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Modelling, Optimization and Cost Analysis of Grid Connected Solar-Battery System for Tripura University Campus

Somudeep Bhattacharjee[1], Samrat Chakraborty[2], Brahma Nand Thakur[3] and Mir Sahidul Ali[4]

[1,2]Department of Electrical Engineering, Tripura University, Agartala, Tripura 799022, India

[3]Department of Electrical & Electronics Engineering, Bhilai Institute of Technology, Durg, Chhattisgarh 491001, India

[4]Department of Chemical & Polymer Engineering, Tripura University, Agartala, Tripura 799022, India

Abstract

Global warming, climate change and pollution are the dangers and threats which the human society is facing currently. Government of every country is trying hard to reduce all these dangers by embracing renewable and non-conventional energy. This paper aims in modelling and optimizing a grid connected solar-battery system for Tripura University Campus. The optimization results are compared first as grid connected solar system and then as grid connected solar-battery system. The modelling and optimization of the system is done by using HOMER Pro® software. Optimization result shows that the hybrid model can satisfy the total load demand of the Tripura University Campus, Agartala, India taking some power from grid with a very low levelized cost.

Keywords: *Solar, Grid, Optimization, Cost, HOMER Pro® Software.*

1. Introduction

Electricity is one of the most important aspect and fundamental part in our day to day life. With the increase in population all around the globe, the urge for electricity is increased. Then the question is all about how to generate clean and green energy. Although the present convention of generating electricity across the globe is generally from renewable and non-conventional resources, but developing countries like India still generates electricity on a large scale from conventional energy. This paper mainly deals with modelling and optimizing a solar-battery system for Tripura University Campus which can easily supply the load demand of the full campus. It is very much known to us that conventional energy produce lots of pollution to the environment, therefore through this paper we have tried to model a system that can produces less pollution and can make the Tripura University campus a green campus.

Various research works has been carried out in modelling hybrid systems which can produce much less pollution and can efficiently replace the conventional way of electricity generation. An off-grid solar-wind hybrid system is proposed in (Khan, 2017) for a University campus in Pakistan which will work during unavailability of power supply or during the load shedding scenario. The designed model for the University campus has a very low Cost of Energy (COE) and Net Present Cost (NPC). In (Zebraoui, 2016) authors proposed an off-grid based PV-wind-battery hybrid system for three areas of Morocco which easily satisfies the load of those areas. The result also indicates that hybrid system can only be applied when there is appreciable amount of resources available. In (Bhattacharjee, 2018) authors proposed both autonomous and grid connected solar-wind-biomass hybrid system for Nakalawaka, Fiji. The optimization result shows that hybrid model can easily satisfy the load and moreover the grid connected mode is highly profitable that autonomous mode if compared with levelized Cost of Energy (COE) and Net Present Cost (NPC). In (Rey, 2017) authors proposed an autonomous solar-wind-hydro based hybrid power plant Calayan Island, Cagayan. The optimization result shows that solar-wind-hydro along with diesel generator (DG) and battery when used all together, have COE and NPC with the highest percentage of renewable resources utilized. In (Hutapea, 2017) authors proposed a PV-generator-battery based hybrid energy system for Aha Village, Morotai Island, North Maluku. Here, the authors have considered two types of loads for the village i.e. communal and administrative. The optimization result shows that the proposed hybrid model can easily satisfy both two types of load in Aha Village. In (Kumari, 2017) authors proposed a PV-wind-diesel-battery system for Perumal Kovilpathy, Tamil Nadu. The optimization result shows that the combination of PV-diesel-battery is the most economical and not only that, the emission is also very low.

The Campus of Tripura University faces regular power-cut for at least 5-6 hours a day. On the other hand the solar energy resource of the Campus is quiet significant. The paper aims in designing and optimizing a grid connected Solar-Battery system for the whole campus so that the problems of regular power-cut can be reduced and the Campus can become a Green Campus.

