Simulation of Small Solar PV Energy System for Home Needs

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Abstract: This paper deals with the control, designing and construction of a small solar power system for home needs. A PV array of 33V to 43.2V is taken as an input and its output voltage is achieved as 360V dc using a fly back converter. The battery of 360V is charged. Then this stored energy is converted to a single phase ac of 220V and 50 Hz using a single-phase voltage source inverter. A closed loop control for maximum power point tracking (MPPT) and a PI (Proportional Integral) controller for output voltage control of VSI are used to control the system. Perturbation and observation method is applied for MPPT. The simulation of the developed model of the designed SPV system is performed in Matlab software. Simulation results are presented with linear and nonlinear loads to demonstrate its operation in satisfactory manner.

Keywords: renewable energy sources, solar pv cell, MPPT, fly back converter, voltage source inverter, PI controller

I. INTRODUCTION

Electricity is the major ingredient for development of any nation. The major problem we are facing today is to generate the electrical power in bulk by non-conventional sources. This is because the major conventional sources is not going to last for long time so there should be some alternative to meet this growing demand. Among all the available options solar energy is the first and most convenient and reliable energy for our requirement. Establishing a centralized bulk unit of solar power generation system not an effective method for generation of electrical energy. A distributed generation in their own premises will reduce the transmission cost and initial investment of huge capital. Out of all the renewable energy sources, Wind energy and solar energy are reliable energy sources. However, the renewable energy generation has a drawback that the change of the output characteristic becomes intense because the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature, and so forth. so this paper we are going to discuss about design of various blocks in solar power generation system.

It can be said that An average home has more than enough area in the roof to produce sufficient amount of solar electricity to meet all its requirements. Using an Inverter, the DC power from the PV array can be conveniently converted to AC similar to connection with normal power grid. There are only two primary disadvantages to using solar power: amount of sunlight and cost of equipment.

This paper discuss about a step-by-step procedure to design different blocks that constitute the PV array, a controller for maximum power point tracking, a dc-de flyback converter, a battery block, a VSI, a filter and the feedback control loop with PI (Proportional-Integral) controller. Detailed performance analysis is carried out for analyzing the controller performance in varying loading conditions [3].

II. SYSTEM CONFIGURATION

Fig.1 block diagram of system

The fig shows a block diagram of the solar PV energy conversion system with a dc-de converter operating in discontinuous mode, a battery, a VSI, an output filter and the feedback control loop with a PWM controller with pi controller. A very simple feedback loop needs only to measure the output voltage is existing.

The fly back converter in DCM operation is much frequently used than continuous conduction mode (CCM) operation, because the DCM contains a very small transformer magnetizing inductance, that responds more quickly and with a lower transient output voltage spike to rapid changes in output load current or input voltage. Here a fly back converter is used at the input voltage side with a feedback control loop that contains MPPT algorithm and generates PWM signal for the fly back converter and output of...
this converter is used to charge the battery. In MPPT the perturbation and observation method is applied in order to track maximum power point. It is an iterative method of obtaining maximum power point on operating curve of PV array.

The output voltage of VSI is compared with the reference output voltage and the error voltage signal is processed in the output voltage controller G(s), which in turn generates the PWM signal output for switching device of the VSI, which generates the PWM signal output for switching device of the VSI. Thus it a simple solution for controlling duty cycle of switches and gives constant output voltage at varying loads [4-5]. Fig. 2 shows the detailed circuit of proposed system.

**III. RESIDENTIAL LOAD VARIATION**

The remote area residential unit is simple and does not require large quantities of electrical energy used for lighting and electrical appliances. Figure 3 shows the proposed residential load profile.

**IV. PRINCIPLE OF OPERATION AND MODELING OF SYSTEM ELEMENTS**

**A. Solar-PV array**

A pn junction forms the base for the pv cell of solar panel, in the pv cell the pn junction is break down by using the temperature of the solar energy. The solar pv array characteristics are varying with environmental conditions and to capture the maximum energy, an MPPT controller is used with a fly back converter. Here a system is designed to feed an average load of 300W so the PV array is taken of total 750W and additional energy to charge the battery. Here three panels of 250W rated power are selected and connected in parallel to achieve the full power of 750W.

