# Design and Simulation of On-Grid & Off-Grid Solar PV System

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*Abstract—* Today, the cost of traditional energy is skyrocketing, especially in countries like India, where most of the non-renewable energy is imported from foreign countries. Especially in India, there is a lot of sun throughout the year. Even in relatively bad months, states like Rajasthan and Gujarat have enormous solar potential. The objective of this article is to plan and design a solar photovoltaic system that can provide electricity to urban facilities while feeding excess electricity to the grid, and a solar photovoltaic system that can operate on its own in rural areas. It can provide comfort even in the absence of sunlight. The design process of the solar photovoltaic system has been described step by step. According to the load requirements and component specifications, i.e., the selection of photovoltaic panels, cables, and inverters, determine the equipment classification to be used. The configuration of the string and its calculations are explained in detail. It also shows the simulation based on MPPT technology as well as the circuit diagram and results. Since the MPPT algorithm is a key factor in the two systems, it has been explained in detail through a neat circuit diagram to ensure that the maximum power can be obtained from the photovoltaic panel at any time. It is connected with a DC-DC boost power converter to ensure various DC loads. The off-grid model has a two-way converter connected between the DC bus of the photovoltaic system and the battery. In order to drive the household AC load, the 3 DC-AC converter is built on the On-grid model and supplies power from the photovoltaic panel through the DC-DC converter. All three models are made with the help of simulation, and the results are verified using MATLAB Simulink.

*Keywords— Solar PV, state of charge, inverter, battery, on grid, off grid.*

## I. INTRODUCTION

Electricity has been an integral part of mankind and scaling up across the world due to widespread usage by many sectors. The major share is contributed by thermal generation but suffers from CO2 emissions. Since last two decades, the paradigm has therefore shifted towards exploring the potential of renewable energy sources. Among the available resources such as wind, biomass, geothermal and others, solar energy gained momentum as it is freely available. The process of converting sun light (photons) to electric energy (voltage) is called the solar photovoltaic (PV) effect. Photovoltaic solar cells are made up of semi conducting material and it is nothing but a normal p-n junction diode which is designed in a such a manner that p-n junction is near to the upper surface of the panel so the radiation directly falls on it. Photovoltaic panel or module is made up of many photovoltaic cells connected in series and this is one component of solar PV system. Solar PV system contain many solar PV panels connected in series and parallel to generate high amount of power from sun light and this generates direct current fed to inverter, which converts the power to alternating current (AC) for use in your home, fed to the grid or stored for future use.

## II. SOLAR PV SYSTEM SIZE COMPUTATION

### A. On Grid PV Solar System

For an On-Grid system, the only consideration in system size calculation is the amount of load or energy consumption followed by a financial analysis of the system.

**Step 1**: Calculate total kWh per day by multiplying the loads by time of use per day.

Power consumption per day (kWh/day) = 51 kW x 9 hr = 459 kWh

**Step 2**: Calculate the size of the solar PV system, by dividing energy consumption per day by sunlight hours per day. Considering the 25% of power losses in panels, wires, and other components.

Size of solar system = kWh/day ÷ (Average peak hrs/day x 1.25) = 459 kWh ÷ (5.7 hr x 1.25) = 100.65 kW.