2. Description of the System Data

The solar-battery system has been designed by using HOMER (Hybrid Optimization of Multiple Energy Resources) Pro® software. In order to optimize the system, we have to put the load data of that area and also the natural resources data. The solar resource data has been taken from NASA Prediction of Worldwide Energy Resources (power.larc.nasa.gov, 2018)

2.1 Load Data Information

The average annual load of Tripura University Campus is 132,226.90 kWh/day. This data is taken from the Sub Station inside the University Campus owned by Tripura State Electricity Corporation Limited (TSECL), Government of Tripura. Figure 1 indicates the hourly load profile on daily basis where it is seen that the load demand is almost same at every hour of a day and the average hourly load is nearly 5,509.4 kW. Figure 2 shows the monthly load profile where it is seen that the highest load is about 10,096 kW at the month of March.

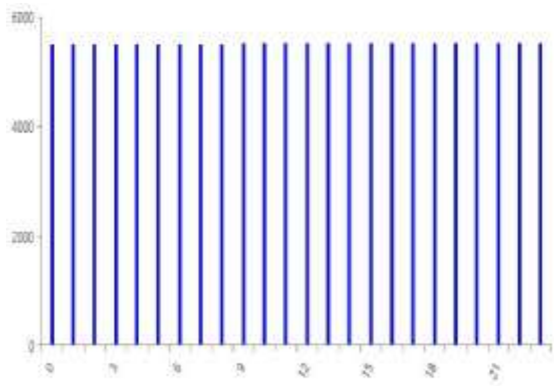

Fig. 1 Hourly Load Profile of Tripura University Campus.

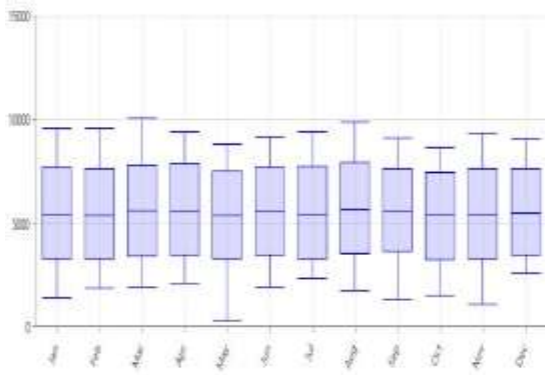

Fig. 2 Monthly Load Profile of Tripura University Campus.

2.2Solar Radiation Data

The latitude and longitude of the Tripura University Campus is 23°45.7´ N and 91°15.9´ E which is found out by using HOMER Pro® software. Figure 3 shows the average solar radiation data of every month. The average of annual solar radiation is 4.64 kWh/m^2/day. Daily radiation ranges from 4.10 kWh/m^2/day to 5.59 kWh/m^2/day. The month of March has the highest solar radiation while the month of September has the lowest.

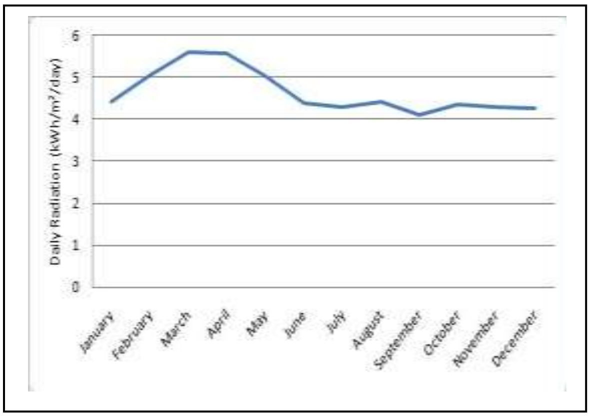

Fig. 3 Average Solar Radiation for Every Month of Tripura University Campus (power.larc.nasa.gov, 2018).

3. Methodology

3.1 HOMER Pro® Software in Brief

HOMER software was first designed by Dr. Peter Lilienthal in NERL Laboratory of USA. Soon after in 2014 the software was developed into HOMER Pro® (homerenergy.com, 2018). Using this software we can model, optimize and analyze an integrated energy system which mainly uses non-conventional and renewable resources. The modelling, optimization and analysis can be done both for grid connected and autonomous system. The software can optimize the cost of the system very well taking all the factors into account.

3.2 Cost Calculation Technique by HOMER Pro® Software

Net Present Cost

The net present cost or NPC consists of installation cost and operating cost of the system throughout its lifetime which is calculated by the following formulae (Nurunnabi, 2015):

$$NPC=TAC/CRF(i,Rpr_j) \quad \text{Eq. (1)}$$

Here, TAC indicates total annualized cost in terms of \$, CRF indicates capital recovery factor, i indicates the rate of interest in terms of % and Rpr_j indicates the project life time in terms of year.

