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DC connected solar plus storage systems: an overview

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ABSTRACT

The different model of PV plus battery connected system is discussed in this paper for the maximum energy storage and full utilization without any interference and restriction. It is beneficial to install the different configurations like AC and DC connected battery system to achieve full self-consumption and reduce the losses. It is desired to store the optimum power generated by the PV solar panel without any power loss. Also, at peak hours the model should be design for maximum storage without any storage capacity limitation therefore avoiding power clipping, to meet the full requirements of the load. The system should be designed to achieve the full benefit of PV panel power generated and reducing grid dependency.

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1. INTRODUCTION

Green Technology is a technology which supports the environment in a healthy way. It replaces fossil fuels with clean and green renewable energy used in many applications which lowers harm to the environment. It involves recycling polluted water and generating power through solar panels, ocean, wind and many other resources. It maintains the environment clean and clear by reusing the waste products into a useful product. Awareness of a healthy environment has now become a social aim. Large numbers of investments are undergoing to support the development of clean and green energy.

Renewable energy generates power from natural resources and diversifies the fuel which split the atmosphere with poisonous gases. It is considered a better way to protect the environment, increasing energy production and reducing air pollution. Renewable energy resources are never-ending, available free of cost in a large extent from nature. This energy has vast applications in all fields. The photovoltaic (PV), is a semiconductor material which converts sunlight into electrical energy. Single PV cell produces approximately 1 or 2 watt of energy is constructed of different materials. PV cells are connected in a manner to form a module or panel. Modules are connected to form an array which is connected to the grid to form PV system. The PV system is designed and developed to meet requirement at small and large scale. The module produces DC current which is converted to AC current which passes to load. System advisor model (SAM) Software is identified for the modeling the performance and economics of the renewable energy systems [1].

2. STORAGE TECHNOLOGY

To connect solar energy, battery technology is better option. The time of maximum generation of solar energy do not match with the time of maximum energy consumption. To meet this problem, the storage system supply electricity to load during low or no sunlight hours. Storage system help maintain constant supply of energy at the output in spite of variations due to amount of sunlight falling changes in a day, different weather conditions, rain, cloud, dust, snow and shadows [2].

Lithium-ion batteries are generally used to capture energy that store energy in and release when it is required. Storage system improves the efficiency and resilience of the system, it also increases the power quality to meet the load requirement with energy generation. When there is high solar generation but load is low, excess energy is stored in a battery for use at other time i.e., after sunset or rainy day when production is low demand is high [3]. Generally, the storage of energy system along with solar plants use the technology of electrochemical storage or batteries connected along with photovoltaic systems. When the electric energy is applied at input it produces chemical reaction and energy is stored and in reverse direction when the battery is discharged then the chemical reaction is also get reversed, resulting in voltage development across both connecting ends which results the flow of current. The commonly used batteries are Lithium-ion battery, other types include lead-acid, sodium and nickel-based batteries.

3. MODEL

It is noticed that in current time as we are moving ahead with the technology, efficiency is improving day by day with decreasing costs to make it affordable among the society. Similarly, in the field of photovoltaic, the generated energy and most important to store that energy is an important factor in terms of costs which is decreasing. To connect this system as a whole has increased many applications [4], [5] . In some areas the high PV production is attained due to which the grid connection system is a matter of concern. This gives rise to design a PV system combined with energy storage which can become in-dependent of grid supply energy and not only meet their load requirement but also can export energy to grid to gain credit.

Many types of storage energy system are designed depending on the PV production and requirement [6]. When electricity produced from PV is low, no energy is exported to grid. In high PV production areas with minimum compensation for extra energy, behind the meter system is introduced. This store energy as a backup with decreased charge services [7]. Several configurations are designed for PV with storage which are broadly classified as DC connected battery system as shown in Figure 1 and AC connected battery system as shown in Figure 2.

