# A Design of Solar Photovoltaic Generation for Distribution Network

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***Abstract:*** In the last few years, the growth of Solar Photovoltaic Generation is increasing drastically. This paper presents the design of SPVG and connection with distribution networks. Total two distribution networks, namely, 8-bus system and 9-bus system are considered. The 40 MW SPVG is connected with 8-bus system and 4 x 8 MW are connected with 9-bus network. The details calculations of SPVG are shown in this paper with calculation of distribution transformers.

***Index Terms:*** **Solar Photovoltaic Generation, Distribution network, Distribution transformers.**

## I. INTRODUCTION

Environmental challenges such as global warming and greenhouse gas emissions are driving the engineering community to seek out more renewable energy sources or develop new technologies that can take use of clean energy sources [1]. The SPVG are gaining a lot of interest as potential sources of electrical power to replace or supplement present fossil and nuclear power generation systems [2]. These generations are currently not cost competitive with conventional power generation systems. Because the cost of concentration optics in bulk is substantially cheaper than the cost of solar cells, different efforts have been made to reduce manufacturing costs by using various concentrator optics. Solar PV outperforms hydroelectric, thermal, and nuclear power in terms of cost of production since it requires nearly little maintenance and does not deplete natural resources or cause pollution. As a result, solar PV power sources could be a viable solution to the world's catastrophic power shortages.

Increasing PV panel efficiency and increasing energy output has now become a global concern, particularly for developing nations like India, where there are few quality R&D facilities and few PV system manufacturing businesses [3]. The design and development of a solar PV system is a critical step in the installation of a solar PV system. The system's performance is solely determined by the solar resource available on site, as well as the system's design and load factors [4]. The energy generated in the PV array depends upon incident solar radiation and solar cell operating temperature which is affected by ambient air temperature, wind speed, etc. These parameters change on hourly, daily, monthly and yearly basis. The daily mean value (averaged over the month) of these variable parameters is, therefore, often considered for solar PV system design. For certain locations even the mean values are not available. This paper presents the sizing and designing of SPVG and connection with grid. Also, the designing of distribution transformers at the PCC is shown with the required parameters.

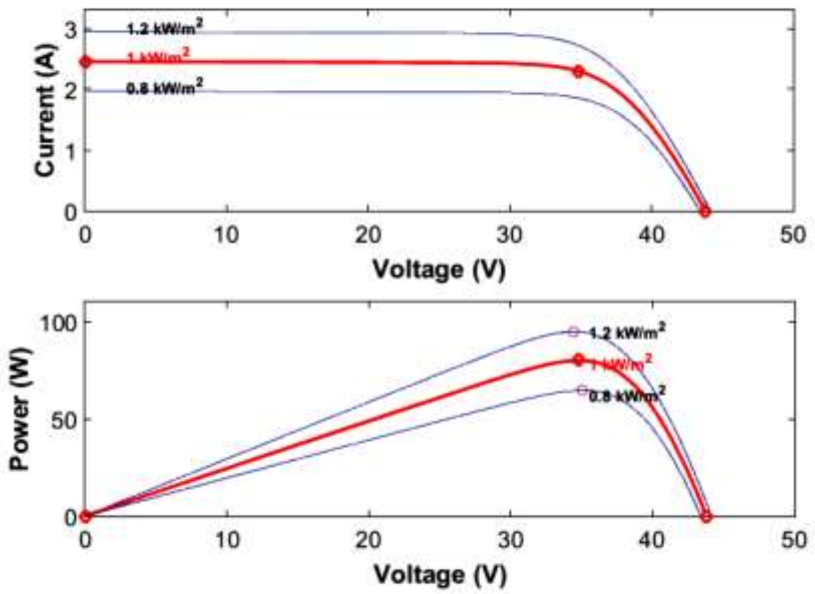


Fig. 1. PV Array I-V and P-V characteristics at 250°C constant temperature and variable solar irradiation [5]