The complete behavior of PV cells can be described by five model parameters (Ipvt, N, Io, Ra, Rb) which represent the physical behavior of PV cell/module. These five parameters of PV cell/module are functions of two environmental conditions of solar irradiance and temperature. Fig.4 shows an equivalent circuit model of PV array. The PV cell is a nonlinear device and can be represented as a current source, parallel diode, however a practical PV cell model includes the connection of series and parallel internal resistance [20], namely R_s and R_b, which is expressed as equation (1) as.

\[ I = \frac{V}{R_s} - I_d \left( \exp \left( \frac{V + R_b}{V_t} \right) - 1 \right) \]  

\[ I_p = I_{pvt} \left( \frac{V + R_b}{N_q \phi_T} \right) \]

In (1), \( I \) = output current of PV, \( V \) = output voltage of PV, \( V_t = N_s K q \) = thermal voltage of array, \( N_s \) = number of cells connected in series, \( q = 1.60 \times 10^{-19} \) C, \( k = 1.380 \times 10^{-23} J K^{-1} \), \( T \) = temperature of the p-n junction (K), \( K \) and \( N \) = the diode ideality constant.

Here Ipvt is current produced by a PV cell, it is function of solar irradiance and temperature. The diode saturation current, Is is function of temperature, which is expressed in

\[ I_p = \left( I_{pvt} + K_d \Delta T \right) \frac{G_1}{G_2} \]

\[ I_d = \frac{I_{pvt} + K_d \Delta T}{\exp \left( \frac{V + K_d \Delta T}{N_q \phi_T} \right) - 1} \]

The Ipvt is the light generated current at the nominal condition which are 25°C and 1000 W/m², \( \Delta T \) =
T1-T2, T1 and T2 = actual and nominal temperature in Kelvin, G1(W/m²) = value of solar irradiation by the PV surface and
G2 = the nominal value of solar irradiation, Kc = shortcircuit current/temperature coefficient, 
Kv = open-circuit voltage/temperature coefficient, ISC = short-circuit current, 
VOC = open-circuit voltage under the nominal condition. The value for series resistance Rs is taken as 0.1Ω and Rs is 500Ω.

**Modeling of PV Cell**
The complete behavior of PV cells can be described by five model parameters (Ipv, N, Io, Ra, Rb) which represent the physical behavior of PV cell/module. These five parameters of PV cell/module are functions of two environmental conditions of solar irradiance and temperature. Fig. 4 shows an equivalent circuit model of PV array

![Equivalent circuit model of PV array](image)

Characteristics of PV array are modeled under varying conditions of temperature which is 0ºC to 50ºC and solar irradiance is changing from 200 W/m² to 1000 W/m². The results obtained for these conditions and performance characteristics of this model are shown in Figs.

![Characteristics of PV array](image)

Using these equations, PV array is modeled in Matlab, from the data sheet of SPSM250 solar panel, characteristics of solar panel is taken for modeling the system [20-21]. Results for different conditions of temperature and solar irradiance are obtained through simulation. Table-1 shows the parameters taken from datasheet.

**Table - 1 Parameters of PV Array**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power</td>
<td>250 W</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>43.21 V</td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td>7.63 A</td>
</tr>
<tr>
<td>Voltage At Max. Power</td>
<td>35.5 V</td>
</tr>
<tr>
<td>Current At Max. Power</td>
<td>7.04 A</td>
</tr>
<tr>
<td>No. of Cells</td>
<td>72</td>
</tr>
</tbody>
</table>

**B. Fly back Converter**
A flyback converter is a simplest topology of isolated dc dc converter because it has only one switch, one transformer and there is no inductor at output stage. The topology of a fly back converter used for this system is shown in Fig.5

![Circuit of flyback converter](image)

**Design of Fly back Converter**
In the fly back converter, during on time of the switch, the energy is stored in the fly back transformer while the load current is supplied by the output capacitor and during off time of the switch, the stored energy in the fly back transformer is delivered as the load current and to the capacitor for charging. In the fly back converter, the duty cycle is restricted up to 50%. This is due to time required to empty the fly back inductor flux to the output capacitor.

The different components of the fly back converter are designed using basic equations. Table-1 shows the design equations for the proposed fly back converter. Here this fly back converter is designed with a 100 kHz switching frequency in DCM operation. A battery is used at high voltage side of 360 V. The solar PV panel supplies at 85-120V with a little variation in the voltage to the converter, where it converts it to 360 V dc and the battery is charged at this voltage, which is supplied to the VSI for generating 220Vac at 50 Hz.

Using equations given in Table 3, the parameters are calculated for the fly back converter at rated power of 750W.