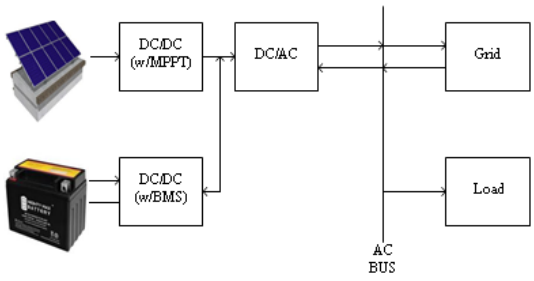

Figure 1. Solar PVplus DC-Connected battery storage system

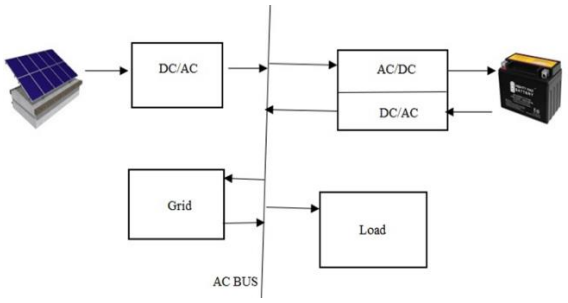

Figure 2. Solar PV plus AC-Connected battery storage system

In alternating current battery, the energy is stored in battery network via the system designed to manage the batteries connected with its inverter or charger of its own separately. The power produced by the photovoltaic inverter or by grid is used to charge the battery and when this power is supplied to electric loads for its operation or function then the battery starts to be discharge. Whereas, the direct current connected battery are connected at the output of the inverter which is bidirectional and in common sharing mode, thereby charging the battery by a stable direct current power. The alternating current power supply from grid also charges the battery through the inverter, which is common and bidirectional. Several types of algorithms are applied to enhance energy flow for PV systems using DC connected batteries. It is suggested that DC-Coupling storage system is beneficial at large scale because of decreased component cost and reduction in power clipping [7]–[9].

4. POWER FLOW IN THE SYSTEM

4.1. Power flow- battery discharging

The DC power stored in battery at one end of the battery management system (BMS) prior to inverter is an important factor for the efficient function. The BMS controls that voltage of the battery and the power of solar photovoltaic that is applied at the input of the inverter are mapped with each other [10], [11].
The power discharge resulted from the output battery balancing system as in (1).

$$Power\ battery\ dc\ =\ Power\ battery\ pre\ bms\ dc * \eta\ BMS \quad (1)$$

Now the power in battery and the solar photovoltaic system both are added to produce as in [12] (2).

$$Power\ dc = Powerpv\ dc + Power\ battery\ dc \quad (2)$$

η = Denote as the efficiency of management system to control the battery operation. It performs two functions:
– When the charge voltage is too high then it controls it to lower down to match with the voltage of the battery storage system
– It protects the battery to get deep discharge and balance it to remain constant till solar Photovoltaic voltage
The output percentage of the power of shared inverter is calculated by added power applied at the input of the inverter.

The modeling of inverter is designed by considering several factors such as the total AC power, the efficiency of the inverter calculated and also the losses which occurs due to the inverter AC power capacity limitation and many other system losses. The output solar photovoltaic power split into:
– Alternating current power produced by solar photovoltaic array

$$Power\ pv = Power\ pv\ dc * \eta inverter \quad (3)$$

– The alternating current power discharged from battery

$$Power\ battery\ =\ Power\ battery\ dc * \eta inverter \quad (4)$$

The other AC components are considered as the amount of power required by the solar photovoltaic and the battery to meet the load. At discharging of the battery phase, this model is designed so that solar photovoltaic will supply power to load first, any excess power is then supplied to grid. Power is supplied by battery to any load if not served by solar photovoltaic [13].

$$Power\ battery\ to\ load = min\ (Power\ battery, Power\ load - Power\ pv\ to\ load) \quad (5)$$

