DESIGN, SIMULATION AND ANALYSIS OF GRID CONNECTED PHOTOVOLTAIC BASED INVERTER

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ABSTRACT
Supplying and sharing power with grid has become one of the most wanted photovoltaic applications (PV). Moreover, PV based inverter and DC to DC converters are getting more attention in recent days mainly in remote areas where connection to the grid is technically not possible. Power generation by Photovoltaic is free and reliable. This paper presents the novel technique for maximum-power point tracking based on perturb and observe algorithm of photovoltaic (PV) energy conversion system. In order to obtain the maximum power extracted from the PV array, usually two parameters are considered, namely solar irradiation and temperature, most of the research work has been carried out by considering these two parameters. The proposed technique gives optimum utilization of PV array and enhances the applications of PV systems for both stand alone and grid connected systems. The study has been carried out in the MATLAB-Simulink environment. And also validation of the simulated results with the theoretical results shows proper matching. The results obtained from the simulation of the system are very much satisfactory. It is found that PV fed inverter system is working better.

Keywords: photovoltaic, direct current, inverter, three phase supply.

INTRODUCTION
Energy has become an important and one of the basic infrastructures required for the economic development of a country. Energy security is imperative for sustained growth of economy. The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, such as solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Solar energy can be a major source of power [1]. Its potential is 178 billion MW which is about 20,000 times the world’s demand. So far it could not be developed on a large scale because of large requirement, uncertainty of availability of energy at constant rate, due to clouds, winds etc [3]. The basic block diagram which represents the overall photovoltaic inverter system is shown in Figure-1. Photovoltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free [3].

Figure-1. Block diagram of the photovoltaic grid system.

Solar electric energy demand has grown consistently by 20%-25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices [1]. This decline has been driven by the factors such as increasing efficiency of solar cells, manufacturing technology improvements and economics of scales. Photovoltaic inverter, which is the heart of a photovoltaic system which is used to convert dc power obtained from photovoltaic modules into ac power to be fed into grid. The applications of solar energy which are enjoying most success today are solar water heating, solar cookers, food refrigeration, solar furnaces and solar photovoltaic cells [4].
PHOTOVOLTAIC MODULE

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. Photovoltaic system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature [2].

The photovoltaic module has 54 multi-crystalline silicon solar cells in series and provides 395W of nominal maximum power. Table-1 shown below gives its electrical specification. The single diode model of photovoltaic cell is shown in Figure-2. The concept of modeling a photovoltaic module is no way different from modeling a photovoltaic cell. Its methodology is same as photovoltaic cell model [6]. There is no change in the parameters, but only a voltage parameter (such as the open-circuit voltage) is different and must be divided by the number of cells.

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Table-1. Electrical characteristics data of PV module taken from the datasheet.

<table>
<thead>
<tr>
<th>Electrical Characteristics</th>
<th>Type / Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power ($P_{max}$)</td>
<td>395W</td>
</tr>
<tr>
<td>Voltage at $P_{max}$ ($V_{mp}$)</td>
<td>26.2V</td>
</tr>
<tr>
<td>Current at $P_{max}$ ($I_{mp}$)</td>
<td>5.95A</td>
</tr>
<tr>
<td>Open-circuit voltage ($V_{oc}$)</td>
<td>32.2A</td>
</tr>
<tr>
<td>Short-circuit current ($I_{sc}$)</td>
<td>8.45A</td>
</tr>
</tbody>
</table>

The model consists of a current source ($I_{ph}$), a diode (D), and a series resistance ($R_s$). The effect of parallel resistance ($R_p$) is very small in a single module, thus the model does not include it. To make a better model, it also includes temperature effects on the short-circuit current ($I_{sc}$) and the reverse saturation current of diode [7]. It uses a single diode with the diode ideality factor ($n$) set to achieve the best I-V curve match.

The basic equation from the theory of semiconductors that mathematically describes the I–V characteristic of the ideal PV cell is

$$I = I_{ph, cell} - I_{O, cell} \left[ \exp \left( \frac{qV}{nkT} \right) - 1 \right]$$

The net cell current I is composed of the light-generated current $I_{ph}$ and the diode current $I_d$.

$$I = I_{ph} - I_d \left[ \exp \left( \frac{V + R_s I}{nV_o} \right) - 1 \right] - \frac{V + R_s I}{R_p}$$

The photovoltaic generator consists of solar cells connected in series and parallel fashion to provide the desired voltage and current required by the load. This photovoltaic generator exhibits nonlinear voltage-current characteristics that depend on the insolation (solar radiation). The power versus voltage characteristics for various values of series and parallel resistance is shown in Figure-3.

