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OPTIMIZATION OF UTILITY SCALE ON GRID SOLAR PV WITH CAPTIVE POWER PLANT

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ABSTRACT
Solar PV is the most famous renewable energy. Due to its popularity and various promotional schemes by government, the solar PV is frequently used in synchronization with state utility. This creates a power pool in which the user can draw required quantity of power & can pump back the surplus power into the grid (if any). The main aim of this paper is to optimize the load sharing of captive generator and solar PV in the event of grid failure. The Captive plants installed at distribution network under consideration shares the load with solar PV, which in turn reduces the efficiency of the captive plant. The reliability of the distribution network is also seeming to be at stake during such situations. During this study we consider the load data & Solar PV generation data of the distribution network of some particular area. This data is then simulated in HOMER Software to optimize the cost of power generation from Solar & Captive plant both. The future perspective, method of improvement and area of implementation is suggested after completion of this study.
Keywords: Solar PV; utility Grid; Distribution network; renewable energy; HOMER software.

I. INTRODUCTION

Solar power plants are the most popular distributed generators now a days. By providing various types of subsidies, the governments are also promoting solar plants to fulfil their commitments to reduce greenhouse gases. The installation of solar plant purely depends on the requirement of power, available area, average insolation availability and financial strength of the user. The solar plant up to 10kW capacity falls under small scale plants. The solar plant between ranges of 10-1000 kW capacity falls under medium scale plants and the solar plant above 1MW capacity falls under utility scale power plant.

The integration of these power plants with power grid also depends on the scale of the plant & type of site. For example, a utility scale solar power plant in a remote area will directly inject the power into the nearest available point at the grid after stepping up the voltage level to required level of the grid voltage (above 11kV) and the same plant in some residential building or institutional building will directly inject the power in to local grid (up to 440V) to utilize the same there only. While injecting the power in the grid directly, the power goes into a power pool where anybody can utilize it without knowing the actual source of the power whereas in the local grid the power is being utilized locally & only surplus power is pumped back to the grid. In this thesis, we will work on an on-grid utility scale solar plant feeding a local area & having an option to inject the surplus power into the grid. This phenomenon of reverse power flow to the grid depends on the capacity of the plant and the consumption profile of the locality where solar panels are installed.

Utility Grid Solar PV

A utility scale grid connected & grid synchronizing solar PV system requires a reference voltage from the grid to synchronize itself with grid. After synchronizing only it is able to inject power in the grid.

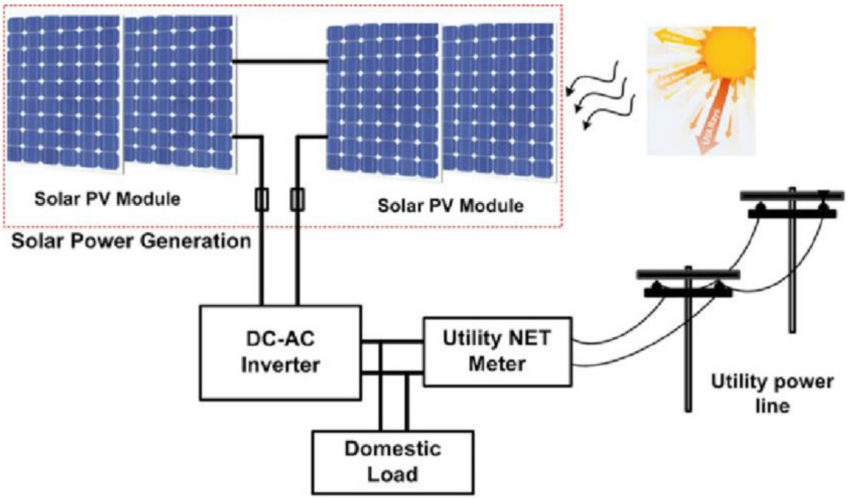

Fig. 1 Grid connected PV System

Generally, the capacity of solar PV installed at any premises is equal to the contracted demand of the premises with the distribution company. However, it may be more than that of contracted demands in some cases. In Fig.1, the solar PV & Grid supply works in synchronization to cater the load on the load bus. During the grid power failure, the captive power (diesel generator) caters the load along with solar PV. All the circuit breakers are electrically & mechanically interlocked so that in any case there is only on supply on the load bus (i.e. either from Grid or from Captive power). The Solar PV will synchronize itself with any voltage available on the load bus.