Excess power generated is passed to grid

$$Power\ battery\ to\ grid = Power\ battery - Power\ battery\ to\ load \quad (6)$$

If load require more power than generated by solar photovoltaic, then it is taken by grid

$$Power\ grid\ to\ load = Power\ load - Power\ pv\ to\ load - Power\ battery\ to\ load \quad (7)$$

4.2. Power flow- battery charging

While battery is charging the actual storage power is calculated as in (8).

$$Power\ battery\ dc = Power\ battery\ pre\ bms/\eta BMS \quad (8)$$

To find out the calculated previous charging power at the battery, some extra power is applied by the BMS having single point efficiency. To calculate charging is somewhat complex, as while charging some part of the solar photovoltaic energy is used for charging and the other part is required to handle the load function. In the PV connected with DC storage battery system, the battery charges from the PV without AC conversion and excess PV passes through inverter [14].

$$Power\ pv\ inverter\ dc\ =\ Power\ pvdc - Power\ pv\ to\ battery \quad (9)$$

When there is low solar photovoltaic power generation to charge the battery, then the extra power required is supplied through the grid as in (10).

$$Power\ Grid\ to\ battery\ dc\ =\ Abs\ (Power\ battery\ dc)\ -\ Power\ PV\ to\ battery \quad (10)$$

Net direct current power passing through inverter is calculated by considering single way power flow as in (11).

$$Power\ dc = Power\ pv\ inverter - Power\ Grid\ to\ battery\ dc \quad (11)$$

The calculate direct current power is passed through the inverter model, produces alternating current power with the inverter efficiency as in (12).

$$Power\ pv\ =\ Power\ pv\ inverter\ dc * \eta inverter \quad (12)$$

Alternating current power components are calculated again by disintegrating the total alternating current power as in (13).

$$Power\ grid\ to\ battery = Power\ grid\ to\ battery\ dc/\eta inverter \quad (13)$$

Now, further the calculations are same as while discharging case, only having a special case that power flow from battery towards load and from battery to grid are considered as zero.

5. COMPARATIVE STUDY

The solar PV connected system is directly connected to electrical load without any storage system is shown in Figure 3. There is variation in photovoltaic energy produced and power consumption from early to late hours throughout the day. Photovoltaic energy produce exceeds the limitation capacity of the inverter at noon hours throughout the day. Therefore, the power is clipped due to the limitation of the inverter especially at noon hours. The power consumption of the loads is higher in the early day time and remains constant somewhat at noon time and again the consumption increases at evening time.

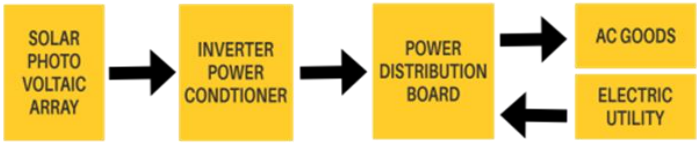

Figure 3. Solar photovoltaic power produced is connected with electric load

Photovoltaic with a combination of direct coupled battery is shown in Figure 4. In such configuration the photovoltaic array fulfills the maximum requirement of the energy consumption for smooth operation during noon hours, as the energy production is maximum in these hours the remaining extra energy is used to charge the battery. This photovoltaic system coupled with direct current energy storage can completely store the generated power during the whole day.

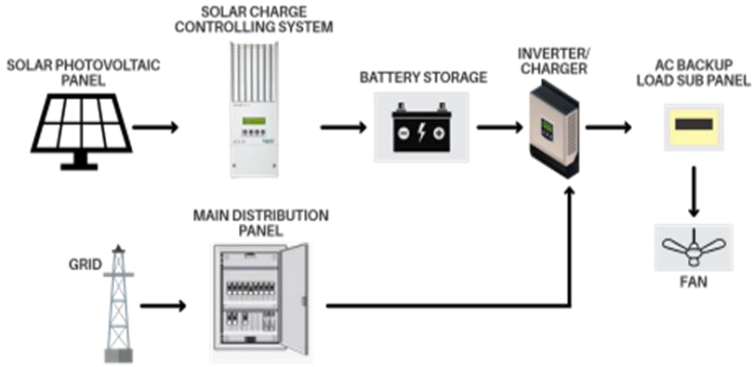

Figure 4. Solar photovoltaic power produced is supplied to load via DC coupled battery storage system