Total Annualized Cost

The total annualized cost comprises of the addition of the cost of all equipment used in power system which comprises of capital cost, operation cost, maintenance cost, replacement and fuel cost calculated annually (Nurunnabi, 2015).

Capital Recovery Factor

The Capital Recovery Factor also known as CRF calculates the series of cash flow annually in ratio with respect to the present value (Nurunnabi, 2015).

$$\mathrm{CRF} = \frac{i\times(1+i)^n}{(1+i)^{n-1}} \quad \text{Eq. (2)}$$

Here, n indicate the years and i indicate the rate for real interest annually.

Annual Real Interest Rate

The Annual Real Interest Rate represents the nominal interest rate as a function (Nurunnabi, 2015).

$$i = \frac{i'-F}{1+F} \quad \text{Eq. (3)}$$

Here, i indicate the real interest rate, i' indicate nominal interest rate and F indicate annual inflation rate.

Cost of Energy

The Cost of Energy also known as COE represents the average cost/kWh of the system producing electrical energy which is useful in practice. The calculative formula for COE is as follows (Nurunnabi, 2015):

$$COE = \frac{TAC}{L_{prim,AC}+L_{prim,DC}} \quad \text{Eq. (4)}$$

Here, $L_{prim,AC}$ indicate primary AC load and $L_{prim,DC}$ indicate the primary DC load.

4. System Model Description

The system has been designed and modeled by using different parts from HOMER Pro® software. In this model we have used PV system, battery, converter and grid. Figure 4 shows the system model for Tripura University Campus.

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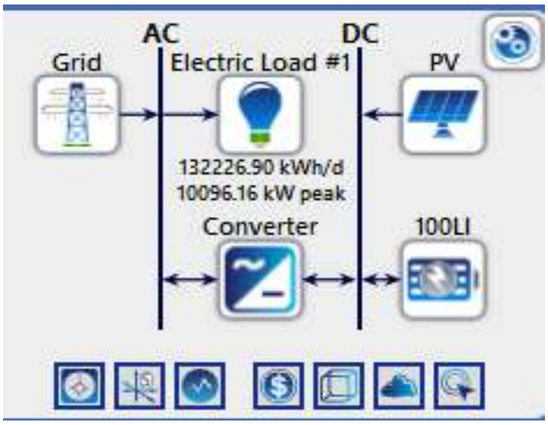

Fig. 4 Grid Connected PV-Battery System for Tripura University Campus.

PV System

In this paper, Generic flat plate PV is used. The rated capacity of the flat plate PV is 18000 kW with its working temperature to be 47°C. The Maximum Power Point Tracker (MPPT) of the PV is 20000 kW. The capital cost of the PV system is $ 70.00 and operation & management cost is $ 10.00/year. The effectiveness is 13% with its life time of about 15 years.

Battery

Here, 100 kWh Li-Ion battery manufacture by Generic has been used. Its nominal capacity and voltage are 100 kWh and 600 V respectively. The throughput of the battery is 300,000 kWh and the lifetime is 15 years. The capital cost and operation & management cost are $ 800 and $ 200/year respectively.

Converter

The converter used here is manufactured by Generic. Its size is about 21000 kW. The capital cost of the converter is $300 with a null operation & management cost. The lifespan of the converter is 15 years with efficiency of about 95%.

5. Optimization Result

In this paper optimization result has been compared on basis of two conditions. In first case, the combination of only grid connected solar PV and in second case grid connected solar-battery system. The two scenarios are seen in Figure 5.

Architecture						Cost				System	
PV (kW)	PV-MPPT (kW)	100LI	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
18,000	20,000		999,999	21,000	CC	$0.0576	$43.2M	$2.33M	$13.1M	47.2	0
18,000	20,000	1,323	999,999	21,000	LF	$0.0656	$48.5M	$2.66M	$14.2M	47.1	0

Fig. 5 Optimization Result for Tripura University Campus.