## II. I-V AND P-V CHARACTERISTICS

SPVG technology is widely employed these days. If solar energy is efficiently harnessed by contemporary technology, it is the most efficient renewable energy source [1]. The sunlight is directly turned into electrical energy in a solar PV system. The quantity of energy that a solar cell can produce is mostly determined by the cells' intrinsic qualities and the amount of solar radiation that falls on the panel. Temperature and sun irradiation are two significant climatic elements that influence the characteristics of all solar panels. Figure 1 shows the I-V and P-V characteristics of a solar array with a constant temperature of 250°C and various solar irradiations of 1.2kW/m2, 1kW/m2, and 0.8kW/m2 [5]. The current across the panel increases dramatically when the irradiance increases, with an almost minimal change in the voltage, resulting in an increase in the power produced. As a result, the more solar irradiation there is, the more power is generated.

Figure 2 depicts the I-V and P-V characteristics of a solar array with shifting temperatures and constant irradiation of 1000W/m2 at temperatures of 650C, 450C, and 250C [5]. With an increase in temperature, the voltage decreases while the current remains unchanged, lowering the array's power. As a result, at extremely high temperatures, the array will not perform efficiently and will not produce a large amount of power.

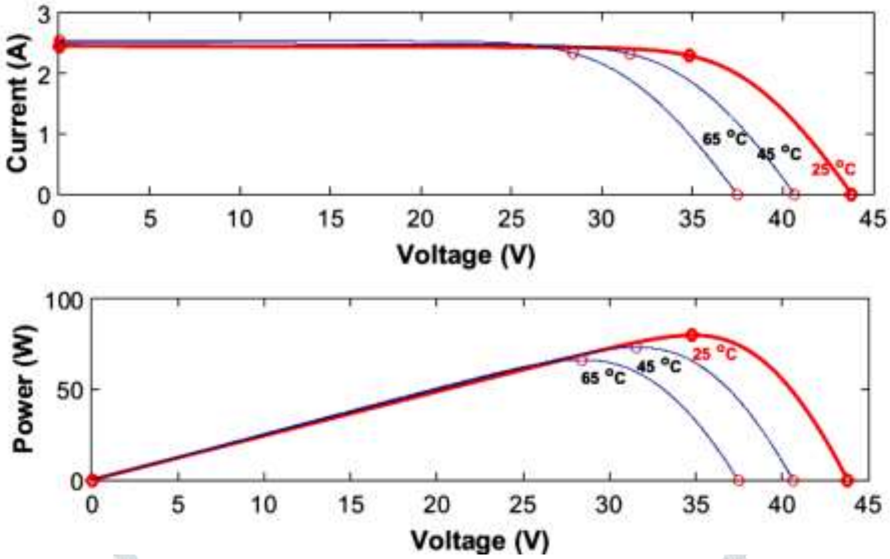


Fig. 2. PV array I-V and P-V characteristics at 1000W/m2 constant solar irradiation and variable temperature [5]

## III. DESIGN AND CALCULATION OF SPVG

*Case 1: 8-bus network*

The 40 MW SPVG is configured based on data given in the literature [6-8]. The configuration of solar photovoltaic (SPV) and inverter is given in Figure 3 and characteristic of SPV module is given in Table 1.