Now, the modes of operation of solar PV depending on the source of power are as follows: -

1. **Grid Only**: - In case solar PV is not generating power, then the Grid will cater the full load of the system independently.
2. **Grid & Solar PV in Synchronization**: - This is normal mode of operation of any system. Both solar PV & grid power will share the load of the load bus depending on their capacity & load requirements.
3. **Solar PV Only: -** In reference to IEEE 929 standard, if the voltage is not available on the point where the solar power is being injected, then solar PV will isolate itself from the grid till unavailability of voltage. This prevents reverse power flow to the grid and enhances the safety if some maintenance work is being carried out on the feeders.
4. **Captive Power & Solar PV in synchronization: -** In the event of grid power failure, the diesel generator caters the load. Now, after sensing the bus voltage solar PV starts operating in synchronization mode. Being a static device, the power generation in solar PV cannot be controlled by conventional methods of generation. So the solar operates on its full efficiency by catering as much power load as it can. Then rest of the load is being catered by the captive power generator (diesel generator). The diesel engine controls the load by controlling the amount of fuel being injected for power generation. So in this case solar is operating on almost constant load & diesel generator keeps on changing the load demand as per the requirement of load bus.

Objectives of the Study

The main objective is to integrate the existing captive generation system with existing solar PV in a manner to optimize power generation from both i.e. Solar PV & Diesel Generators. However, we can further divide the main objective into three sub-objectives:

- Simulation by combining the Diesel Generator & Solar PV system components.

- Optimize the power generation from Diesel Generators & Solar PV.
- Optimize the cost of power generation from Diesel Generators & Solar PV.

II. LITERATURE REVIEW

In present scenario, the grid connected solar PV in encountering so many problems ranging from power quality issues to grid synchronization. In my work, the problems encountered with grid connected solar in case of grid failure will be discussed. To understand the same a no. of literature was surveyed & the reviews of the same are given below.

The challenges faced during the integration of solar PV-DG are studied on utility scale solar PV. The impact on the system due to reverse power flow, voltage rise, voltage fluctuation, reactive power fluctuation, interaction with capacitors & their steady state analysis are discussed [1]. The author considers various situations like power factor changing, changing set points of voltage regulators, fast overloading & discuss the case specific solution of each problem in dynamic analysis. Whereas some discussed the power quality events associated with grid connected solar using discrete wavelet transforms. The simulation results after considering cases of outage of solar PV, Grid synchronization of solar PV & sudden change of insolation level are studied & the identified THD for corresponding case is represented.

The author presents technical & commercial parameters of an off grid renewable energy system for electrification of remote area [2]. The optimization of available resources of power i.e. Solar PV, micro hydro, wind turbine and battery storage is carried out by using HOMER. The estimated annual energy production along with their option wise cost of production & operation and maintenance is also discussed to adopt the best possible option for the remote area.

The synchronization of solar PV with local grid & battery power is being analysed for a domestic load. The load demands for DC & AC are considered separately & the scenario is simulated in MATLAB environment to achieve a smart power system for domestic purpose [3].

The independent solar PV based electric vehicle charging station with battery as power storage medium is discussed. As the power from solar PV is fluctuating due to its dependency on the insolation, the use of energy storage device will regulate the power required for charging the EV. The use of battery as energy storage device reduces the dependency of the EV charging system on electrical grid. The charging of battery can be carried out even if the power from solar PV is not available. The results are simulated in MATLAB to depict the state of charging & discharging of battery (used as energy storage device) which will further charge the battery of electrical vehicle [4].

The author discussed a domestic solar plant in which the surplus power is used for charging a battery of electric vehicle instead of feeding it back to the grid. The house hold load is considered as primary load. After completing the demand of house hold load, the surplus power supplied to EV battery & further surplus power will be discarded. Also, the load of household & generation of the solar PV is forecasted depending on which the surplus power available for electric vehicle charging is forecasted [5].

A detailed analysis of auto synchronization of solar PV with grid is discussed. The variation in parameters like load, frequency fluctuation, phase angle difference between grid and solar PV are simulated to ensure stability, reliability & power quality as per IEEE 929 standard. The islanding issue has also been addressed & results are verified to meets out required standards of Utility-Solar PV interconnection [6].

