply electricity to high load demand.

Case study:

In order to discuss optimization of the system, a case study can be considered. The considered place is at Paratoli, Narsingdi, Bangladesh. The latitude of the proposed location is 23.95 ° N and longitude is 90.92 °E. The solar irradiance profile [6] of the project location is as shown in Table 1. Optimum tilt angle for solar panels in Bangladesh is considered to be 23.7±1 degrees at any place in Bangladesh [7]. Average solar insolation in Bangladesh is considered to be 4.5 kWh/m^2/day. In the project site, the average insolation is 4.65 kWh/m^2/day which is greater than the average of the country by 3.33%. Insolation data of the project site suggests that the project location is suitable for solar mini grid as the solar insolation profile is steady all through the year and the plant is expected to yield high energy output.

Survey summary:

Solar mini grid project development starts from a detailed survey among the potential customers. The survey focuses on demand of electricity and affordability to pay the monthly bill. Notably, few potential customers possess Solar Home System (SHS) of their own. Replacement possibility of energy consumption from SHS to mini grid is also considered during the survey. Finding of the survey is summarized in Table 2.Based on the demand and affordability of the customers, the daily load demand is estimated. The estimated daily demand of the locality is shown in Table 3.

Seasonal variation of loads (winter season) is also considered to calculate the monthly energy demand from the targeted customers. After the demand calculation, optimization to find the plant capacity along with the design is the most important part of project development.

Table 1: Average monthly irradiation in Paratoli.

Month	**Average solar insolation at 23 degree tilted angle (kWh/m^2/day)**
January	4.36
February	4.92
March	5.59
April	5.76
May	5.3
June	4.53
July	4.23
August	4.29
September	4.01
October	4.32
November	4.28
December	4.21
Yearly average	4.65

Table 2: Survey summary

Load	Total number	Potential Customer	Percentage of targeted customer	Number of targeted customer
Household	1468	1448	50%	724
Shops	165	165	75%	124
Total	1633	1613	52.75%	848

Table 3. Estimated daily load profile (summer)

Time	Load (kW)	Time	Load (kW)
1:00 AM	24	1:00 PM	13
2:00 AM	24	2:00 PM	13
3:00 AM	24	3:00 PM	13
4:00 AM	24	4:00 PM	13
5:00 AM	13	5:00 PM	13
6:00 AM	13	6:00 PM	46
7:00 AM	13	7:00 PM	46
8:00 AM	13	8:00 PM	46
9:00 AM	13	9:00 PM	46
10:00 AM	13	10:00 PM	46
11:00 AM	13	11:00 PM	46
12:00 PM	13	12:00 AM	24

Optimization:

Optimization in this paper refers to the selection of plant sizing in a way that energy consumption from diesel and amount of excess energy both remains at minimal level. System size calculation with a particular load variation is shown in Table 4.

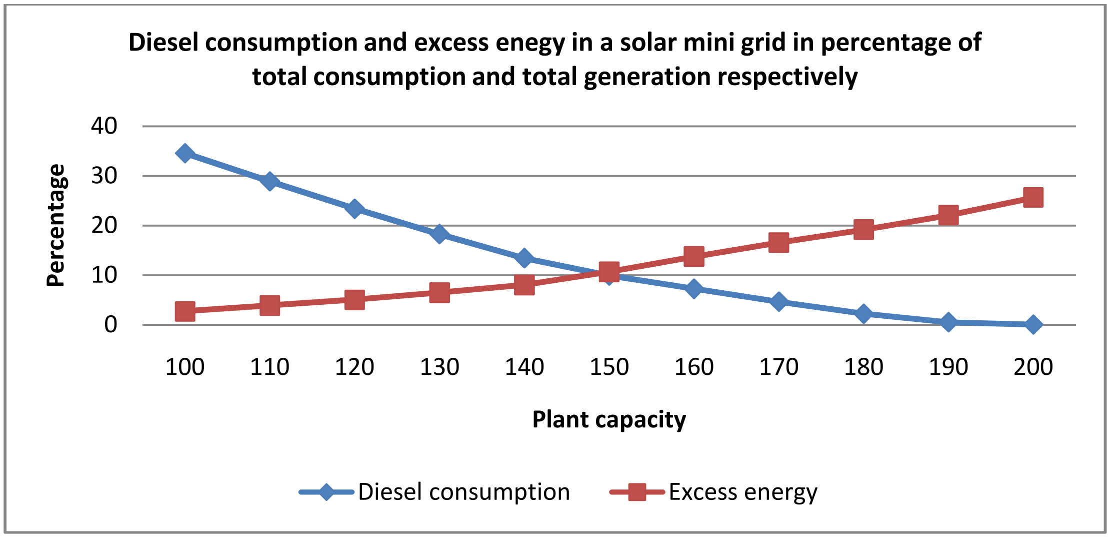
Table 4. Parameters with variation in system size.