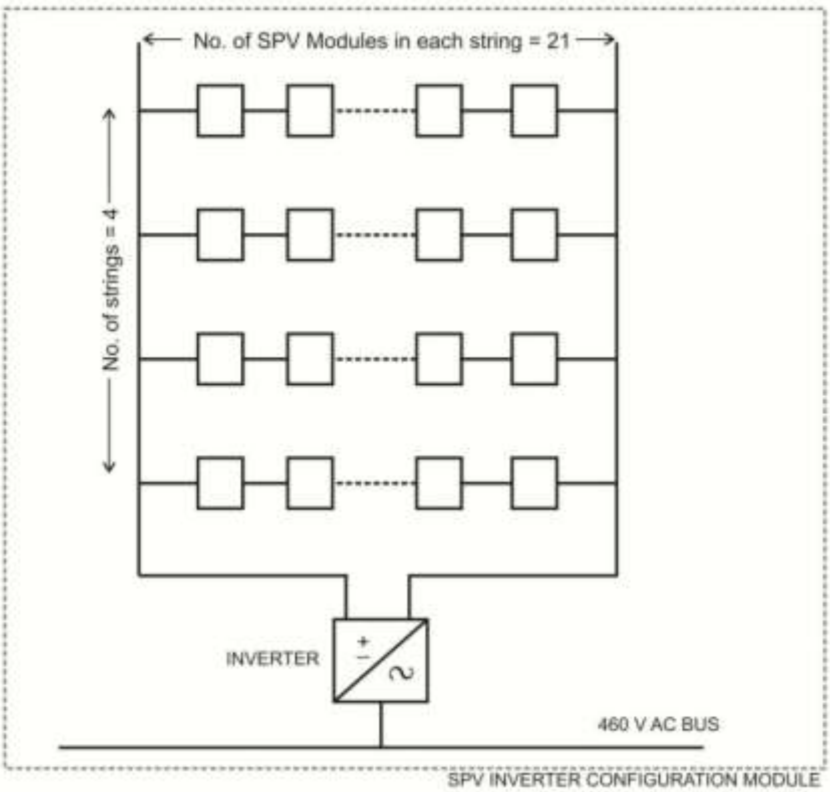


Fig. 3. Solar Photovoltaic (SPV) modules and inverter configuration

**Table 1.** SPV module characteristic

| SPV parameters | |
|---|---|
| $P_{MPP}$ (W) | 250 |
| $V_{OC}$ (V) | 37.20 |
| $V_{MPP}$ (V) | 30.10 |
| $I_{SC}$ (A) | 8.87 |
| $I_{MPP}$ (A) | 8.31 |
| Design | IEC-61853- |
| Technology | Si-Poly |

In each string, 21 SPV modules are connected in series providing an average voltage and current of 632 V (30.1×21) and 8.31 A respectively. Such four strings are connected in parallel. This way, the DC input given to inverter is 632 V and 33.24 A (8.31×4). The inverter and SPV array connection details are given in Table 2. The inverter characteristic is given in Table 3.
The inverter output is calculated using following equations.

$$V_m = \frac{\pi \times V_{DC}}{3} \quad (1)$$

$$V_{AC} = \frac{V_m}{\sqrt{2}} \quad (2)$$

$$I_m = \frac{\pi \times I_{DC}}{3} \quad (3)$$

$$I_{AC} = \frac{I_m}{\sqrt{2}} \quad (4)$$

$$P_{AC} = \sqrt{3} \times V_{AC} \times I_{AC} \quad (5)$$

**Table 2.** Inverter and SPV array connection detail

| | |
|---|---|
| Inverter type | String inverter with MPPT |
| Total no. of inverters | 51 |
| $P_{DC}$/ $P_{AC}$ of inverter | 23 KW (1-Φ)/ 20 KW (3- Φ) |
| MPP voltage range | 490V- 800V |
| AC voltage range | 230V-460V |
| Efficiency of inverter | 98.7 % |
| No. of strings/inverter | 4 |
| Connection of string/inverter | Parallel |
| No. of SPV module in each string | 21 |
| SPV connection in each string | Series |
| Total no. of strings | 204 (51 × 4) |
| Total no. SPV modules | 4284 (204 × 21) |

**Table 3.** Inverter characteristic

| Parameters | Input (DC) | Output (AC) |
|---|---|---|
| Voltage (V) | 632.1 | 468 |
| Current (A) | 33.24 | 24.61 |
| Power (KW) | 21 KW | 20 KW |

The calculated output quantities of inverter are 468 V, 24.61 A and 20 KW as listed in Table 3. A total no. of 51 SPV-inverter configuration modules is connected in parallel to 460 V AC bus as shown in Figure 4. The 1.25 MVA transformer (TD) is used to step up the voltage to 11 kV and the average transmitted current is 52 A. The details of transformers are given in Table 4. This results in a 1 MW SPVG as presented in Figure 4.

