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KPI for Solar PV-diesel hybrid mini grids in remote islands of Bangladesh

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Abstract

Solar Photovoltaic (PV)-Diesel based hybrid mini grids are getting popular in Bangladesh in order to electrify remote rural areas i.e. islands. Grid quality electricity is provided to the poor people through these mini grids. Due to the high initial investment and associated risks, financial viability of the mini grids depends largely on the performance of the plant. Hence, a Key Performance Indicator (KPI) model is proposed for a mini grid to identify the overall performance of the plant. A mini grid project at Paratoli, Narsingdi, Bangladesh has been taken as a case study to validate the KPI model. Analysis from the data based on the KPI has also been done.

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Keywords: KPI, Solar PV, diesel, mini grid, Bangladesh.

1. Introduction

With global energy demand on the rise, Bangladesh, considered as a developing country, is facing challenges in ensuring access to electricity. It is reported that the global energy demand will rise up to 33% by 2020 where it will increase to approximately 218 billion megawatt (MW) with increase rate of 49% by 2035[1]. Bangladesh relies mostly on its natural resources e.g. natural gas, coal, for producing electricity. The main source of energy in Bangladesh is natural gas (24%) which is reported to be depleted by 2020 [2]. Hence, Bangladesh is trying to emphasize on renewable energy. With challenges like scarcity of usable land and high initial investment, Bangladesh government has a target to meet 10% of the total demand from

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renewable energy by 2020 [3]. According to the World Bank database [4], only 59.6% of the people in Bangladesh have access to electricity. Bangladesh is building necessary infrastructure to connect more people to the grid. 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 could be one of the solutions since possibility of grid expansion is remote in near future in such islands. Performance of these solar based mini grids depend upon many factors. References of work on Key Performance Indicators (KPIs) of solar mini grids are not available. Hence, development of KPI model for solar mini grids is necessary.

1.1. Solar mini grids in Bangladesh:

Solar PV based electrification projects with diesel generator as back-up have already been implemented in many countries around the world. Subsequent to the success of Solar Home System (SHS) program, Bangladesh is moving towards installation of Solar PV based mini grids in the rural off grid areas. The first solar mini grid of the country came into operation in 2011, a 100 kilo Watt peak (kWp) plant in Sandwip, an island in the south eastern coast of Bangladesh [5]. In Bangladesh, Solar PV based mini grid 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.

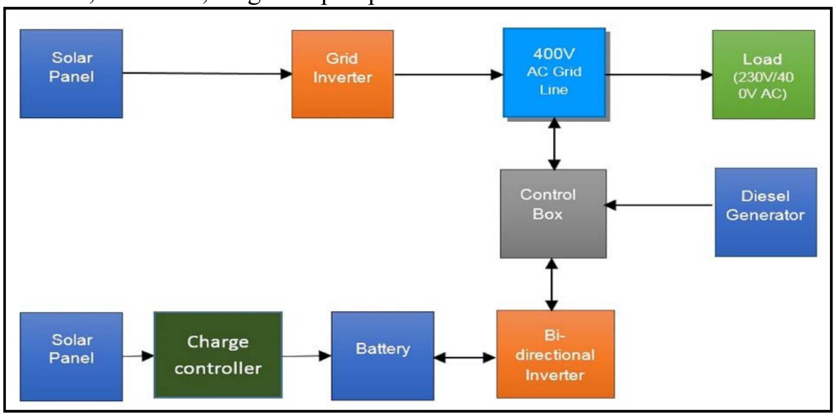

Figure 1: Process flow diagram of solar mini grids

Diesel generator is normally kept as back up for the rainy and foggy days when solar irradiation is inadequate. The process flow diagram of the solar a solar mini grid project is shown Figure 1. 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 night-time, AC output is generated through bidirectional inverters from the battery storage. Battery banks consist of 2V low maintenance lead acid type batteries, each of 1540 Ah capacity. Notably, electricity will be supplied to the customers at 230V (AC).

2. Proposed KPI model for solar mini grids:

A well-developed KPI model plays an essential role in ensuring required performance of any electricity generation project. Idea of solar mini grid is relatively new in Bangladesh. Hence, unlike traditional power plants, KPI model for solar mini grid is not available. Based on our experience with different stakeholders of mini grid project, we have identified most important factors to recognize how a solar mini grid plant is performing technically. Proposed KPI model includes capacity utilization factor (CUF), renewable energy-diesel ratio, percentage of targeted customers connected to grid, energy consumption per customer, percentage of maximum load in comparison with the estimated peak load, loss study , performance of major equipment i.e. panel, battery, inverter and generator. Explanation of each parameter is given below.