5.1 Optimization Result for Grid Connected Solar Scenario

In figure 5 optimization result for grid connected PV scenario can be seen, where the levelized COE is only $ 0.0576 and the NPC is $ 43.2M. The fraction of renewable energy used is 47.2%. Figure 6 shows the net present cost and Figure 7 shows the annualized cost. Table 1 shows the production summary data and Table 2 shows the consumption summary data. The Generic flat plate PV production is 28,826,249 kWh/year and the AC load demand is 48,262,817 kWh/year. This shows that the renewable energy can satisfy easily half percentage of the load demand. Figure 8 shows the Summary plot between grid purchase and grid sales. Figure 9 shows the plot between global solar input and the flat plate PV output.

5.1 Optimization Result for Grid Connected solar-battery Scenario

In figure 5 optimization result for grid connected solar-battery scenario can be seen, where the levelized COE is only $ 0.0656 and the NPC is $ 48.5M. The fraction of renewable energy used is 47.1%. Figure 10 shows the net present cost and Figure 11 shows the annualized cost. Table 3 shows the production and

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Table 4 shows the consumption summary data. Figure 12 shows the plot between grid purchase and grid sales. Figure 13 shows the state of charge of battery in percentage.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic Flat Plate PV	$5.40M	$4.65M	$0.00	$0.00	$0.00	$10.1M
Grid	$7.15	$20.2M	$0.00	$0.00	$0.00	$20.2M
PV Dedicated Converter	$1.40M	$2.59M	$593,983	-$111,794	$0.00	$4.47M
System Converter	$6.30M	$0.00	$2.67M	-$503,071	$0.00	$8.47M
System	$13.1M	$27.5M	$3.27M	-$614,865	$0.00	$43.2M

Fig. 6 Net Present Cost of Grid Connected Solar for Tripura University Campus.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic Flat Plate PV	$417,714	$360,000	$0.00	$0.00	$0.00	$777,714
Grid	$0.553	$1.57M	$0.00	$0.00	$0.00	$1.57M
PV Dedicated Converter	$108,296	$200,000	$45,947	-$8,648	$0.00	$345,596
System Converter	$487,333	$0.00	$206,762	-$38,915	$0.00	$655,810
System	$1.01M	$2.13M	$252,710	-$47,563	$0.00	$3.34M

Fig. 7 Annualized Cost of Grid Connected Solar PV for Tripura University Campus.

Table 1: Production Summary Data of Grid Connected Solar PV for Tripura University Campus

Component	Production (kWh/year)	Percent
Generic flat plate PV	28,826,249	48.4
Grid Purchases	30,695,162	51.6
Total	59,521,410	100

Table 2: Consumption Summary Data of Grid Connected Solar PV for Tripura University Campus

Component	Consumption (kWh/year)	Percent
AC Primary Load	48,262,817	83.1
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	9,817,281	16.9
Total	58,080,098	100