Table I – Power consumption of the building

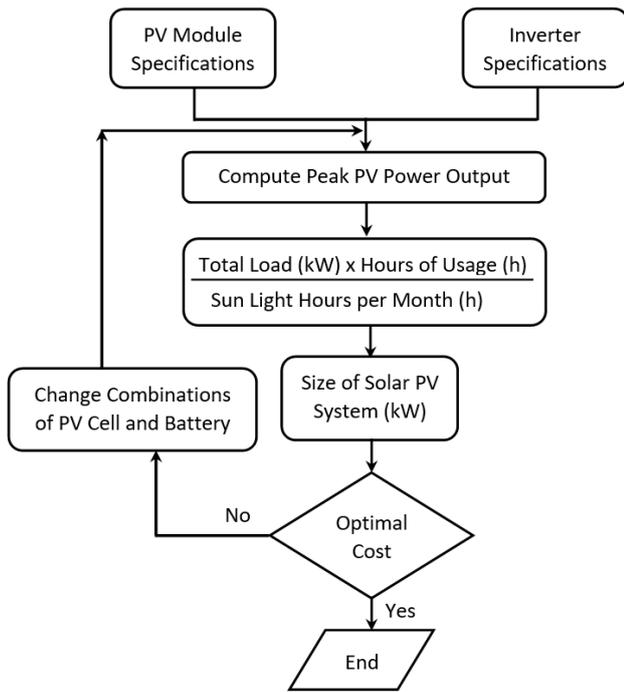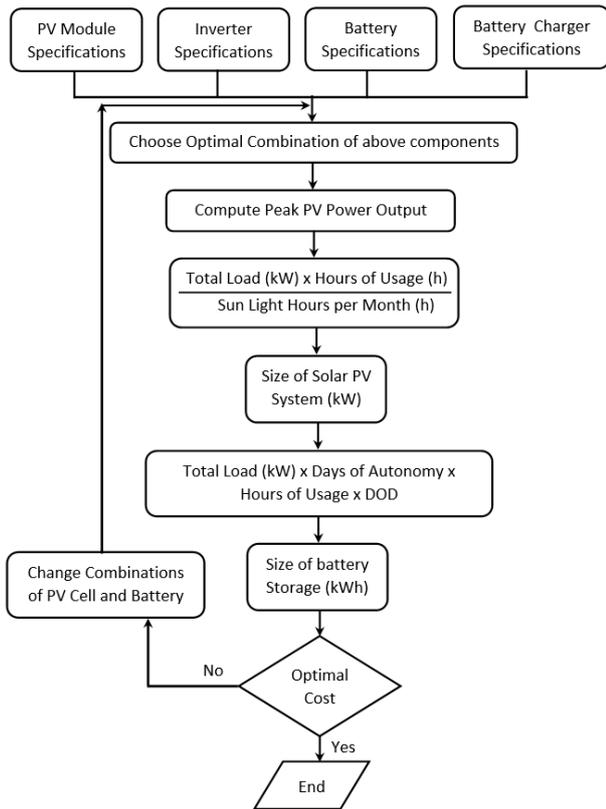| Type of load | Power consumption |
|---|---|
| Lights (40W) | 29.58 kW |
| Fans (80W) | 4.018 kW |
| Air conditioning (3Hp) | 17.4 kW |
| Total Load | 51 kW |

Fig. 1: On-Grid PV System Design



Fig. 2: Flowchart for Off-Grid PV System Design

## B. Off-Grid Solar PV System

For sizing of an Off-Grid system, the load during sunlight hours is considered and the load during hours when sunlight is not available. On top of that, the batteries should be able to power essential loads during an elongated period of time when sunlight is not available however, this data is location specific. The PV system sizing process for the stated loads in the previous section would be identical but it is required to calculate the battery capacity. Hence, the battery bank size calculation is stated as follows:

**Step 3:** For calculating battery bank size, let's assume we need 3 days of autonomy and our Depth of Discharge (DoD) is 90% for Li-ion batteries.

Size of battery bank
= kWh per day x Days of Autonomy ÷ Max DoD
= 459 kWh x 3 ÷ 0.9 = 1530 kWh.

The output voltage ($V_{out}$) of the AC coupled battery inverter is 120 V. Thus, the battery capacity 1530 kwh / 120 V= 12750 Ah.

### III. STRING CONFIGURATION

According to last two-years data of Vadodara (Gujarat), minimum temperature was 10 °C and maximum temperature was 45 °C. Therefore, temperature effect on 330 Watt 72 cells polycrystalline panel of different manufacturers were considered and Jinko 330M PV panel is selected for our system. For the grid connected system Solaredge 82.8 kW inverter is chosen as it can be oversized to 133% which is 110 kW and firmly inside our system capacity of 100 kW. This inverter eventually helps to reduce capital cost of the system and increase the efficiency. Due to varied design considerations as well as compatibility with the AC-coupled inverter, for the Off-grid solar PV system, 3 Fronius ECO 27.0 kW inverters have been chosen. Their combined capacity will be just under 100 kW. Each of these inverters will be then power-chained together. The Solar PV panels remains the same for both the systems.

Table II – String configuration for the On-Grid system

| 100 kW Solar PV System | |
|---|---|
| Total number of panels | 305 Panels |
| Number of parallel strings possible | 17 Strings |
| Number of parallel strings finalized | 9 Strings |
| Minimum number of panels per string | 10 Panels |
| Maximum number of panels per string | 40 Panels |
| Number of panels per string (Finalized) | 34 Panels |

The battery and AC coupled inverter should be selected simultaneously as their ability to efficiently communicate with each other can increase the efficiency as well the long-term battery health. New age Bi-directional inverters are capable of both charging the battery via PV inverter input as well as provide the load with electrical power. The Selectronic SPLC1200 with the Powerplus LiFe series Li-ion batteries have been selected. Total load is 51 kW but the Selectronic SPLC1200 can only provide a 20 kW continuous output; Hence, it was preferred to use 3 battery inverters power-chained with each other and each inverter on one phase.