III. RESEARCH METHODOLOGY

Method

The Methodology adopted for this project is described in following steps.

a) A detailed data of load on various feeders at Amity University – Noida was collected.
b) With this collected data, feeder wise load profile is prepared. This gives an idea about the load on the feeder on various days & various time zone of the day. Depending on this data on we will be able to identify the minimum load on the feeder.
c) The minimum load observed on the feeders is compared against the installed capacity & estimated generation of the solar PV. With this estimation only we were able to identify the chances of reverse power flow.
d) During the grid power availability, system doesn't encounter any issue in reverse power flow. Now at the time when the grid power failure occurs & system is working on captive power plant (i.e. Diesel Generator) will feed this reverse power in the alternator of Generator (if reverse power flow relay doesn't operates) any may damage the alternator. In our case the reverse power flow relay operated & caused tripping of the system.
e) If the system is not working on base load & reverse power is not flowing. The power generated by solar PV will be shared with the diesel generator which will further reduce the efficiency of the diesel generator and the under loaded generator will produce less energy while consuming more diesel.
f) Out of the several identified locations, a sample location was selected to take the study further.
g) A system having battery banks to store the excess energy while system is working on diesel generator is proposed. By installing battery banks, we will be able to stop reverse power flow during the captive plant operation. The energy stored in the batteries can be further be utilized to cater the peak load demand in the university or to operate battery operated vehicles in the campus. This on one hand will increase the efficiency of the diesel generator by producing more Kwh/litters and will flatten the maximum demand curve of the consumption.
h) The data collected in the study is simulated using HOMER software.
i) A system design is proposed in which the system will work in normal mode of operation during grid power availability & will start saving energy in battery banks in grid failure situation.

Distribution Grid and its parameters

The area under study is a university named as Amity University Noida. It is situated at Sector 125, Noida on Greater Noida expressway. The University campus is spread over 60 acres of land with well transport connectivity of State Road transport. The details of the location of the university Campus are as follows: -

Particular	Detail
Facility Name	Amity University Noida
Substation No.	3
District	Gautam Buddha Nagar
State	Uttar Pradesh
Country	India

Continent	Asia
Time Zone	IST (UTC + 05:30)
Currency	Rupee
Latitude	28.5355° N
Longitude	77.3910° E
Elevation/ altitude	200 meter above sea level
Pin code	201301
Nearest railway station	Ghaziabad
Electricity availability	24 Hours
Communication System	Available
Mobile signal	Available

Table 1 Details of the Site

The University have a sanctioned load of 9 MVA from state electricity utility to cater the load demand. There are three electrical substations for distributing the power in 17 nos. administrative buildings (G+4 Floors each), 7 Nos. hostels (3 with G+10 Floors & 4 with G+4 floors) & other facilities like Sewage treatment plant, RO water plant, Water softening plant, HVAC plant & sports complex. The brief details of electrical infrastructure of the campus is as below

Parameter	Specification
Voltage Level	33 KV
Sanctioned Load	9.056 MVA
MDI	8.944 MVA
No. of Transformers	8 Nos.
Power Transformer	1 No.
Distribution Transformers	7 Nos.
Transformation Capacity	16.000 MVA
No. of Diesel Generator	13 Nos.
Diesel Generator Back Up	9.750 MVA
No. of HT Panels	6 Nos.
No. of LT Panels	7 Nos.
Solar Power	1 MWp

Table 2 Technical Parameter of System under Study

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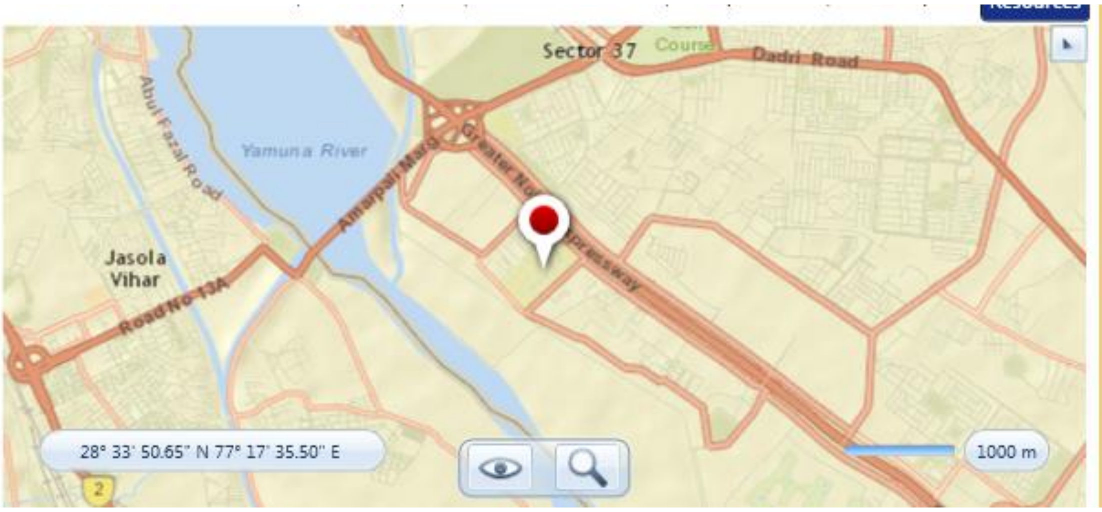

Fig. 2 Geographical Location of System Under Study

SOFTWARE

For the modelling and optimization purpose of any hybrid system different kinds the software can be used like HOMER Hybrid 2, HOGA, PVsysts, MATLAB etc.

