Comprehensive Approach of Modeling and Simulation of Solar Photovoltaic Power Plant

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ABSTRACT

The growing energy demand in developing nations has triggered the issue of energy security. This has made it essential to utilize the potential of renewable resources. Grid connected PV systems is the best alternatives in renewable energy at large scale. Analysis of these grid connected plants could help in designing, operating and maintenance of new grid connected systems. The objective of this paper is to model the design and simulation of grid connected 10 MW solar photovoltaic power plant by using the specifications of equipment provided based on the availability of the component in Shivanasamudram, Karnataka, India. The PV generation system behaves well in different conditions of solar radiance and temperature of PV panels, preserving its stability and succeeding in extracting the maximum power from the PV panels by MPPT technique.

Keywords: Grid-connected PV plant, MPPT, Photovoltaic, Solar Power Plant, Solar cell, Semiconductor material.

I. INTRODUCTION

Increasing demand and scarcity in conventional sources have triggered the scientist for the development of research in the field of renewable energy sources especially solar energy. India has tremendous scope of generating solar energy. The reason being the geographical location and it receives solar radiation almost throughout the year, which amounts to 3000 h of sunshine. This is equal to more than 5000 trillion kWh. Almost all parts of India receive 4–7 kWh of solar radiation per sq meter[1]. Solar cells are made of semiconductor materials, such as silicon. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity [2]. The solar power where sun hits atmosphere is 1017 W. The solar power on the surface of earth is 1016 W. The total worldwide power demand of all needs of civilization is 1013 W. Therefore, the sun gives us 1000 times more power than we need. If we can use 5% of this energy, it will be 50 times what the world will require [3].The ever increasing energy consumption, the soaring cost and the exhaustible nature of fossil fuel, and the worsening global environment have created increased interest in green power generation systems[4]. The amount of energy generated from PV power has a greater importance in the energy generation. With the increase of renewable penetration, the grid support provided by these sources is fundamental. As a result, new grid are appearing or being updated, forcing PV power plants to provide grid support [5]. In one day, it provides more energy than our current population would consume in 27 years. In fact, “The amount of solar radiation striking the earth over a three-day period is equivalent to the energy stored in all fossil energy sources.

The operation of a photovoltaic (PV) cell requires 3 basic attributes:
1. The absorption of light, generating either electron-hole pairs or excitons.
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit[6].

This technology requires little maintenance but it needs a good implementation of the DC-DC or/and DC-AC converters to obtain high efficiencies. There are lots of researches made in the field of photovoltaic conversion and propose new converters, among them a SEPIC converter is designed [7]. A photovoltaic array is made with combined series/parallel combinations of pv solar modules which are composed of combination of pv cells usually assembled in series [8]. This will be a very good way to boost the existing electricity production.
capacity in the country, which is mainly from hydro and thermal sources. This will contribute positively to the worsening energy situation in the country. Solar energy, being a renewable source, will also provide energy without pollutants and greenhouse gas emissions. This can go a long way to help mitigate the adverse effect of global warming as well as contribute to sustainable energy development [9].

To the best of author’s knowledge, minimal work is dealt with the design and simulation of grid connected 10MW solar photovoltaic plant by using the specifications of equipment are provided based on the availability of the component in plant. The present work concentrates to get an optimization of the power supplied to the network, depending on the irradiance intensity of the sun.

II. CIRCUIT MODELLING OF SOLAR CELL

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modeled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered here

![Equivalent circuit of photovoltaic cell](image)

General mathematical description of I-V output characteristics for a PV cell has shown below. The PV cell is usually represented by the single diode model. The single diode equivalent circuit of a solar cell is shown in Figure 1. The I-V characteristics equation of solar cell is given as follows:

\[
I = I_{ph} - I_s \left[ \exp \left( \frac{q(V + R_s I)}{nKT} \right) - 1 \right] - \frac{V + R_s I}{R_{sh}}
\]

Where:
- \( I \): cell current (A).
- \( I_{ph} \): light generated current (A).
- \( I_s \): diode saturation current (A).
- \( q \): charge of electron = 1.6x10^-19 (Coulomb).
- \( V \): cell output voltage (V).
- \( R_s \): series resistor (Ω).
- \( K \): Boltzmann constant = 1.380662 x 10^-23 (J/K).
- \( T \): cell temperature (K).
- \( R_{sh} \): shunt resistor (Ω).

For a given irradiance and temperature, the photovoltaic cell based on silicon has a nonlinear I-V characteristic as it is shown in Fig.2.