**Table 4:** Transformers detail

| Transformer | $T_D$ | $T_H$ |
|---|---|---|
| Rated MVA | 1.25 MVA | 25 MVA |
| HV rating | 11 kV | 150 kV |
| LV rating | 0.460 kV | 11 kV |
| Impedance | 4.7 % | 4 % |

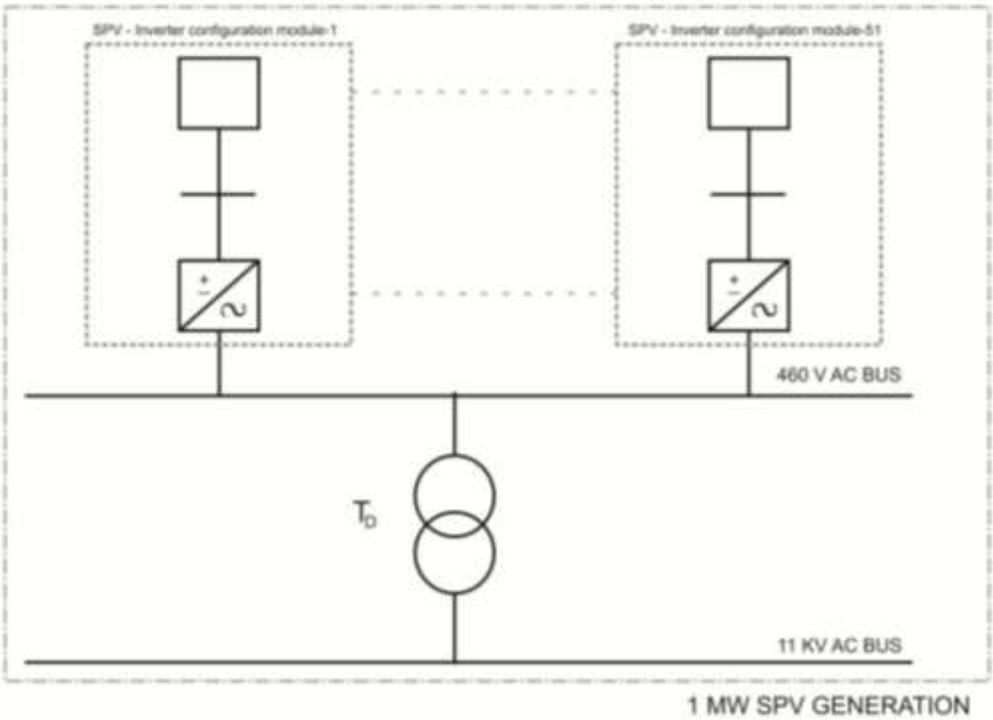


Fig. 4. MW SPV Generation

The configuration of 40 MW SPVG plant is shown in Figure 5. A pair of 20 x 1 MW SPVG is connected in parallels to a pair of transformers (TH) which is step-up the voltage to 150 kV. The TH is connected between each 20 MW SPVG and bus 9. The average current supplied by 2 x TH to the grid is 150 A.