The photovoltaic with a combination of alternating current coupled battery is shown in Figure 5. In which the storage is somewhat same like direct current coupled battery, but during operation the power need to be inverted separately due to separate inverter configuration before entering the battery, hence extra photovoltaic power generated is not captured or the power is somewhat lost.

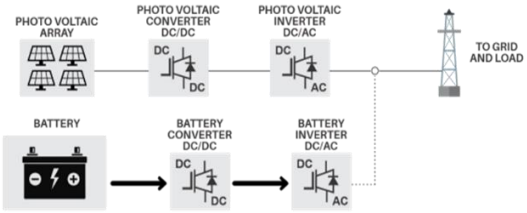

Figure 5. Solar photovoltaic power produced is supplied to Load via AC coupled battery storage system

6. SELECTING A MODEL

A performance model of a detailed PV model for a residential owner was selected on SAM software. Location for Lucknow, India with latitude of 26.85 and Longitude of 80.95 was selected and the corresponding weather file of this location was downloaded. Module Multi-c-Si database with module database along with an inverter plus DC Connected battery storage, Lithium Ion- nickel manganese cobalt oxide (NMC/Graphite) was selected. Figures 6 and 7 shows the selection of model and selection of inverter on Sam software.

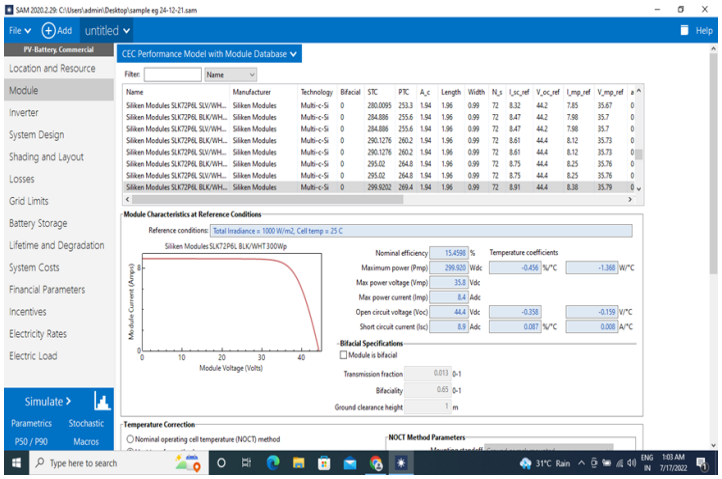

Figure 6. Selecting a module

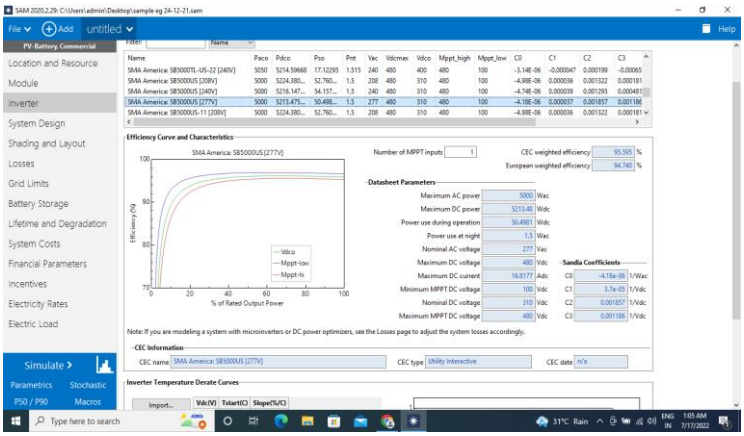

Figure 7. Selecting an inverter

7. SIMULATION RESULTS

In Figure 8, energy production data is shown at monthly basis. This shows that the maximum energy is produced in the months of March, April and May, the least energy produced is in the months of January and December. In Figure 9, the energy production data at yearly basis is shown for a span of about 25 years. The simulated result shows that energy production in KWh gradually decreases with respect to year.