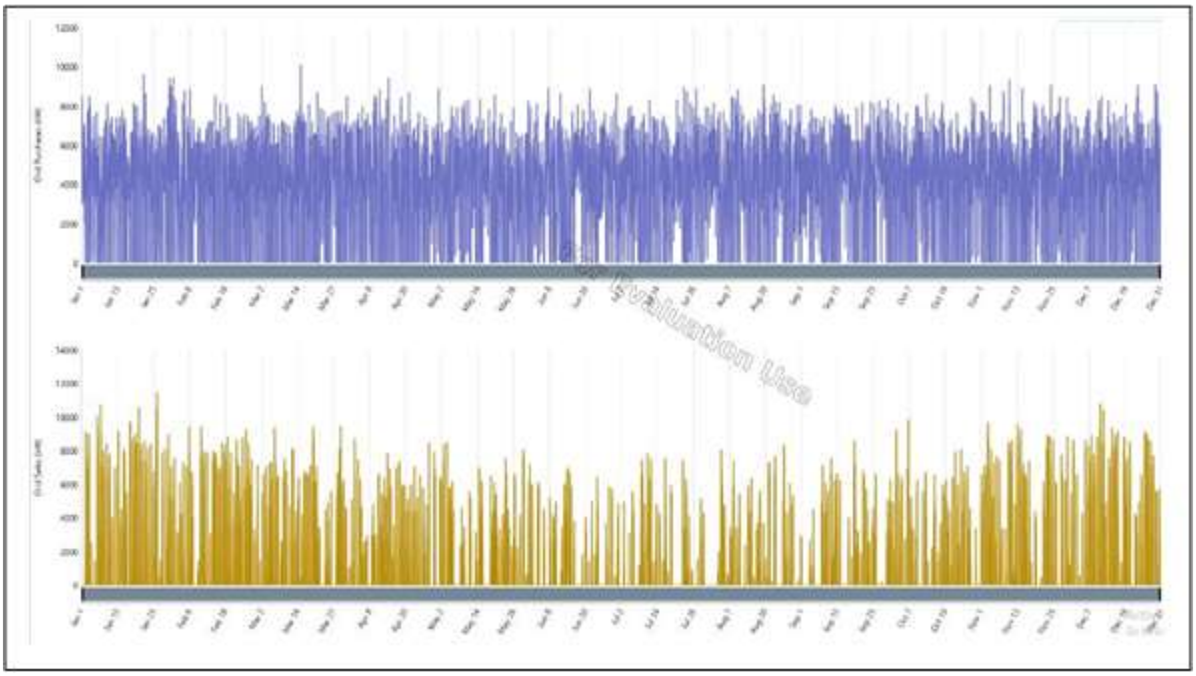

Fig. 8 Plot between Grid Purchases (kW) and Grid Sales (kW) of Grid Connected Solar PV for Tripura University Campus.

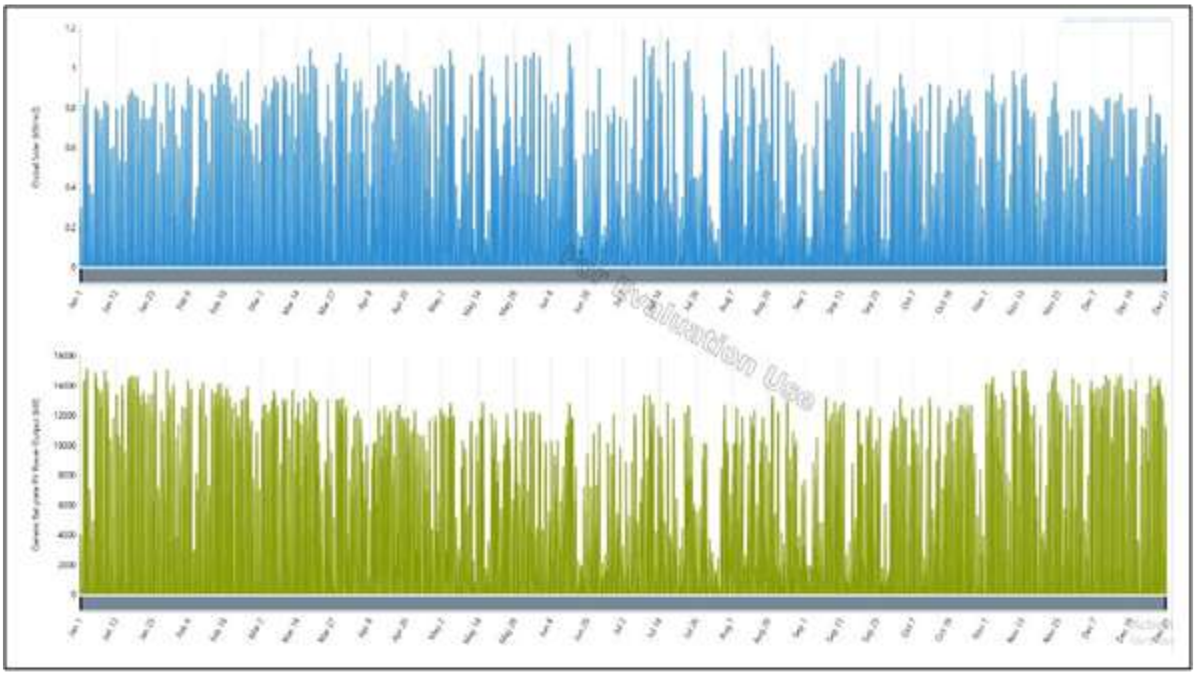

Fig. 9 Plot between Global Solar (kW/m^2) and Generic Flat Plate PV Power Output (kW) of Grid Connected Solar PV for Tripura University Campus.