Table III – String configuration for the Off-Grid system

| 3 x 33 kW Solar PV System = 99 kW | |
|---|---|
| Total no. of panels | 100 x 3 = 300 panels |
| No. of parallel strings | 5 Strings per inverter |
| Minimum no. of panels per string | 15 panels |
| Maximum no. of panels per string | 27 panels |
| No. of panels per string (Finalized) | 20 panels |

## IV. SIMULATION OF SOLAR PV SYSTEM

The grid-connected system essentially has two important sections; the boost converter and DC-AC inverter responsible for matching the system voltage to the grid voltage. The boost converter output is fed to the DC-AC three phase inverter, hysteresis current controller is used to limit the inverter current. LC filter is used to remove the unwanted frequency components from the inverter. The inverter operates at 415 V in compliance with the Indian Standards. Three phase supply is fed to the step-up transformer, function of the transformer is voltage source output power constant, the voltage and current ratio should be changes, power output fed to grid and this system arrangement in shown in Fig. 5.
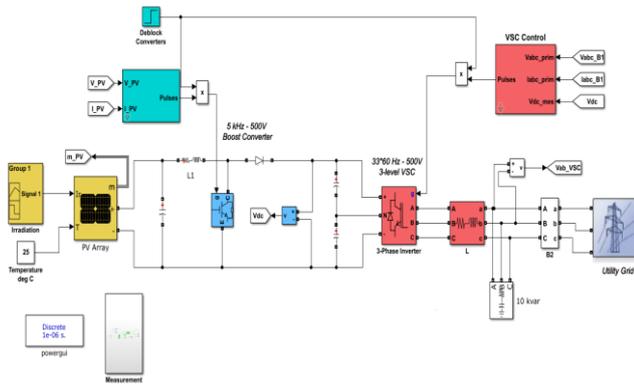


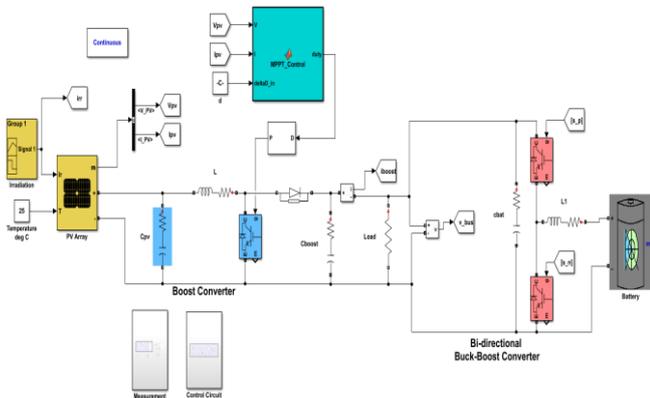Fig. 3: Simulink Model of the On-Grid Solar PV System



Fig. 4: Simulink Model of the Off-Grid Solar PV System

In a battery inverter which is used in an off-grid solar PV system, a link between the storage device and the DC bus of the boost converter is required. This is fulfilled by a bi-directional DC-DC buck-boost converter. It provides charging and discharging states for the storage device i.e., the battery. The bidirectional Buck-Boost converter operates depending on the battery voltage. If the DC bus voltage is greater than that of the battery voltage, the converter operates in boost mode, supplying power to the DC link. On the contrary, if the battery voltage is lower than that of the DC link, the converter operates in buck mode and the battery will be charged by any excess power available from the DC bus side of the system.

## V. SIMULATION RESULTS ON-GRID

There will be 9 parallel strings with 34 330W PV panels in each string. That brings the total to 306 panels.
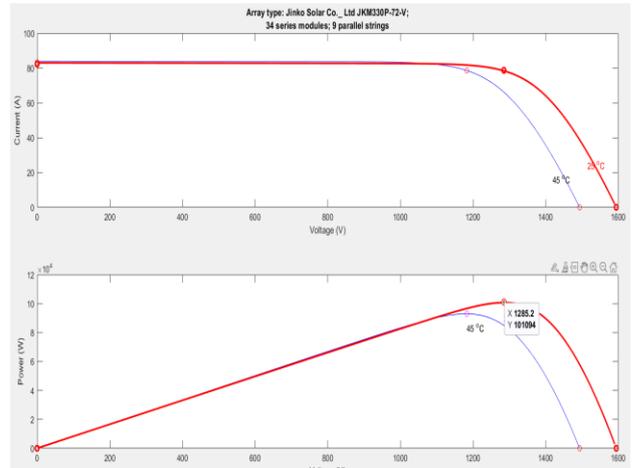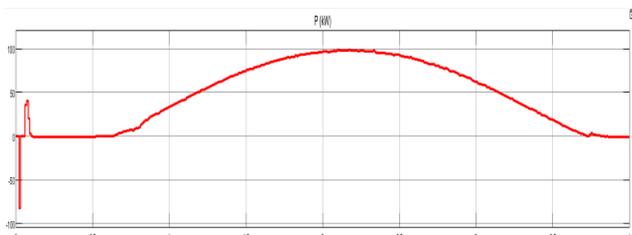


