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Designing & load flow analysis of 50 kW off-grid PV System with battery storage and bio-diesel generator

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Abstract— So many countries are empowering their nation with grid electricity but still, there are some unavoidable issues to empowering every place. The demography and geographical situation are varying with every 50 km. It is difficult to provide grid electricity everywhere, therefore, the country is looking to empower those areas with off-grid system with battery backup and tied with bio-diesel generator. These systems are independent and self-reliant that can play a major role in the development of the country. A 50 kW PV Standalone hybrid System can provide proper supply to villagers and remote areas. In this document, we will design the off-grid system and analyze performance at the different conditions in software.

Index Terms— Standalone System, Battery Storage, Solar Array, Biodiesel Generator, Inverter, E-tap etc.

1 Introduction

This document gives a brief idea and analysis of the off-grid system with battery storage and integrated with a biodiesel generator. The developing countries are actively looking for energies in their own country with a single grid network to empower the nation in the field of the power sector which directly helps in the primary, secondary, and tertiary sectors in the economy of the country. As per the analysis of some global reports it shows many countries are installing the standalone systems in remote areas, hilly areas, and where the insurgency takes place.

In India, so many private organizations took it as an opportunity that can generate good revenue and develop employees as well which makes the village self-reliant and Independent. They would not be depending on the Grid electricity supply. They have the power supply from the stand-alone system.

A 50 kW (AC Output) plant is sufficient for 30 households and 20 commercial shops. The system is designed for 30 households and 20 shops and if the village have more or less than 30 households and shops then the plant capacity may vary accordingly [1].

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India has an abundance of solar radiation, with the peninsula receiving more than 300 sunny days in a year. PV is progressively becoming more attractive, than other renewable sources of power, as its cost declines. The various factors leading to decline in cost includes setting up of large-scale plants, integration across the value chain, declining cost of raw material, reducing material consumption and higher efficiency of modules [2].

The use of renewable energy sources (RES) increases and there is an enormous increase in the installed capacity of renewable energy sources in the distribution networks. Therefore, there is an increased number of photovoltaic systems that are connected to the distribution networks. With this, distribution system operators have problems with feedback currents and power flows, as well as voltage violations [3].

2 Current Scenarios

In the current situation, villagers do not have proper supply due to grid instability, however India is maintaining their grid stability but there are so many places where the grid supply is unable or tough to reach. To amid this condition the best way is to provide supply through standalone system. Government is providing small standalone system have the capacity of 500 W but this is not good enough to operate commercial appliances. Commercial appliances like a wheat grinder, mixer, grinder, and other shops that are using inductive and other capacitive load comes under consideration. These appliances cannot operate through small sources. They need a source that has the potential to accommodate the surge load and its factor. To maintain the surging demand, it requires a big plant that can manage the peak load and operate the appliances easily. Engineers and researchers are continuously working in this field and providing pioneer solutions.

In Bihar, Chhattisgarh, Jharkhand, and the eastern part of Uttar Pradesh, the standalone system is very famous among the villages. Inverter with latest technologies are capable of maintaining load demand even in peak demand.

3 CONTEXT AND PERSPECTIVE

As India is setting their target for solar energy up to 100 GW from which 37,627 MW is already achieved. Now the government is looking to empower the remote areas so they can start their commercial activities and improve their economy and improve the standard of living. The total mini grid installed so far in India is about 212 MW and yet there is huge potential for mini grid to install more power pack plants in remote or high terrain area.

Ministry is also implementing a scheme for 70 lakh Solar Study lamps, which aims to provide rural students with high quality and affordable clean light. Scheme is being implemented in 5 states viz., Assam, Bihar, Jharkhand, Odisha and Uttar Pradesh, which have more than 50% un-electrified households, as per census, 2011. Blocks with more than 50% kerosene dependent households are being covered under the scheme [4].