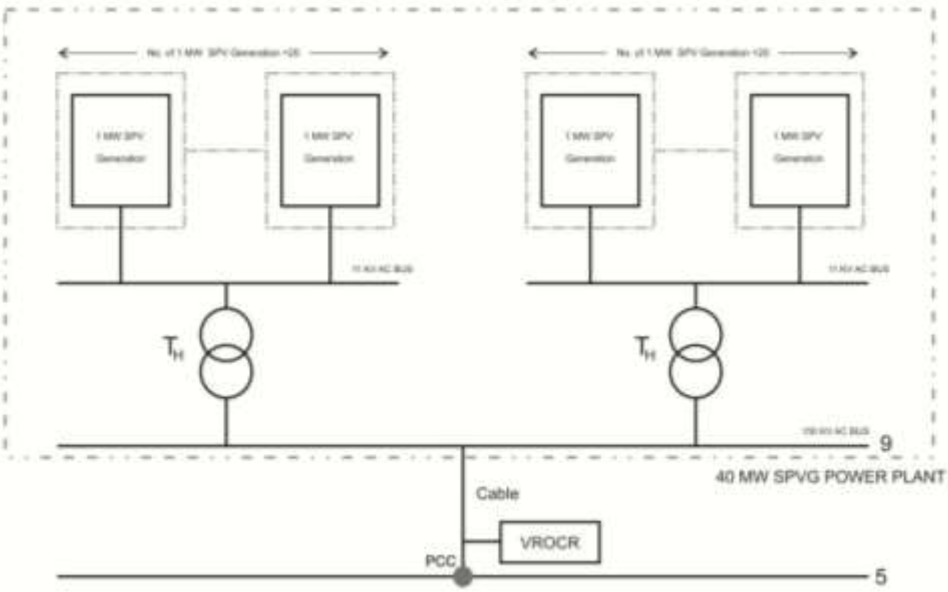


Fig. 5. 40 MW SPVG

The 40 MW SPVG is connected to the 8-bus network by a 10-km cable. The resistance and reactance of the cable are 0.0057 ohm/km and 0.071 ohm/km respectively. The minimum rating of 40 MW is required for SPVG, if it is connected to the high voltage grid of 132 kV or above [1]. Accordingly, the 40 MW SPVG is designed and it supplies 150 A current to the 8-bus network through bus 5 as shown in Figure 6. The 8-bus system data can be found in [9].

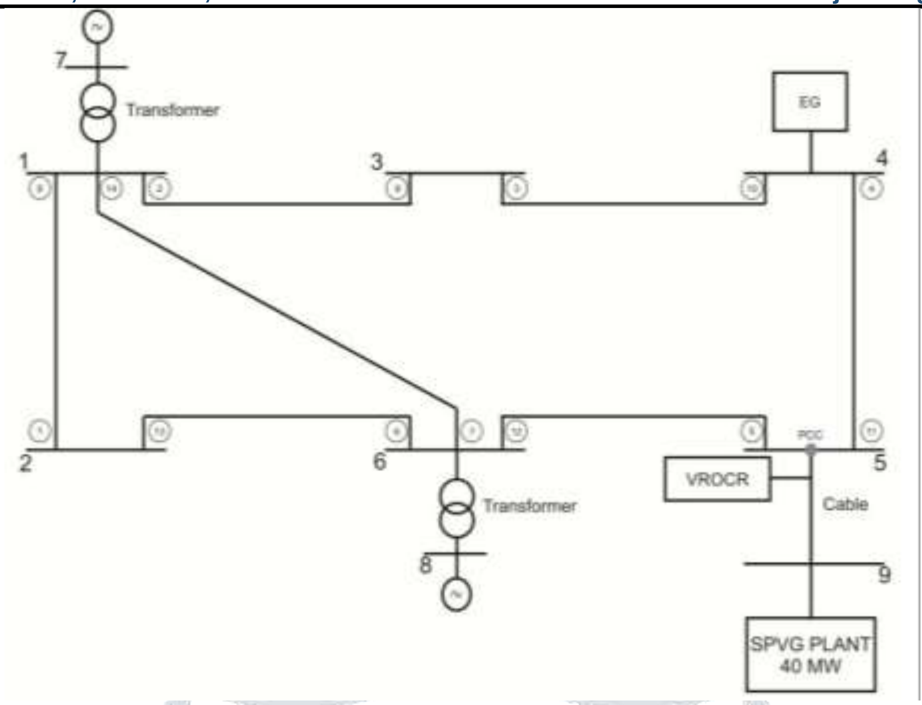


Fig. 6. Single line diagram of 40 MW SPVG connected 8-bus network [10]