DC-DC CONVERTER

A DC-DC converter can be considered as DC equivalent to an AC transformer with a continuously variable turn’s ratio. Since the output of the solar array is very less, a buck-boost regulator is used to decrease and increase the output voltage level. The DC-DC converter converts directly from DC to DC and is also known as a DC chopper [5]. The photovoltaic system displays an
inherently nonlinear current-voltage (I-V) relationship, requiring an online search and identification of the optimal maximum operating power point. The MPPT controller is a power electronic DC/DC chopper or DC/AC inverter system inserted between the PV array and its electric load to achieve the optimum characteristic matching, so that PV array is able to deliver maximum available power which is also necessary to maximize the photovoltaic energy utilization. Photovoltaic cell has a single operating point where the values of the current and Voltage of the cell result in a maximum power output [9].

Figure-4. DC-DC buck boost converter circuit.

Most common used DC to DC converters in MPPT are the buck and boost, due to easy way of duty cycle control. In this paper, it is presented that a tracker for MPP using a buck - boost DC/DC converter which is able to operate in a wide range of output voltages and different loads demands. The basic relationship between input and output voltage of this converter is given by Equation 3.

\[ V_{out} = \frac{D}{1-D} V_{in} \]  

(3)

As shown in above equation, duty cycle is not support directly a linear relationship between \( V_{out} \) and \( V_{in} \). This means that a linear change in duty cycle \( D \) will not imply for example a linear change of \( V_{in} \) for keeping \( V_{out} \) constant. Thus, in this paper is proposed an alternative way of photovoltaic voltage control for achieving MPP. So, in algorithm implementation using Mat lab/Simulink, it is essential to control and change only \( D \) and not the actual duty cycle, \( D \). The circuit diagram for DC to DC converter with solar panel is shown in Figure-4.

INVERTER

The main circuit is the part where the DC electric power is converted to AC. The inverter control is based on a decoupled control of the active and reactive power. The lowest DC voltage will occur with high ambient temperature and high irradiance because the irradiance increases the cell temperature, and this effect predominates over the increase of optimal voltage caused by an increment of the irradiance at a constant cell temperature [8]. So, the minimum number of series connected modules should be determined by this worst case.

Figure-5. SVPWM based three phase inverter.

Space Vector PWM (SVPWM) is a more sophisticated technique for generating a fundamental sine wave that provides a higher voltage to the load and lower total harmonic distortion. However, the traditional Direct Current/Alternating Current technology has the disadvantages such as low utilization of DC voltage, complex operation control and high harmonic content, which cannot meet the requirements of inverter. The SVPWM can be effective to solve these problems and obtain the higher inverter’s utilization of DC voltage and lower harmonic contents [10].

SVPWM refers to a special switching sequence of the upper three power transistors of a three-phase power inverter. It has been shown to generate less harmonic distortion in the output voltages applied to the phases of an AC load and to provide more efficient use of supply voltage compared with sinusoidal modulation technique.

The circuit model of a typical three-phase voltage source SVPWM inverter is shown in Figure-5. \( S_1 \) to \( S_6 \) are the six power switches that shape the output, which are controlled by the switching variables \( a, a', b, b', c \) and \( c' \). When an upper transistor is switched on, i.e., when \( a, b \) or \( c \) is 1, the corresponding lower transistor is switched off, i.e., the corresponding \( a', b' \) or \( c' \) is 0. Therefore, the on and off states of the upper transistors \( S_1, S_3 \) and \( S_5 \) can be used to determine the output voltage.

MPPT ALGORITHM

Renewable energy sources such as solar energy are acquiring more significance, due to shortage and environmental impacts of conventional fuels. The photovoltaic system for converting solar energy into electricity is in general costly and is a vital way of electricity generation only if it can produce the maximum possible output for all weather conditions [11].

The photovoltaic array has a highly non-linear current-voltage characteristic varying with the irradiance and temperature that substantially affects the array power output. The Maximum Power Point Tracking (MPPT) control of the photovoltaic system is therefore critical for the success of a photovoltaic system. MPPT algorithms, ranging from simple hill-climbing algorithms to fuzzy
logic and neural network algorithms, have been considered extensively in the literature.

The hill climbing algorithm is widely used in practical photovoltaic systems because of its simplicity and because it does not require prior study or modeling of the source characteristics and can account for characteristics’ drift resulting from ageing, shadowing, or other operating irregularities. The basic hill climbing algorithm is the Perturb and Observe (P&O) algorithm. Although the P&O algorithm works well when the irradiance changes slowly, it exhibits erratic behavior for rapidly changing irradiance level that causes incorrect or slow power tracking. This led to the development of the Modified (MP&O) algorithm.