4 SYSTEM DESIGN

Here we have considered 30 Households and 20 commercial shops in a village and decided to consider all equipment that either they have the appliances or they will have them in future but we designed the system as it entertains the villagers up to next 15 years. The considered appliances and its consumption load are categorized in the Table 1,Table 2 and Table 3.

Total Load of Household				
Equipment	**Load (W)**	**Quantity**	**Surge factor**	**Total Load (W)**
LED Bulb	10	6	1	60
Fan	60	3	3	540
T V	120	1	1	120
Mobile Charger	15	4	1	60
Cooler	200	1	1	200
			Total Load	**980**

Table 1 Total Load of Households

In the above table, the expected load of 30 households is considered. The inductive load i.e. cooler is taken for grant that up to 200 W the villagers may have any inductive or another load. If the household does not have any inductive load as above mentioned so the load will be considered as a futuristic approach.

Total Load of Shops				
Equipment	**Load (W)**	**Quantity**	**Surge factor**	**Total Load (W)**
Mobile/TV Repair Shops	900	5	1	4500
Wheat Grinder	7000	1	1.5	10500
General Store	300	10	1	3000
Showrooms and Tailor Shops	1250	2	1	2500
			Total Load	**20500**

Table 2 Total Load of shops

In the table no. 2, there are expected loads for shops of different category. All the shops are open at different time so we can assume that the surge factor will not be an issue furthermore we have designed the system accordingly.

Energy Demand					
Demand	**Load (kW)**	**Usage in Summer (hrs)**	**Usage in Winter (hrs)**	**Demand in Summer (kWh)**	**Demand in Winter (kWh)**
Demand for House hold (30 HH)	29	10	6	294	176
Demand for Shops	21	12	8	246	164

Table 3 Total Energy Demand

In the table no. 3, we have seen the expected load demand form households and shops for two different seasons. The demand is taken as the average consumption of load in summer and winter seasons. In the summer season, the average demand for consumption considered 10 hrs. while in summer the average demand is considered for 6 hours. For the shops, the average consumption of the load is 12 hours in summer and 8 hours in winter.

5 Proposed Methodology

As discussed in section 3 we have seen the demand estimation and, in this section, we will design the system for the above-mentioned demand.

As we have seen the demand is 50 kW, and if we considered the surge factor so we need to design more than the 50. After the calculation of surge demand, we need to design system for about 60 kW.

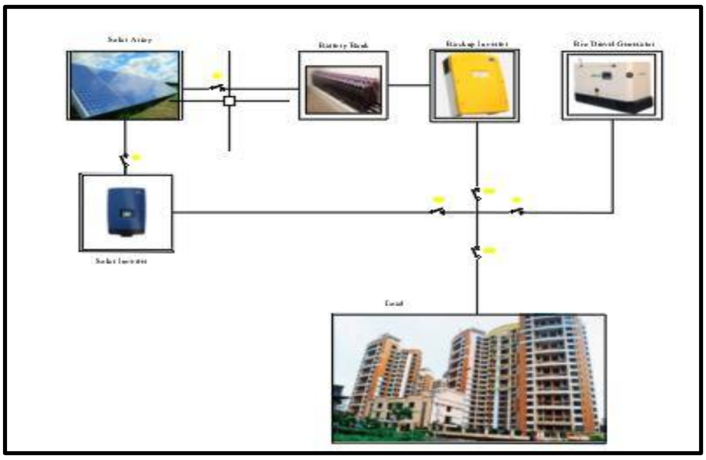

Figure 1 Conceptual Diagram of OFF grid Battery storage and equipped with battery storage.

For this, it is required to design the system based on renewable energy which is self-reliant and independent from the conventional source of energy so we have decided to design a system that has Solar panels with battery storage and equipped with 50 kW biodiesel generator which helps villagers during no sunny days. The solar array will design for 60 kWp and the rated output will be 50 kW. Hence as we know the 50 kW will never be the consumption load it is only contracted demand. 50 kW will never use at the same time.