Fig. 5: I-V and P-V Curve of PV System
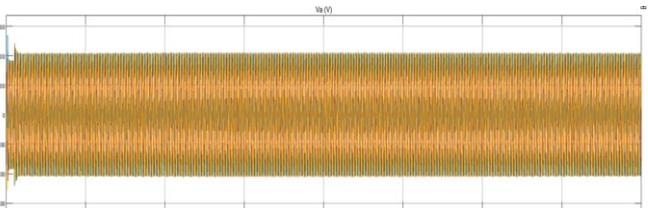


Fig. 6: Power Fed to the Grid



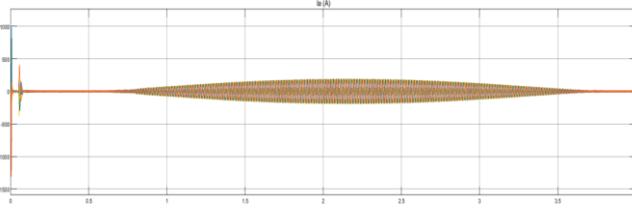Fig 7: Inverter Three Phase Voltage



Fig. 8: Inverter Current
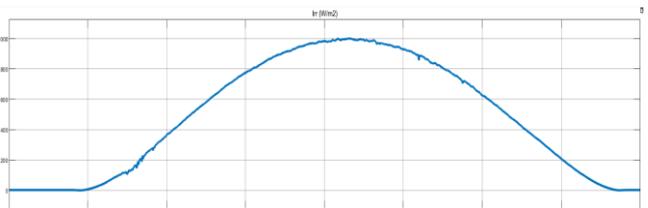
## VI. SIMULATION RESULTS OFF-GRID
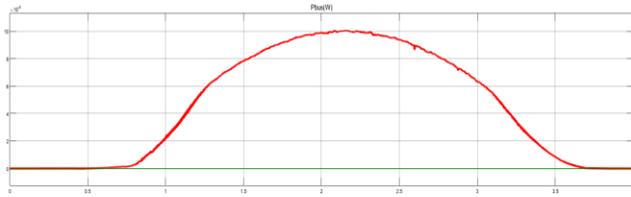


Fig. 9: Irradiance

Fig. 10: Overall Power

In the above fig. 5, 6, & 7, it is seen that the 100 kW system is operating at its peak efficiency and maximum power. The voltage and power seen at the peak can be compared to the values in Fig. 5 i.e., power curves for entire PV panels connected in the system.



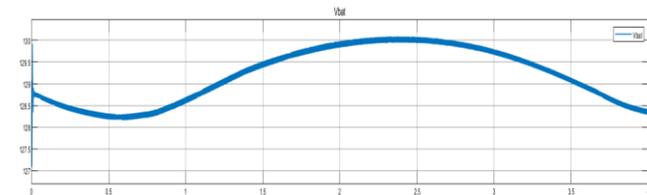Fig. 11: State of Charge of Battery
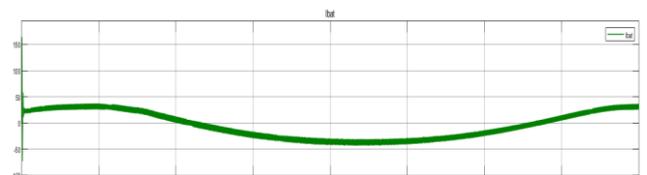


Fig. 12: Battery Voltage



Fig. 13: Battery Current

In the fig. 13, it is seen that current is fed into the battery when the PV system is operating at optimal conditions but draws current from the battery when the system is not generating enough electrical power. This can be noted from the change in SoC in Fig. 10. The battery was kept at 45% during system initiation and drops down in the first phase, the SoC rises again as the battery charges from the PV system.

## VII. CONCLUSION

This paper illustrates how the nation might overcome its severe power shortage brought on by the energy crisis by harnessing solar energy. The solar plant can be harnessed wherever that is suitable, and solar energy is accessible across the nation. However, the cost of solar PV panels is decreasing. It is clear that, despite the solar system's initial seeming cost, it is actually quite economical in the long run—that is, provided the software is used to choose the right equipment combinations.

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