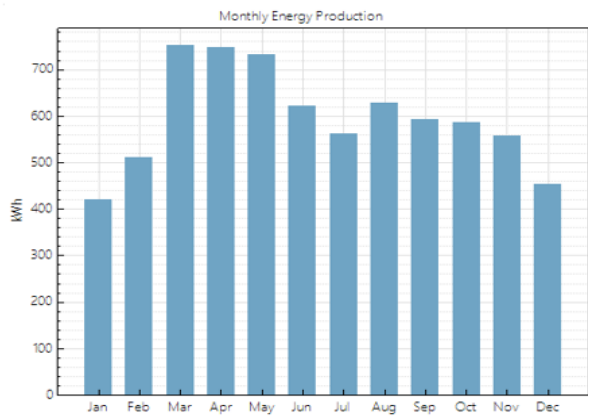

Figure 8. Monthly energy production

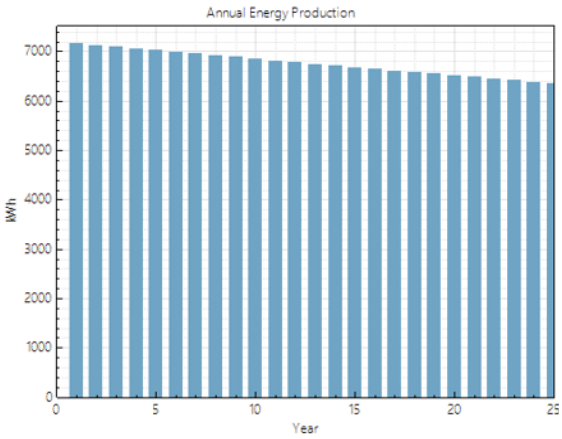

Figure 9. Annual energy production

8. RESULT SUMMARY

After simulation, the result summary indicates, as shown in Table 1, that the annual energy production is 7136 kWh, with a capacity factor of 17.4% and an energy yield of 1526 kWh/kW. The battery charging in a PV-plus-battery-connected system is 100% efficient, with no clipping. The economic benefits of the PV system with DC battery storage compared to the PV system without battery storage are presented in the results. The findings reveal that the electricity bill without the system amounts to Indian Rupees (INR) 74821.66, while the bill with the system is INR 30444.12, resulting in a net savings of Rs 44377.54. The capacity factor represents the amount of energy produced relative to the estimated maximum energy output. The energy yield is the calculated output energy obtained from a solar panel after accounting for factors such as shade, dust, and heat.

Table 1. The result summay

Metric	Value
Annual Energy	7163 kWh
Capacity Factor	17.4%
Energy Yield	1,526 kWh/kW
Performance Ratio	0.77
Battery Charge Energy from System	100.0%
Electricity Bill without system	Rs 74821.66/-
Electricity Bill with system	Rs 30444.12/-
Net Savings with system	Rs 44377.54/-

9. CONCLUSION

The different configuration of the PV plus battery storage system is analyzed as storage system has become an essential part in most solar PV applications. As without any storage system, power is clipped in some cases. The modeling representation can feature the different configurations such as AC or DC coupled battery system. It can be seen that of all three photovoltaic connected system, DC coupled battery storage system gives the best results as in AC coupled battery storage system, extra inverter is required and some of PV power generated is lost, which is taken care of in DC coupled storage system. A residential model was studied on SAM software was studied showing that battery storage system gives better result.

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