Along with the solar panel, we will use the battery storage system for the sake of days of autonomy. Here we are considering only 300 sunny days and 65 days are considered as days of autonomy. Hence, the system is designed as per the radiation data available for the meteorological station.

Sn No.	Equipment	Capacity	Numbers
1	PV Modules	370 Wp	162
2	Inverter	50 kW	1
3	Battery Bank	3300 kWh	72 Cells

Table 4 System Sizing

As mentioned in the table, the total number of the PV modules [5] are 162 which means the total capacity will be 59.94 kWp and the configuration is set as per designing parameters which are as follows.

Location	18.419781° N, 81.673940° E
Lowest Temperature (°C)	9
Highest Temperature (°C)	45
Total number of modules in a string	18
Total number of strings are in parallel	9
Tilt angle	20°

For this, the tilt angle will be 20 degree and the solar TPV plant will be designed and installed on the aforementioned location as per given parameters.

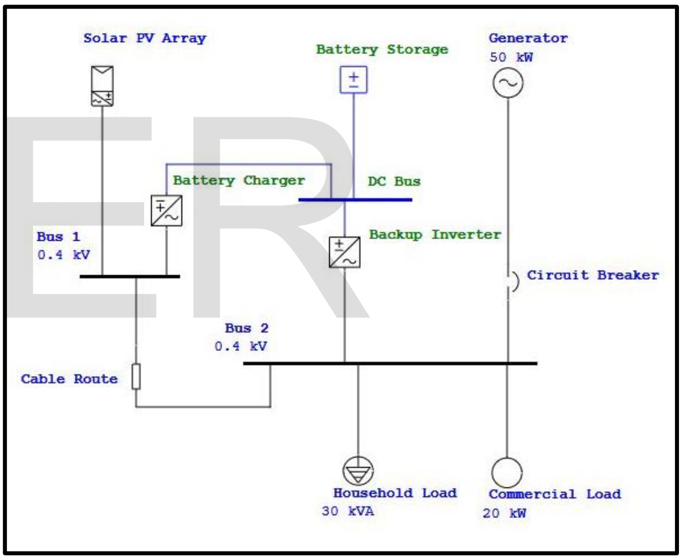

Figure 2 Single Line Diagram of Designed System

As shown in the above picture, Solar PV array equipped with 50 kW inverter [6] is connected with the AC bus and the battery charger which is having AC input and DC input is connected with DC bus which is further connected with battery. Here the battery is connected having the capacity of 3300 kWh [7] and can supply energy up to 10 hours at full load condition without charging.

In the designed system, 18 Solar PV modules are connected in a series called string, and these 9 strings are connected in the parallel. One string constitutes 9.25 Amps and voltage 720 Vdc, hence the whole system will have current 80 Amps and 720 Vdc. The output of the inverter will be 50 kW and the output voltage will be 400 V or o.4 kV and the current will be 86 Amps.

The safety equipment like MCB, MCCB and SPD are connected in ACDB and DCDB.

6 Simulation and analysis

The battery controller will cut off the supply as the battery energy reaches 25%. This will be the cut-off point for the battery for better performing areas. DC bus is connected with a backup inverter which is further connected with the AC bus. Households and commercial loads are connected with the AC bus.

Here the housing load is connected with 30 kW and commercial load is connected with 20 kW which is not an issue. Because both loads are connected with the same bus and it is confirmed that all loads will not be operated at the same time for the safety perspective, we will fix the time of the start of the load.

For Example, if the starting time for a wheat grinder or shops that have inductive load is fixed then it will help to manage the commercial load from the surge factor issue.

The 50-kW bio-diesel generator is connected with the AC bus for the parallel operation, it is a cost-effective system and in the village area, jatropha oil are very common and easily available. The operation cost of this system is affordable for villagers. The system can help to operate the system when the solar system having days of autonomy, then this type of pioneer solution can help villagers.