VOLTAGE MEASUREMENT

This circuit is designed to monitor the supply voltage. The supply voltage that has to monitor is step down by the potential transformer. The step down voltage is rectified by the precision rectifier. The precision rectifier is a configuration obtained with an operational amplifier in order to have a circuit behaving like an ideal diode or rectifier. The fundamental circuit for voltage measurement is shown in Figure-8.

The full wave rectifier is the combination of half wave precision rectifier and summing amplifier. When the input voltage is negative, there is a negative voltage on the diode, too, so it works like an open circuit, there is no current in the load and the output voltage is zero. When the input is positive, it is amplified by the operational amplifier and it turns the diode on. There is current in the load and, because of the feedback, the output voltage is equal to the input.

In this case, when the input is greater than zero, D₂ is ON and D₁ is OFF, so the output is zero. When the input is less than zero, D₂ is OFF and D₁ is ON, and the output is like the input with an amplification of $- \frac{R_2}{R_1}$. The full-wave rectifier depends on the fact that both the...
half-wave rectifier and the summing amplifier are precision circuits. It operates by producing an inverted half-wave-rectified signal and then adding that signal at double amplitude to the original signal in the summing amplifier. The result is a reversal of the selected polarity of the input signal.

Then the output of the rectified voltage is adjusted to 0-5v with the help of variable resistor VR1. Then given to ripples are filtered by the C1 capacitor. After the filtration the corresponding DC voltage is given to ADC or other related circuit.

**SIMULATION AND RESULTS**

The overall simulation model of grid system fed by Photovoltaic based inverter is shown in Figure-9. The solar panel is used here to generate DC voltage to supply to the overall system. The output voltage from the solar array is stepped up to the required level by means of buck boost converter. This converter has some of the advantages like producing higher output voltage and lower operating duty cycles when compared to other dc to dc converters.

In this system, the MOSFET based buck boost converter is used which is powered by photovoltaic array. The SVPWM technique is used to generate the triggering pulse to the MOSFET.

The maximum power in solar panel is tracked by Perturb and Observe method. Since the intensity of solar light is varying time to time, the maximum power point tracing is needed. The Perturbation and Observation algorithm is the most popular MPPT algorithm due to its simplicity. It operates by disturbing the voltage of the panel periodically, and by comparing the energy previously delivered with those after disturbance. The output of dc to dc converter is given as input to three phase SVPWM based voltage source inverter. The simulink output for the performance characteristics of three phase grid connected photovoltaic system shown in Figure-10.

Figure-9. Simulink diagram of PV based inverter grid system.

Figure-10. Simulation output of solar PV power.

The power is supplied to the grid after the it has been filtered out using the harmonic filter to get the output in sinusoidal manner. Apart from that the power supply and measurement circuits are incorporated in the system.

A power supply can be built using a transformer connected to the ac supply line to step the ac voltage to desired amplitude, then rectifying that ac voltage, filtering with a capacitor and RC filter, if desired, and finally regulating the dc voltage using an IC regulator.

Figure-11. Simulation output for three phase grid connected PV system.
CONCLUSIONS

In this paper, a theoretical study concerning the application of the SVPWM control strategy on the three-phase inverter was presented. This last aimed on the one hand to prove the effectiveness of the SVPWM in the contribution in the switching power losses reduction, and on the other hand to prove the effectiveness of the SVPWM in the contribution in the switching power losses reduction, modeling of photovoltaic array has been validated with the theoretical results obtained. An attempt has been made to develop an economical photovoltaic energy conversion for charging low power devices.

A robust MPPT methodology has been devised, which can prove more useful in terms of providing usable voltage with very little fluctuations. The P&O power point tracking algorithm when applied, it is found that an accurate PV model has the ability to increase the efficiency of the system. In addition to that a controller has to be used in order to achieve the synchronization to the grid and to perform the power management between the system and the electrical grid.

This work creates a path for the modeling and simulation of the photovoltaic based inverter systems on grid applications using MATLAB. The various system components like photovoltaic module, buck-boost converter and inverter were studied and modeled with practical data and it is validated using MATLAB. The results obtained from the simulation of the system are well and good. It is found that photovoltaic based inverter on grid applications are functioning better. The fuzzy logic application to track the maximum power in PV model may be considered as future work.

REFERENCES