Case 2: 9-bus network

As shown in Figure 7, four SPVG connected system with nine buses (b1 to b9), is considered in this case. The SPVG of 8-10 MW is required for connecting to 30-34.5 kV grid [1]. Therefore, the 8 MW SPVG is configured by connecting the pair of 8 × (1 MW SPVG as shown in Figure 4) in parallel. These are connected as SPVG1 at b7, SPVG2 at b5, SPVG3 at b9 and SPVG4 at b3 through 10 MVA, 11/33 kV transformer (transformer is not presented in Figure 7). This way, each SPVG is designed with ratings of 8 MW and 33 kV ratings, and each SPVG supplies the current of 138 A to the network. The remaining data of this system can be found in [11].

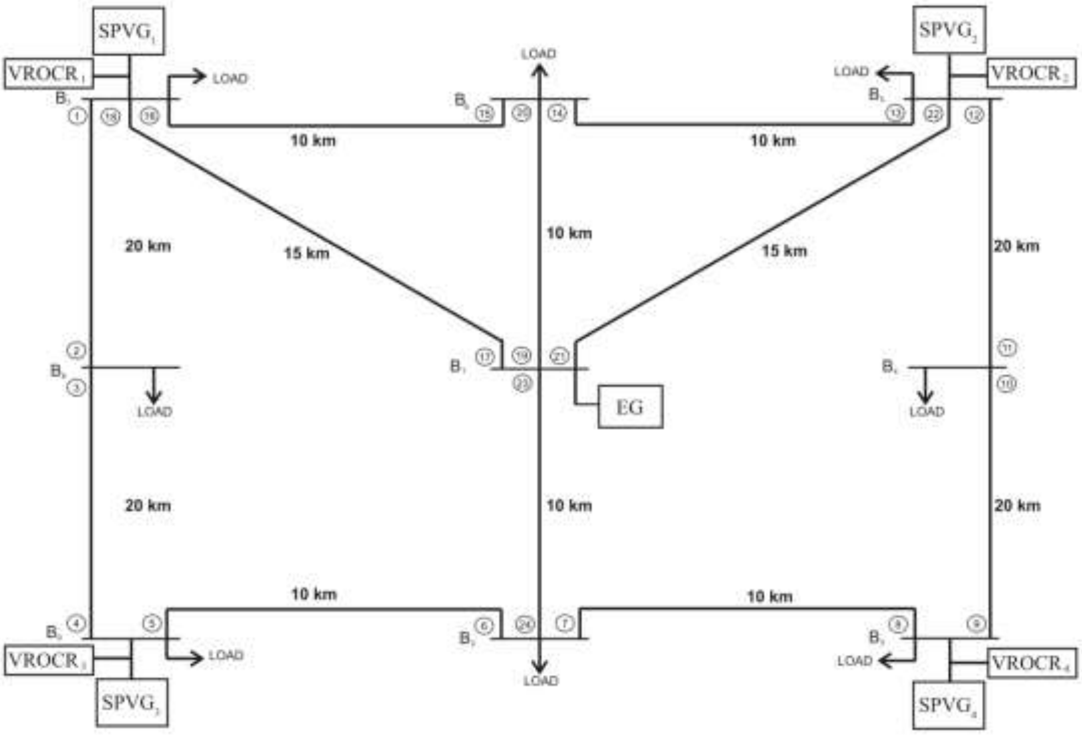


Fig. 7. Single line diagram of 9-bus network [11]

## IV. CONCLUSION

The demand for electrical power is increasing every day, and it is currently supplied by fossil fuels, resulting in massive carbon emissions in the environment, prompting electrical engineers to look for ways to create power using renewable energy sources. The goal of this work is to design and calculate the SPVG that can meet power demand in isolated places or in stand-alone mode. In this paper, the SPVGs are deign and connected with standard benchmark systems, namely, 8-bus and 9-bus systems. The 8-bus system have 40 MW SPVG connection and 9-bus system have 4 x 8 MW SPVGs connection. This paper provides the basic designing and calculation methodology for SPVG and its connection with the grid.

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