The required system is designed and modeled in the worldwide accepted platform named e-TAP in the latest version and the system is modeled in the various parameter. In this system, total harmonic distortion very low and taken care of harmonium waveform and spectrum as we can see the images shown below [8].

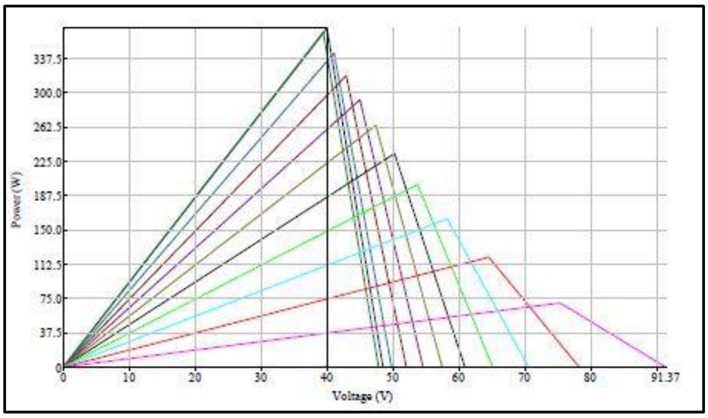

Figure 3 PV Curve for 370 Wp PV module

In the Figure 3 and Figure 4 we can see the power versus voltage and current versus voltage curve, on the STC conditions the modules are working as per module data sheet. The STC parameters for the 370 Wp is 40 V_{mp} and 9.25 I_{mp}. These are the conditions given by the manufacturers.

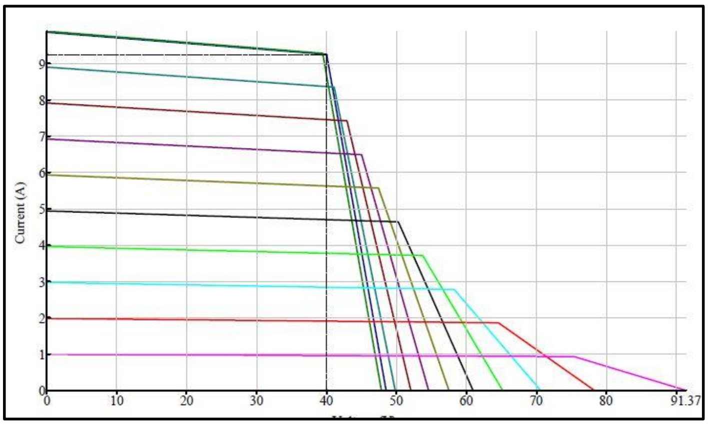

Figure 4 IV Curve for 370 Wp Modules.

In the Figure 5 we can see the harmonic spectrum and waveform are normal and as per requirement. This waveform and spectrum are considered as ideal for practical work and reliable for equipment's.