IV. RESULTS AND DISCUSSION

In the paper "optimization of utility scale on grid solar PV with captive power plant" a large no. of calculations and results were obtained. Different results obtained are related to the performance of the system in terms of costs and emissions.

Present System Parameters

The schematics of the actual system are as below:

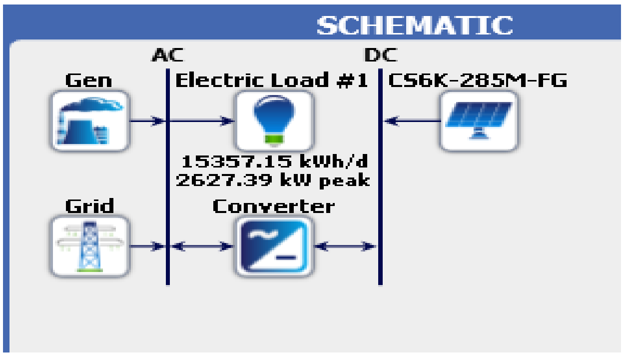

Fig 3 Schematic of the Present System

In our system we are having actual load data. The load data is entered at the required place so that software can calculate the exact consumption data. The data entered is as follows: -

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Yearly Load Data

Weekdays | Weekends

Hour	January	February	March	April	May	June	July	August	September	October	November	December
4	189.000	176.000	880.000	310.000	840.000	763.000	763.000	763.000	763.000	763.000	233.000	256.000
5	190.000	154.000	940.000	330.000	880.000	756.000	756.000	756.000	756.000	756.000	254.000	254.000
6	191.000	189.000	900.000	320.000	932.000	756.000	756.000	756.000	756.000	756.000	265.000	228.000
7	200.000	189.000	910.000	345.000	952.000	763.000	763.000	763.000	763.000	763.000	234.000	292.000
8	595.000	500.000	940.000	354.000	900.000	786.000	786.000	786.000	786.000	786.000	256.000	285.000
9	430.000	490.000	1,342.000	1,280.000	1,450.000	1,729.000	1,821.000	1,817.000	1,617.000	1,540.000	728.000	623.000
10	445.000	495.000	1,210.000	1,352.000	1,500.000	1,517.000	1,517.000	1,517.000	1,517.000	1,517.000	646.000	612.000
11	495.000	444.000	1,222.000	1,412.000	1,613.000	1,552.000	1,552.000	1,552.000	1,552.000	1,552.000	654.000	589.000
12	520.000	530.000	1,320.000	1,449.000	1,559.000	1,578.000	1,578.000	1,578.000	1,578.000	1,578.000	564.000	582.000
13	524.000	520.000	1,311.000	1,338.000	1,458.000	1,652.000	1,652.000	1,652.000	1,652.000	1,652.000	456.000	556.000
14	540.000	543.000	1,324.000	1,392.000	1,392.000	1,712.000	1,712.000	1,712.000	1,712.000	1,712.000	562.000	456.000
15	555.000	490.000	1,310.000	1,344.000	1,344.000	1,717.000	1,717.000	1,717.000	1,717.000	1,717.000	554.000	546.000
16	580.000	430.000	1,316.000	1,352.000	1,352.000	1,652.000	1,652.000	1,652.000	1,652.000	1,652.000	342.000	386.000
17	530.000	330.000	1,209.000	1,209.000	1,209.000	1,412.000	1,412.000	1,412.000	1,412.000	1,412.000	123.000	398.000
18	532.000	320.000	1,100.000	1,100.000	1,100.000	1,315.000	1,315.000	1,315.000	1,315.000	1,315.000	118.000	337.000
19	320.000	260.000	800.000	800.000	800.000	792.000	792.000	792.000	792.000	792.000	101.000	378.000
20	230.000	240.000	600.000	600.000	600.000	600.000	600.000	600.000	600.000	600.000	110.000	189.000
21	130.000	130.000	750.000	750.000	750.000	750.000	750.000	750.000	750.000	750.000	152.000	178.000
22	110.000	110.000	870.000	870.000	870.000	870.000	870.000	870.000	870.000	870.000	154.000	143.000
23	130.000	120.000	940.000	940.000	940.000	940.000	940.000	940.000	940.000	940.000	172.000	103.000

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Fig 4 Yearly load data

In the sensitivity analysis below, the present cost of generation of power from solar plant as well as consumption from Grid is being used at 6.01 Rs/kWh.