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Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 100kWh Li-Ion	$1.06M	$3.42M	$449,051	-$84,516	$0.00	$4.84M
Generic Flat Plate PV	$5.40M	$4.65M	$0.00	$0.00	$0.00	$10.1M
Grid	$7.15	$20.7M	$0.00	$0.00	$0.00	$20.7M
PV Dedicated Converter	$1.40M	$2.59M	$593,983	-$111,794	$0.00	$4.47M
System Converter	$6.30M	$0.00	$2.67M	-$503,071	$0.00	$8.47M
System	$14.2M	$31.3M	$3.72M	-$699,381	$0.00	$48.5M

Fig. 10 Net Present Cost of Grid Connected Solar-Battery system for Tripura University Campus.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 100kWh Li-Ion	$81,872	$264,600	$34,736	-$6,538	$0.00	$374,670
Generic Flat Plate PV	$417,714	$360,000	$0.00	$0.00	$0.00	$777,714
Grid	$0.553	$1.60M	$0.00	$0.00	$0.00	$1.60M
PV Dedicated Converter	$108,296	$200,000	$45,947	-$8,648	$0.00	$345,596
System Converter	$487,333	$0.00	$206,762	-$38,915	$0.00	$655,180
System	$1.10M	$2.42M	$287,446	-$54,100	$0.00	$3.75M

Fig. 11 Annualized Cost of Grid Connected Solar-Battery System for Tripura University Campus.

Table 3: Production Summary Data of Grid Connected Solar-Battery System for Tripura University Campus

Component	**Production (kWh/year)**	**Percent**
Generic flat plate PV	28,826,249	48.8
Grid Purchases	30,253,141	51.2
Total	59,079,389	100

Table 4: Consumption Summary Data of Grid Connected Solar-Battery System for Tripura University Campus

Component	**Consumption (kWh/year)**	**Percent**
AC Primary Load	48,262,817	84.4
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	8,935,052	15.6
Total	57,197,869	100

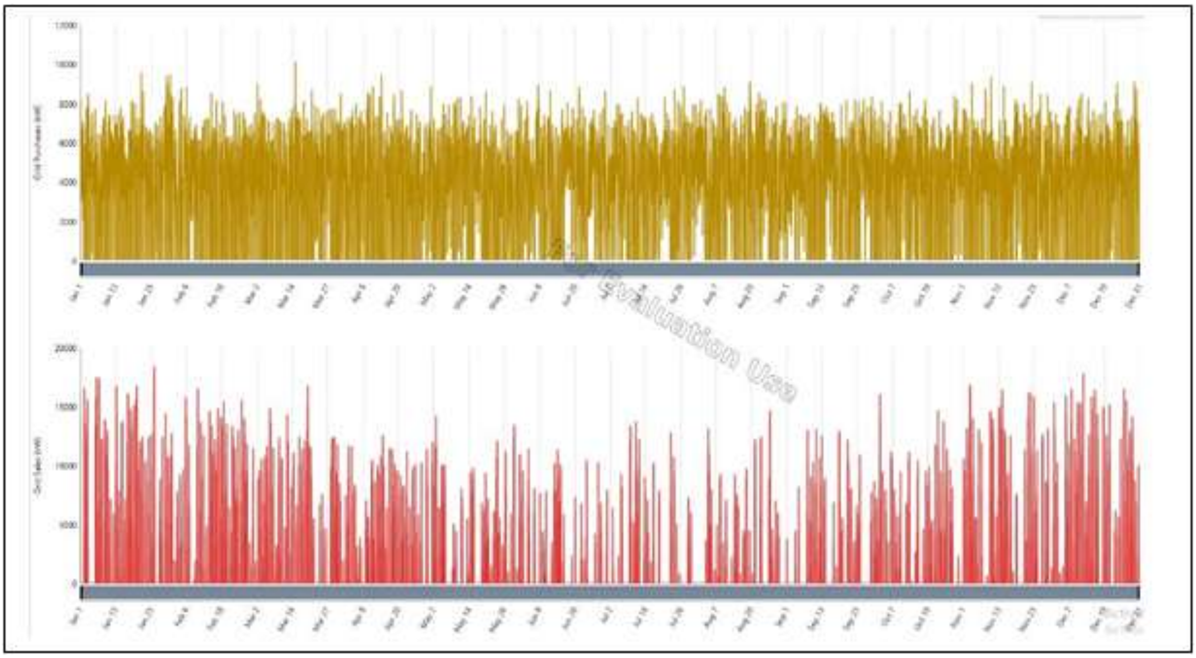

Fig. 12 Plot between Grid Purchases (kW) and Grid Sales (kW) of Grid Connected Solar-Battery System for Tripura University Campus.