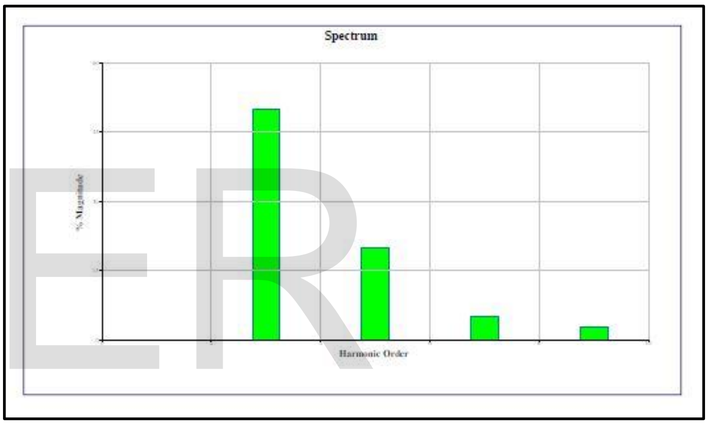

Figure 5 Harmonic wave spectrum

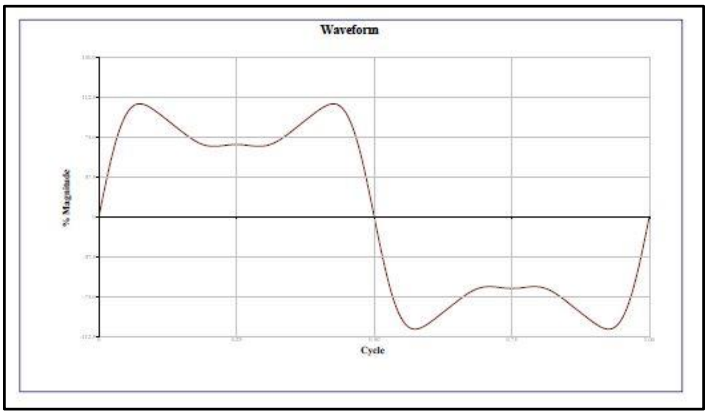

Figure 6 Harmonic ideal waveform

After the consideration of all factors, when we simulate the data in the software, we have seen analysis shown in below picture. The system is showing the load flow analysis and showing the connected load and consumption during the day light.

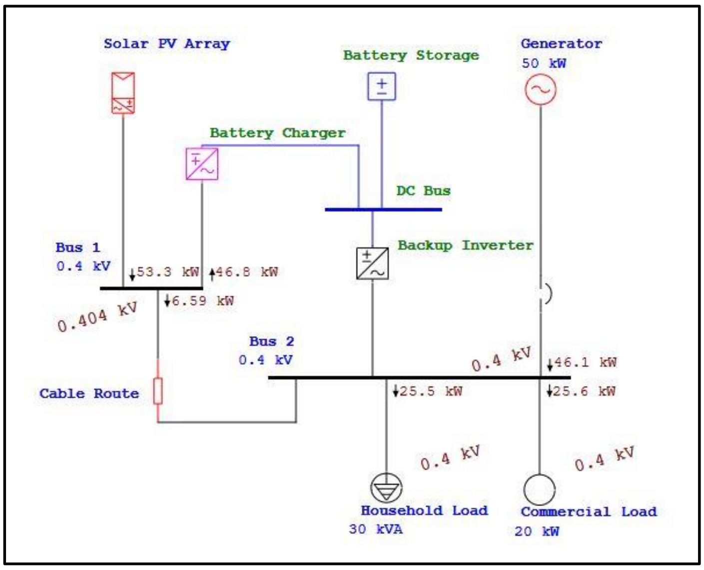

Figure 7 Modelling of designed system

In the above diagram black bus is shown for AC where as blue bus is for DC. The flowing voltage is mentioned as 0.4 kV three phase grounded connection. The distributed supply line will be 0.4 kV source from the inverter having inbuilt one to one transformer.

Bus ID	kV	Voltage % Mag.	Voltage Ang.	Generation MW	Generation Mvar	Load MW	Load Mvar
Bus 1	0.400	100.928	2.9	0.053	0.000	0.047	0.029
* Bus 2	0.400	100.000	0.0	0.046	0.058	0.051	0.029

Figure 8 Load flow

The load flow analysis in both of the AC buses is shown, Bus 1 which has connected with backup inverter and Biodiesel generator having the running load of 0.053 MW while the generation of both the busses is proving the power as per demand. This seems this system has the potential to maintain the load demand as per requirement at all the condition.