The Operation of Diesel generator shoots the unit rate to 16.95Rs/kWh. In both the cases the solar PV is working in synchronization with the Grid as well as diesel generators.

Categorized | Overall

Architecture	Cost						System	Gen		Converter		Grid	
	COE (Rs.)	NPC (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Fuel cost (Rs.)	O&M (Rs.)	Ren Frac (%)	Hours	O&M Cost (Rs.)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
	Rs.6.01	Rs.534M	Rs.32.2M	Rs.26.8M	Rs.0.00	Rs.32.2M	10			0	66	5,066,639	38,954
	Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.7M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,040,834	224,268

Fig 5 System Architecture & Cost of Energy

The Monthly usage of energy from all the three sources is given below: -

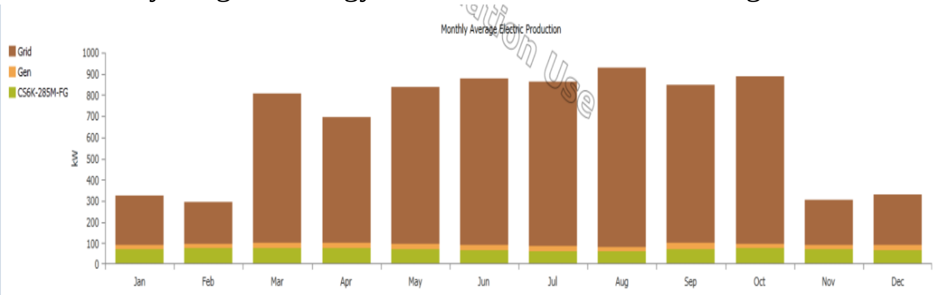

Fig 6 Month wise utilization of Grid power, Captive Power & Solar PV

The grouped total of all three sources of energy is as below: -

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Production	kWh/yr	%
CanadianSolar Dymond CS6K-285M-FG	610,611	10.42
Autosize Genset	211,120	3.60
Grid Purchases	5,040,834	85.98
Total	5,862,565	100.00

Table 3 Cumulative Utilization power

The annual excess electricity which could not be utilized due to failure of grid is given as follows: -

Quantity	kWh/yr	%
Excess Electricity	2,532.4	0.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Table 4 Excess Electricity

The results of optimization of present system are shown below: -

Cost						System	Gen		Converter		Grid	
COE (Rs.)	NPC (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Fuel cost (Rs.)	O&M (Rs.)	Ren Frac (%)	Hours	O&M Cost (Rs.)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
Rs.6.96	Rs.614M	Rs.37.7M	Rs.19.7M	Rs.0.00	Rs.37.3M	0.0082			0	0.05	5,604,901	0
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.7M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,040,834	224,268
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.7M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,040,834	224,268
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.8M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,039,014	224,328
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.8M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,039,014	224,328
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.9M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,038,540	224,337
Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.9M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0	66	5,038,540	224,337
Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.47.5M	Rs.3.15M	Rs.93.0M	9.7	104	60,320,000	0	64	5,053,642	223,717
Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.47.5M	Rs.3.15M	Rs.93.0M	9.7	104	60,320,000	0	64	5,053,642	223,717
Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.17.06	Rs.1.57B	Rs.96.4M	Rs.47.0M	Rs.3.15M	Rs.93.6M	8.1	104	60,320,000	0	54	5,138,818	217,492
Rs.17.06	Rs.1.57B	Rs.96.4M	Rs.47.0M	Rs.3.15M	Rs.93.6M	8.1	104	60,320,000	0	54	5,138,818	217,492
Rs.17.06	Rs.1.57B	Rs.96.2M	Rs.51.1M	Rs.3.15M	Rs.93.3M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.17.06	Rs.1.57B	Rs.96.2M	Rs.51.1M	Rs.3.15M	Rs.93.3M	10	104	60,320,000	0	66	5,038,497	224,338
Rs.17.11	Rs.1.57B	Rs.96.4M	Rs.52.8M	Rs.3.15M	Rs.93.5M	10	104	60,320,000	0	66	5,038,497	224,338

Table 5 Optimization with Cost of Energy

The optimized result based on cost of generation of electricity is shown in the fig below