![Characteristic of I-V curve of photovoltaic cell for a given temperature and irradiance](image)

Where:
- \( I_{sc} \): short circuit current (A).
- \( I_{MPP} \): current when power is max (A).
- \( V_{oc} \): open circuit voltage (V).
- \( V_{MPP} \): voltage when power is max (V).

III. TYPES OF SOLAR PHOTOVOLTAIC POWER SYSTEM

The PV systems are designed to supply power to electrical loads. The load may be of DC or AC type and depending on the application, the load may require power during the daytime only or during the night time only or even for 24 hours a day. Since a PV panel generates power only during sunshine hours, some energy storage arrangement is required to power the load during the non-sunshine hours. This energy storage is usually accomplished through batteries. During the non-shine hours the load may also be powered by auxiliary power sources such as diesel generator, wind generator or by connecting the PV system to the grid or some combination of these auxiliary sources as shown in Fig.3. Here preferring grid connected solar PV system only PV systems can be broadly divided into the following categories as shown in fig 3.

![Classification of photovoltaic system](image)
IV. DESIGN OF THE PV POWER GENERATION SYSTEM

The design of a PV power generation system, with an installed power of 10 MW, is proposed as follows.

1) A PV array of panels strings such as to obtain a maximum power of 10 MW;
2) A SEPIC converter used as a load regulator and respectively to convert the output voltage of the PV array to a suitable voltage for the inverter;
3) Inverter to export the electrical energy to the three-phase grid;
4) A three-phase step-up transformer to adapt the low voltage output of the inverter to the grid;
5) The PV power generation system controller, which contains the MPPT controller for the SEPIC converter and the inverter's controller.

The design controller is used to control the duty cycle inorder to maintain the operating point as close as possible to the maximum power point of the PV array.

![Block Diagram of PV Power Generation System](image1)

V. SIMULATION OF SOLAR POWER PLANT

By using the designing parameters of the PV grid given above and a simulation of a field with PV cells was done in the Simulink module which belongs to MATLAB. The Simulink model of the PV field is built using Elements from the library SimPowerSystems. The model of PV field includes the configuration of the number of PV cells in series and in parallel. The control system MPPT allows for a maximal energy recovering, irrespective to temperature and illumination. The control system MPPT allows for a maximal energy recovering, irrespective to temperature and illumination. The voltage $V_{PV}$ and the current $I_{PV}$ are continuously measured in order to deduce the power extracted from the panel. The control of the three-phase inverter is performed such as to export the power provided by the PV field in the AC network of and to preserve a constant voltage of at the output terminals. The model of the network in which the PV generating system exports power includes a MV load, step-up Transformer’s, models for long lines and connected by using a step-up transformer. Below figure shows the simulation model of 10 MW solar power plant.

![Simulink model of 10 MW solar PV grid connected power plant](image2)
VI. RESULTS AND DISCUSSIONS

In this chapter we will discuss simulation results of the components design and the simulation of a photovoltaic power generation system using MATLAB and Simulink software. The simulation results of voltage waveform, current waveform, output power are presented. The simulations results of 10 MW solar PV grid connected power plant is shown below in Figures.

A transformer is used to increase the voltage level to the voltage level of the grid and hence the power is supplied to the grid. The voltage generated is 11kV and it is same as the voltage generated by the proposed power plant.

In order to supply this electrical energy to the grid this energy needs to be converted to A.C. For this task we use an inverter thus inverter helps in converting this D.C. supply into three phase A.C. It is observed that inverter permissible DC voltage is 900 V and the same is obtained.

It is observed that 10MW solar PV grid connected power plant produces 9MWp power initially and later as the irradiation of sunlight it produces the power as shown in the below table. A special analysis tool was used from the user graphic interface "PowerGUI". By using this instrument one can notice the waveforms of the phase voltages and currents at the output are depicted. The power produced is approximately 54000 kWh/day and the generation of the proposed power plant is 50240 kWh/DAY. From generation details it is said that generation of the power is almost same as the solar power plant so therefore we can say that the PV generating system was designed properly.

VII. CONCLUSION

The present paper deals with the simulation of the designed PV grid by using Simulink. The PV generation system behaves well in different conditions of solar radiance and temperature of PV panels, and extracting the maximum power from the PV panels owing to the MPPT technique. The study shows that the PV generation system is also providing a voltage, current, power same as the real-time power plant and it is compared with the simulation power plant. The generation of the power is almost same as the real-time solar power plant so therefore the modeled design is found to be well suited for the PV generating system.
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