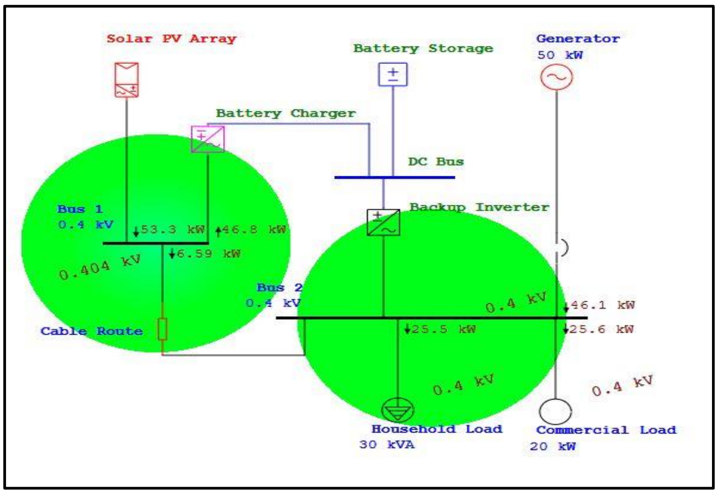

Figure 9 Colour showing overload and underload conditions

SUMMARY OF TOTAL GENERATION, LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	0.046	0.058	0.074	62.18 Lagging
Source (Non-Swing Buses):	0.053	0.000	0.053	100.00 Lagging
Total Demand:	0.099	0.058	0.115	86.37 Lagging
Total Motor Load:	0.093	0.055	0.108	86.10 Lagging
Total Static Load:	0.005	0.003	0.006	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.002	0.000		
System Mismatch:	0.000	0.000		

Number of Iterations: 2

Figure 10 Summary of total generation

The summary report of the total generation is shown above in the table which guides the detail of total demand and total consumption load.

BUS 1 Load is 0.047 MW and Bus 2 Load is 0.057 MW these loads are considered as a maximum in 10 iterations.

Alert Summary Report

Loading	% Alert Settings Critical	% Alert Settings Marginal
Bus	100.0	95.0
Cable	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0

Figure 11 Alert Summary Report

7 Discussion

The critical load for all the equipment is considered as 100% and the marginal load is 95% which means our system is designed for full load condition but initially the PV system and the distribution will operate at 85% load condition, the rest of the 15% are considered as marginal load.

There is a highly positive change that villagers may connect heavy load systems without prior information, to amid these issues it is required to connect a small monitoring system in every household or shops. MCB at the input side can also be a solution to install a 10 Amps MCB at the input side as the sink is demanding more than 10 Amps the MCB got a trip and isolate the system itself. These are the small problems which can be sorted out at ground level. For this, the operator and engineer should be highly qualified and experienced.

We can see in Figure 9 that the green colour showing that when the load is connected to the system it is still in good condition if the load is going high then the colour would become yellow or red.

Economic Analysis

For the economic analysis we have simulated the data in HOMER software which analyse all the data and provided the economic analysis [9].

Total Net Present Cost: ₹1,00,42,349

Levelized cost of Energy (₹/kWh): ₹ 3.87

8 Conclusion

As per the result, we have seen the per-unit cost of electricity generation costs up to ₹ 3.87/kWh which is affordable for the villagers. If the utility cost is low then only the product may increase or villagers can look for commercial activity. This solution is very good for a big village having more than 50 households and shops as well.

The energy cost per unit may increase after the distribution cost taken into consideration. In this way, the per-unit cost may hike up to ₹ 5/kWh for household and ₹ 6-7/kWh for shops. These charges are affordable for the villagers. Hence this way, the entrepreneurs and other engineering services can take lead and install these types of system in remote areas, villages in high terrain, insurgency area.

The renewable energy is the only option which is widely taken because these systems widely help the environment, it reduces the carbon excretion, greenhouse gases, usage of coal, manpower, economic cost, etc.

9 Future Aspects

In the future, engineering companies can make this system a business opportunity already there are so many companies that are working in this sector. This system may be working as a portable system. If the system has installed in lower capacity then it can be a movable thorough tractor.

This system can be used for commercial activity. This is useful for a wheat grinder, paddy wheeler, etc. There are many aspects that could follow by engineers. GOI is set a new milestone with installing solar energy plant but due to days of autonomy, this biodiesel generator can play a remarkable role in this off-grid system. In the future, the new researchers can start work on battery optimizations.

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