Cost						System	Gen		Converter		Grid	
COE (Rs.)	NPC (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Fuel cost (Rs.)	O&M (Rs.)	Ren Frac (%)	Hours	O&M Cost (Rs.)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)	Energy Sold (kWh)
Rs.6.07	Rs.539M	Rs.32.4M	Rs.28.6M	Rs.0.00	Rs.32.3M	10			0	66	5,064,298	39,019
Rs.6.11	Rs.543M	Rs.32.8M	Rs.26.2M	Rs.0.00	Rs.32.8M	8.4			0	54	5,165,951	33,505
Rs.6.11	Rs.543M	Rs.32.8M	Rs.26.2M	Rs.0.00	Rs.32.8M	8.4			0	54	5,165,951	33,505
Rs.6.12	Rs.544M	Rs.32.6M	Rs.30.3M	Rs.0.00	Rs.32.5M	10			0	66	5,064,298	39,019
Rs.6.12	Rs.544M	Rs.32.6M	Rs.30.3M	Rs.0.00	Rs.32.5M	10			0	66	5,064,298	39,019
Rs.6.17	Rs.549M	Rs.32.8M	Rs.31.9M	Rs.0.00	Rs.32.7M	10			0	66	5,064,298	39,019
Rs.6.17	Rs.549M	Rs.32.8M	Rs.31.9M	Rs.0.00	Rs.32.7M	10			0	66	5,064,298	39,019
Rs.6.31	Rs.557M	Rs.35.3M	Rs.225,347	Rs.0.00	Rs.35.3M	0.0082			0	0.05	5,604,901	0
Rs.6.31	Rs.557M	Rs.35.3M	Rs.225,347	Rs.0.00	Rs.35.3M	0.0082			0	0.05	5,604,901	0
Rs.6.31	Rs.557M	Rs.35.3M	Rs.327,991	Rs.0.00	Rs.35.3M	0.0082			0	0.05	5,604,901	0
Rs.6.31	Rs.557M	Rs.35.3M	Rs.327,991	Rs.0.00	Rs.35.3M	0.0082			0	0.05	5,604,901	0
Rs.6.31	Rs.557M	Rs.35.4M	Rs.430,634	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.31	Rs.557M	Rs.35.4M	Rs.430,634	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.32	Rs.558M	Rs.35.4M	Rs.635,920	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.32	Rs.558M	Rs.35.4M	Rs.635,920	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.28	Rs.559M	Rs.33.2M	Rs.35.2M	Rs.0.00	Rs.33.0M	10			0	66	5,064,298	39,019
Rs.6.28	Rs.559M	Rs.33.2M	Rs.35.2M	Rs.0.00	Rs.33.0M	10			0	66	5,064,298	39,019
Rs.6.33	Rs.559M	Rs.35.4M	Rs.841,207	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.33	Rs.559M	Rs.35.4M	Rs.841,207	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.34	Rs.560M	Rs.35.5M	Rs.1.25M	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.34	Rs.560M	Rs.35.5M	Rs.1.25M	Rs.0.00	Rs.35.4M	0.0082			0	0.05	5,604,901	0
Rs.6.35	Rs.561M	Rs.35.5M	Rs.1.66M	Rs.0.00	Rs.35.5M	0.0082			0	0.05	5,604,901	0

Table 6 Optimized case

Optimized System Parameters

The schematics of the proposed system are as below: -

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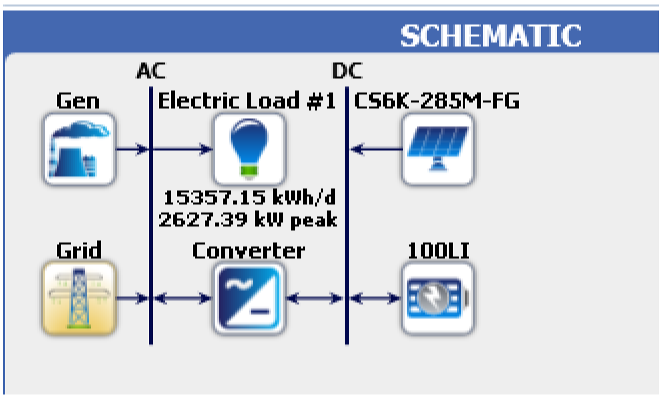

Fig 7 Proposed System Schematic

The architecture of optimized system with all the four sources of energy is given below