2.1. Capacity Utilization Factor:

Capacity utilization factor (CUF) is the single most important parameter to indicate overall performance of the plant. CUF can be defined as the ratio of actual annual energy consumption and estimated annual energy consumption from the plant.

2.2. Renewable Energy Fraction

Renewable energy fraction (REF) depicts the energy mix of consumption from the plant. Renewable energy fraction is the percentage of total energy consumption that is coming from the solar PV. Notably, the rest of the consumed energy is coming from the diesel. Solar PV based mini grids are designed to use renewable as the main source. In addition, frequent usage of diesel generator is challenging due to lack of transportation facilities to the remote islands and excess expenditure.

2.3. Load Estimation Factor

A solar mini grid is designed based on an estimated load profile. Peak load usually occurs during the summer season. In reality, value of peak load may differ from the estimated peak load. Load estimation factor will indicate the deviation from the estimation. This factor will also help project implementers to consider future expansion of the existing plant.

2.4. Customer Acquisition Factor:

Solar mini grid is designed keeping certain number of beneficiaries under consideration. Energy consumption grows with gradual acquisition of customers. Hence, a factor indicating status of customer acquisition is an important parameter. Implementing organization can have a better understanding of the target to achieve from this number.

2.5. Consumption Factor

Mini grids are developed assuming that the customers will use energy efficient appliances; otherwise the monthly bill will not match with their affordability. However, in reality, customers are reluctant to use energy efficient appliances. Hence, a factor which can reveal, how much energy per customer is consuming compared to the assumed one, will help the implementing organization to understand why the plant has not been able to perform financially and also why targeted customers could not avail electricity from the plant.

2.6. Voltage Drop Factor:

Voltage should be measured from the energy meter of the last customer of each feeder under the mini grid and compared against 230V AC. As per Rural Electrification Board (REB), Bangladesh, allowable voltage drop is 4-5%. Voltage drop factor should be near to 1 and this will indicate losses in overhead conductors.

2.7. Panel Performance Factor:

PV modules are the main components of the mini grid and if PV modules perform poorly, it is going to affect the overall plant performance. However, panel performance will depend largely on the solar irradiance (W/m^2) on a particular day. Assumed energy generation from the PV plant is dependent upon several factors i.e. solar irradiance, temperature, soiling. Panel performance factor can be defined as the ratio of the measured generation from the solar panels and expected generation from the solar panels, given that the solar irradiance is considered to be the same for both the cases.

$$PPF = E_i / (P \times Ir \times \eta) \tag{1}$$

Where, PPF= PV performance factor
E_i= Annual/Monthly/Daily generation of electricity from the solar panels (kilo Watt Hour or kWh)
P= Plant capacity or capacity of panel in Kilo watt peak (kWp)
Ir=Annual/Monthly/Daily average solar irradiance
η= Efficiency of system (from panel to inverter side)

Efficiency is considered to be 90% during the design of the system. This factor can be calculated daily, monthly or annually based on the requirement.

2.8. Inverter Efficiency Factor:

DC electricity is converted to AC electricity through inverters. If the inverters are not converting the electricity efficiently, there will be unnecessary losses. Inverter efficiency factor is simply ratio between the output and input of the inverters. Implementer can calculate this factor for each of the inverters to find out any weak or faulty equipment. However, average for all the inverters will also indicate the overall performance of the inverters.

2.9. Battery Performance Factor:

Measurement techniques to understand battery performance have been developed. The most feasible of them is to measure the DC resistance during the commissioning and finding out the deviation from that. It is reported by Gunnar Heldand [6] that a deviation by more than 25% indicates poor condition of the battery cell. It is hard to comment on the residual capacity only from this deviation, but this deviation can be a good indicator to find out the state of health of batteries. Reference value of DC resistance should be measured during the commissioning. If the DC resistance has increased by more than 25% from the reference value, then further testing is needed. Battery resistances should be measured during night time when the batteries are discharging. This factor can be measured in cell or string level or for all the batteries.

2.10. Generator Performance Factor:

Generator performance factor will indicate how effectively the diesel has been used to convert into electricity. If fuel consumption per kWh of electricity is higher than the initial assumption, then this factor will indicate inefficiency of the generator set.

3. Case Study:

Shouro Bangla Ltd., established a 141 kWp of solar mini grid with a 60 kVA diesel generator in Paratoli Island in Narsingdi, Bangladesh under financing of Infrastructure Development Company Limited

(IDCOL), Bangladesh. This project has been commercially running from December, 2014. This project has been selected for collecting data to validate the proposed KPI model.