Size [kWp]	Diesel consumption [% of total consumption]	Excess Energy [% of total generation]
100	34.60	2.73
110	28.93	3.91
120	23.39	5.05
130	18.27	6.49
140	13.42	8.02
150	9.93	10.68
160	7.23	13.76

170	4.64	16.56
180	2.19	19.17
190	0.49	22.10
200	0.02	25.64

The general assumption for selection of plant size is both diesel consumption and excess energy percentage should not be higher than 10%-15% of their respective reference. The graphical representation is given in Fig 2.

Fig 2: Diesel consumption (%) and excess energy (%) versus plant capacity (kWp)



The optimized size of the plant is between 140 to 150 kWp. Plant capacity at Paratoli was selected to be 141 kWp by the designer of the project. Taking battery efficiency and design into consideration, diesel consumption was found to be 16.14% of total consumption and excess energy was found to be 4.6% of total generation for 141 kWp Paratoli solar mini grid.

Battery Capacity Selection:

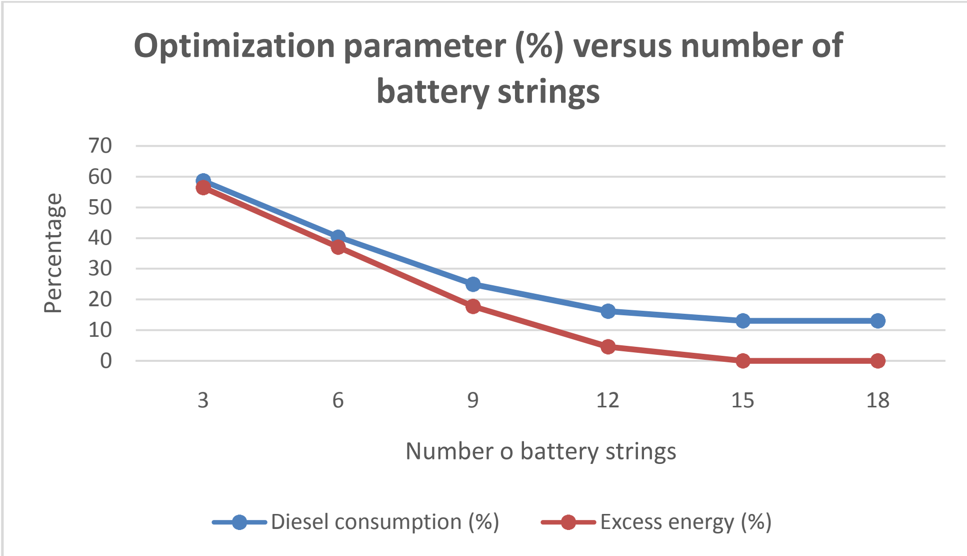
If battery size is changed the optimization parameters will also change. Normally, 24 batteries are connected in series to form 48 V DC bus. 24 batteries in series form one string of batteries. Changing battery requirement of the 141 kWp system, the output is shown in Table 5.

Table 5: Variation in diesel consumption (%) and excess energy with number of battery strings

Battery string	Energy storage kWh/day	Diesel consumption %	Excess Energy %
3	111	58.6	56.4
6	222	40.3	37.0
9	333	24.9	17.7
12	444	16.14	4.6
15	555	13.03	0
18	666	13.03	0

It is to be noted that the energy requirement at night time is 431 kWh. Hence, battery size should be selected in a way that stored energy is adequate to support the night load. Hence, a designer may choose between 12 or 15 strings. Since larger battery will mean more inverters and more space, twelve strings were selected for Paratoli project. Graphical representation of the calculation in Table 5 is shown in Fig 3.

Fig 3: Optimization parameter (%) versus number of battery strings



The results shown above indicate that, battery up to 15 strings will affect the parameters (for this particular case). If battery size is increased further, the performance of the plant will not improve rather will remain constant. The reason behind the result is that the night load will remain constant irrespective of the energy storage capacity. Hence, selection of battery strings is also one important feature to optimize the design.

Conclusion:

Optimization presented in this paper can be developed into a tool to find out the best way to design solar mini grids in Bangladesh. This can also be replicated in other countries with certain adjustments in parameters. Optimization in plant capacity will ensure minimum initial investment for the project implementing organizations while giving access to more people.

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