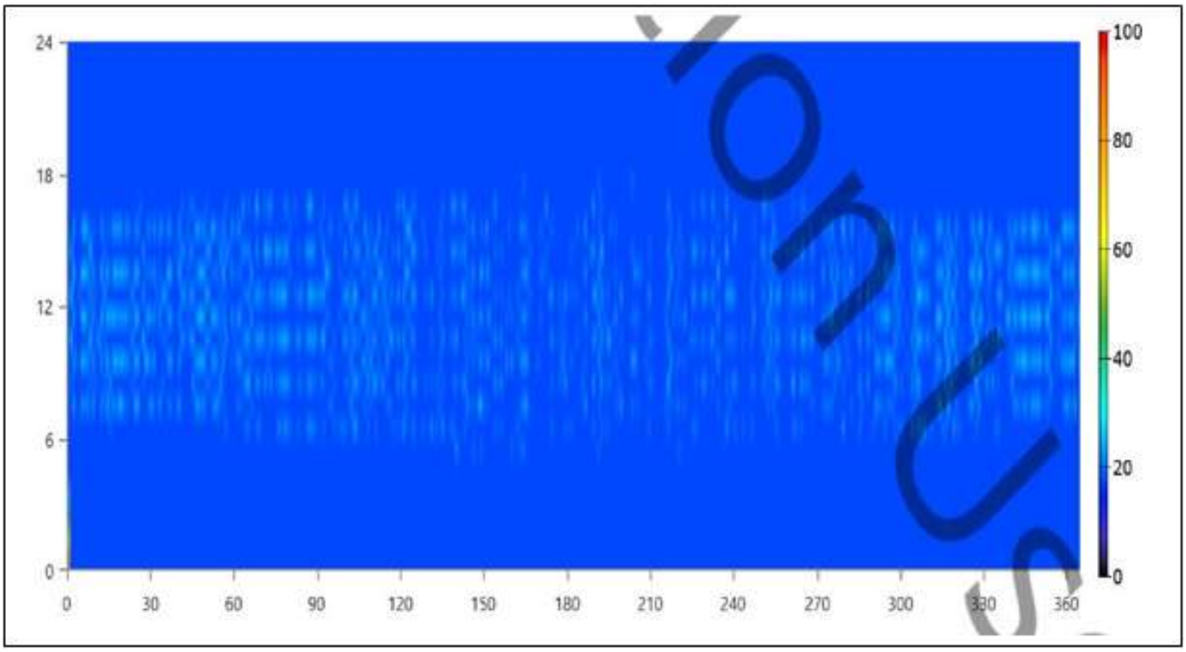

Fig. 13 Generic 100kWh Li-Ion Battery State of Charge (%) of Grid Connected Solar-Battery System for Tripura University Campus.

6. Conclusion

From this case study work about Tripura University Campus it can be concluded that grid connected Solar energy system is much more profitable that grid connected Solar-Battery system in terms of both NPC and renewable energy percentage. In both the cases, grid sales is between 14%-16%, which implies that the system not only purchase power from the grid but also sales power to the grid. In grid connected Solar energy system it is true that cost is low but on the other hand, solar power is only available for day time and at night grid is the main source for power. If grid fails, then the whole University Campus will be powerless. On the other hand in case of grid connected Solar-Battery system, in case of grid failure the battery will give the backup for the time being. So, grid connected Solar-Battery system is much more preferred.

Tripura University Campus have four hostels, six staff quarters, two guest houses, one building for Vice Chancellor's residence and three canteen. So, on a daily basis huge amount of vegetative waste is generated from these buildings. If taken into account from these wastes huge amount of biomass can be generated. The research work can be further extended by adding biomass generator as a backup with the grid connected Solar-Battery system.

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