3.1. Panel, Battery and Inverter performance factors:

In order to assess the quality of the panels, those connected to Grid Tied Inverters (GTIs) were considered. Data were taken from 8 March, 2016 to 14 March, 2016. Panel performance factor of PV modules are shown in Table 1.From Table 1, average PPF of the panels are 0.95 which is satisfactory considering the losses due to dusts and temperature. Notably, solar irradiation data was taken from on-site pyranometer. As far as battery is concerned, there was no reference DC resistance value to compare with. Data of all 12 battery strings (each having 24 batteries) were measured from 13 October, 2015 to 19 October, 2015, at 6:00 pm each day. String DC resistances were measured. Average DC resistance of 7 days was taken as the reference value for each string. Deviation from this was calculated and shown as BPF. Findings are shown in Table 2.

Table 1: Panel Performance Indicators

Panels considered	14 March 2016	13 March 2016	12 March 2016	11 March 2016	10 March 2016	9 March 2016	8 March 2016	Average PPF
GTI No 1	1.01	1.04	1.01	1.02	1.03	0.96	0.97	1.01
GTI No 2	0.90	0.92	0.91	0.93	0.92	0.89	0.88	0.91
GTI No 3	0.99	1.02	0.99	0.99	1.01	0.95	0.96	0.99
GTI No 4	0.89	0.92	0.92	0.95	0.96	0.85	0.90	0.91
GTI No 5	0.95	0.99	0.95	0.96	0.98	0.92	0.92	0.95
GTI No 6	0.96	0.99	0.95	0.97	0.97	0.92	0.92	0.95
Total	0.95	0.98	0.95	0.97	0.98	0.91	0.93	0.95

Table 2: Battery Performance Factor

Date	String 1	String 2	String 3	String 4	String 5	String 6	String 7	String 8	String 9	String 10	String 11	String 12
13-10-15	1.00	1.01	1.04	1.03	1.08	1.09	1.12	0.96	0.92	0.93	1.12	1.04
14-10-15	1.28	1.31	1.31	1.24	1.32	1.40	1.26	1.24	1.25	1.17	1.21	1.25
15-10-15	1.07	1.07	1.06	1.08	1.07	1.08	1.11	1.10	1.12	1.04	1.05	1.08
16-10-15	0.87	0.82	0.81	0.83	0.67	0.67	0.87	0.85	0.85	0.80	0.87	0.77
17-10-15	0.91	0.96	0.96	0.98	0.96	0.94	1.00	0.98	0.99	1.31	0.89	0.96
18-10-15	0.89	0.87	0.88	0.89	0.90	0.87	0.85	0.89	0.90	0.82	0.88	0.89
19-10-15	0.99	0.95	0.94	0.95	0.99	0.95	0.78	0.97	0.98	0.92	0.98	1.01

It was discussed earlier that, 25% increase in resistance is acceptable. Keeping this in mind, it seems that most of the batteries have performed well in all 7 days except 14 October, 2015. However, since battery reference DC resistance values are not available, it is not possible to comment on state of health of batteries. Inverter efficiency was measured from instantaneous data of inverters. This efficiency will work as Inverter Performance Factor (IPF). Findings from the measurement are given below in Table 3.

Table 3: Inverter Performance Factor

Time	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	Average
GTI 1	0.97	0.95	1.01	0.97	0.95	0.94	0.92	0.79	0.83	1.05	0.89	0.93
GTI 2	1.04	1.37	1.44	0.96	0.90	0.92	0.76	0.73	0.89	0.88	1.13	1.00
GTI 3	0.74	0.63	1.01	0.97	0.94	0.96	0.73	0.70	0.80	0.77	1.14	0.85
GTI 4	0.76	0.87	0.94	0.96	0.98	1.01	1.93	1.60	1.59	1.04	1.13	1.16
GTI 5	0.85	0.81	0.91	0.92	0.96	1.01	0.99	1.11	0.86	0.66	1.12	0.93
GTI 6	1.02	0.94	0.93	1.00	0.97	0.94	0.85	0.58	0.98	0.63	1.14	0.90

Other performance indicators have also been calculated which are as follows in Table 4.

Table 4: Other KPIs

Indicator	Value	Indicator	Value
Capacity Utilization Factor	0.43	Voltage Drop Factor	0.97
REF	0.97	Consumption Factor	1.25
Load Estimation Factor	0.87	Customer Acquisition Factor	0.70

4. Conclusion

A KPI model has been proposed in this paper which can provide indication on how the plant is working technically. However, this model needs further development and validation from field data. Solar mini grids are different from conventional power plants in many ways. Hence, a technical KPI model is necessary for project implementing organizations. A financial KPI model can also be developed from this model, which may include levelized cost of energy (LCOE) and other financial parameters.

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