Categorized Overall

Architecture		Cost						System	Gen		100LI		Converter		
100LI	COE (Rs.)	NPC (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Fuel cost (Rs.)	O&M (Rs.)	Ren Frac (%)	Hours	O&M Cost (Rs.)	Autonomy (hr)	Annual Throughput (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purchased (kWh)
	Rs.6.01	Rs.534M	Rs.32.2M	Rs.26.8M	Rs.0.00	Rs.32.2M	10					0	66	5,066,639
1	Rs.6.03	Rs.536M	Rs.32.3M	Rs.28.1M	Rs.0.00	Rs.32.2M	10			0.13	80	0.01	66	5,064,838
	Rs.16.95	Rs.1.56B	Rs.95.8M	Rs.47.7M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000			0	66	5,040,834
1	Rs.16.97	Rs.1.56B	Rs.95.8M	Rs.49.0M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.13	80	0.01	66	5,039,036

Table 7 Architecture of All resources with Cost of Electricity

The Monthly usage of energy from all the three sources is given below: -

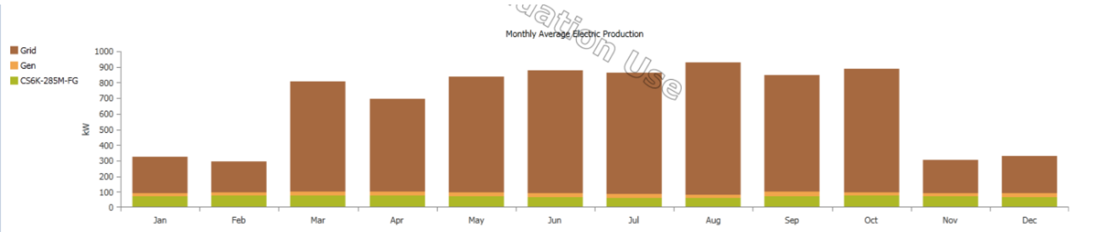

Fig 8 Month wise utilization of electricity

The grouped total of all three sources of energy is as below: -

Production	kWh/yr	%
CanadianSolar Dymond CS6K-285M-FG	610,611	10.42
Autosize Genset	211,120	3.60
Grid Purchases	5,039,036	85.98
Total	5,860,767	100.00

Table 8 Cumulative Utilization power

The annual excess electricity which could not be utilized due to failure of grid is given as follows:-

Quantity	kWh/yr	%
Excess Electricity	554.5	0.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Table 9 Excess Electricity

The optimization results of hybrid system are given below:

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Categorized ◉ Overall

Architecture		Cost						System	Gen		100LI		Converter		
100LI	COE (Rs.)	NPC (Rs.)	Operating cost (Rs.)	Initial capital (Rs.)	Fuel cost (Rs.)	O&M (Rs.)	Ren Frac (%)	Hours	O&M Cost (Rs.)	Autonomy (hr)	Annual Throughput (kWh)	Rectifier Mean Output (kW)	Inverter Mean Output (kW)	Energy Purcha (kWh)	
	Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.47.5M	Rs.3.15M	Rs.93.0M	9.7	104	60,320,000			0	64	5,053,642	
	Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.96	Rs.1.56B	Rs.95.8M	Rs.48.1M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.97	Rs.1.56B	Rs.95.9M	Rs.48.3M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
1	Rs.16.97	Rs.1.56B	Rs.95.8M	Rs.49.0M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.13	80	0.01	66	5,039,036	
1	Rs.17.02	Rs.1.56B	Rs.95.8M	Rs.49.0M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.13	16,839	0.5	67	5,023,838	
	Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
	Rs.16.98	Rs.1.56B	Rs.95.9M	Rs.48.7M	Rs.3.15M	Rs.93.0M	10	104	60,320,000			0	66	5,038,497	
2	Rs.16.99	Rs.1.56B	Rs.95.9M	Rs.50.1M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.25	160	0.02	66	5,040,877	
2	Rs.17.09	Rs.1.56B	Rs.95.9M	Rs.50.1M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.25	33,028	1	67	5,011,068	
2	Rs.17.00	Rs.1.56B	Rs.95.9M	Rs.50.5M	Rs.3.15M	Rs.93.0M	9.9	104	60,320,000	0.25	160	0.02	66	5,038,540	
	Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000			0	66	5,038,497	
	Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000			0	66	5,038,497	
	Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000			0	66	5,038,497	
	Rs.17.01	Rs.1.56B	Rs.96.0M	Rs.49.5M	Rs.3.15M	Rs.93.1M	10	104	60,320,000			0	66	5,038,497	

Table 10 Optimized case

Annual output of solar PV is given as below:

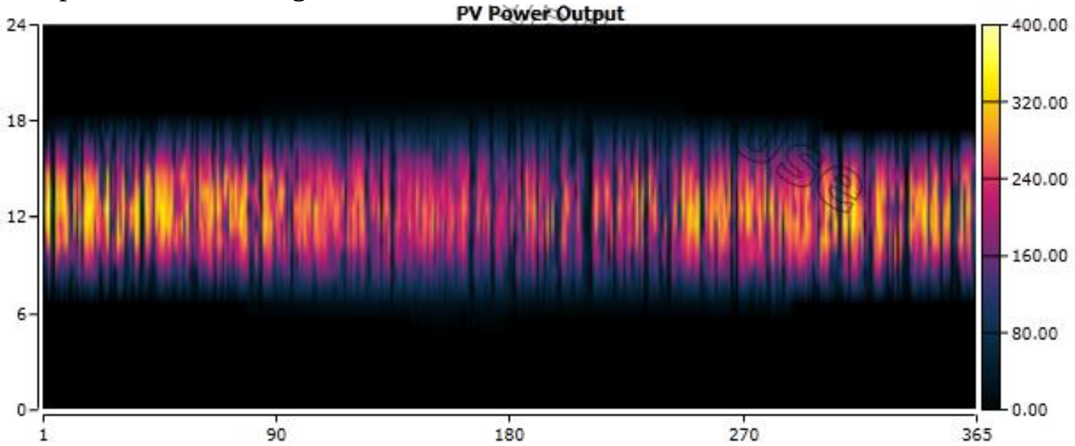
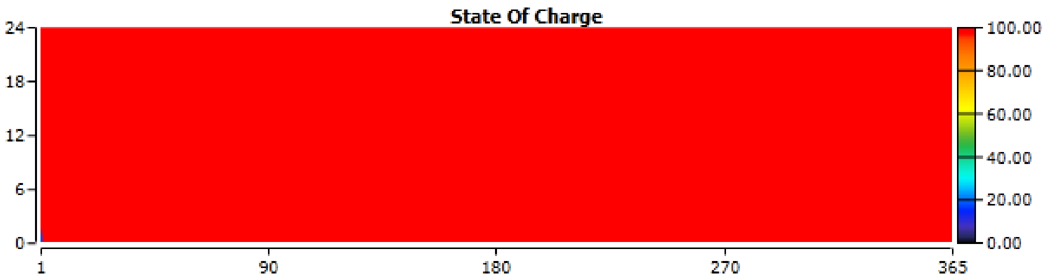


Fig 9 Solar PV Output

The state of charge of battery is as below: -



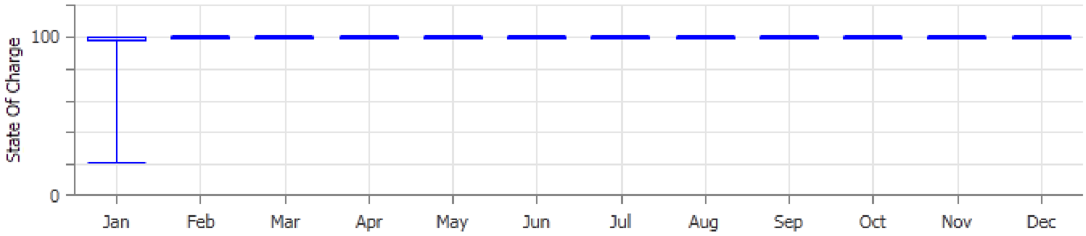


Fig 10 State of Battery Charge

V. CONCLUSION

The project was undertaken for "Optimization of utility scale on grid solar PV with captive power plant" and preventing the reverse power flow to the alternator of captive power generator in the event of grid failure. By studying the present system simulation model, 2632 kWh is excess production every year. The Li-ion batteries are proposed to store the excess amount of energy which will prevent the reverse power flow. These batteries then further could have been used in Electric Vehicles or can draw power during peak period so that the maximum demand can be limited. Cost of Electricity in this case is 6.01 Rs/kWh in case the power is taken from grid & 16.95 Rs/kWh if the power is taken from Diesel Generator (both are in synchronisation with Solar PV).

Now, the Li-ion are introduced in the simulation software which indicates the cost of energy 16.97 Rs/kWh in case of all four i.e., Grid, Solar, Diesel Generator & battery bank are used in synchronization. Though, the excess power produced in this is 545 kWh which can be saved in batteries but the cost of electricity is increased.

The state of charge of battery also shows that once the battery is charges in is seldom used & remains in its state of charge throughout the year. Since the cost of energy is rising by introducing batteries in the existing system, it may be concluded that the batteries are proved to be uneconomical in this work.

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