**Table.3. Design Equations and Calculated Values for Fly back Converter**

<table>
<thead>
<tr>
<th>Name of Component</th>
<th>Equation for Flyback</th>
<th>Calculated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turns Ratio</td>
<td>( n = \frac{N_2}{N_1} = \frac{\eta D_{max} V_i}{(1 - D_{max}) V_o} )</td>
<td>1:4</td>
</tr>
<tr>
<td>Magnetizing Inductance</td>
<td>( L_m(\text{max}) = \frac{V_i D_{max}}{f_s c M_{max}} )</td>
<td>1.2 mH</td>
</tr>
<tr>
<td>Output Capacitance</td>
<td>( C_o = \frac{D_{max} V_o}{f_s c R_s V_{pp}} )</td>
<td>20 μF</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>( f_s c )</td>
<td>100 kHz</td>
</tr>
</tbody>
</table>

Considering, 
\( f_s c \) (Switching Frequency of converter switches) = 100kHz, 
\( L_m \) (magnetizing Inductance) = 1.2 mH, 
\( V_o \) (output voltage) = 360V,
Vin (Input voltage) = 85-120 V,
Co (output capacitance),
n=N2/N1 (Turns ratio for fly back transformer),
Pmax (maximum output power)=750W,
Dmax (maximum duty cycle for operation in DCM)=0.5,
\( \eta = 90\% \),
Vcpp (allowed ripple voltage across the output capacitor) = 1V.

C. MPPT Algorithm

In proposed solar PV energy conversion system, the perturbation and observation method is applied in order to track maximum power point. It is an iterative method of obtaining maximum power point on operating curve of PV array. This algorithm operates by periodically measuring array terminal voltage and current and increments or decrements them after comparing it to the change in output power. Here operating voltage of PV array is perturbed by a finite increment value and due to this, the change in output power is observed. If this change is positive then it shows that operating point is moving closer to the maximum power point (MPP) else it moving away. This determines the direction of next perturbation [7]. The maximum power point can be determined when \( \frac{dP}{dV} = 0 \), where P is the output power and V is the output voltage of PV array. As the power-voltage relationship of a typical PV module is not linear, the maximum power point can be tracked using this algorithm when condition \( \frac{dP}{dV} = 0 \) is true for any value of solar radiation and temperature.

D. Design of Battery System

The battery model that used in the PV system was based on a lead-acid battery. The battery model has two modes of operation: charge and discharge. The battery is in charge mode when the current into the battery is positive, and discharge mode when the current is negative. The code of battery model was written in MATLAB and used to simulate the performance of solar PV system during charging and discharging. The storage capacity of the battery was calculated using the following relation [9]

\[ \text{Storage capacity}= N_C \times \frac{E_{LOAD}}{\text{DOD}} \times \frac{\text{b}}{\text{a}} \]

Where,
- DOD: Maximum permissible depth of battery discharge
- Eload: Average energy consumed by the load
- NC: Largest number of continuous cloudy days of a Area
- Efficiency of the battery

The battery plays an important role in case of the solar power system. The battery stores part of the energy generated by the solar PV power source and delivers to the load during the periods when the solar power source is unable to supply the power to the load due to any reason. The capacity of the battery depends on the daily load and days of autonomy [13]. To calculate the battery capacity for feeding 250W power at 360V, (1) is used as.

The battery is considered to deliver a power for 16 hours. So here it is taken as 30 batteries of 12V, 11Ah in series connection.

Modeling of Battery

For modeling of the battery here, its Thevenin’s equivalent circuit model is used. Fig. shows the Thevenin’s equivalent model of the battery, where \( R_{eq} \) is the equivalent series resistance of parallel/series combination of a battery which is usually a small value. For this analysis \( R_{eq} = 0.01 \Omega \). The parallel circuit of R and C describe the stored energy and voltage during charging or discharging. \( R \) in parallel with \( C \), represents discharging of the battery, the self-discharging current of a battery is small, so the resistance \( R \) is large and the typical value of \( R \) for this battery is used 10kΩ

Here the battery is considered of having 450 W for 16 hours peaking capacity, and variation in the voltage of order of 355 V-365 V. The battery stores the energy from PV system. Its energy is represented in kWh. A capacitor is used in an equivalent circuit for modeling of battery, and the value of capacitance is calculated using

\[ C = \frac{kWh \times 3600 \times 16}{0.8 \left( \frac{V_{max}^2}{2} - \frac{V_{min}^2}{2} \right)} \]

\( V_{max} \) is the maximum voltage of the battery fully charged and \( V_{min} \) is the minimum voltage of the battery when it is fully discharged [22]. The calculated value of \( C \) for this battery from equation (14) is \( C = 7200F \). The controller regulates the charging and discharging ability of battery.

D. Voltage Source Inverter

A full bridge voltage source inverter is used. A full-bridge voltage source inverter (VSI) is used here which consists of four switches. The work of the VSI is to convert 360 Vdc voltage supplied by the dc-dc converter into an ac of 220Vrms 50 Hz. The Two pulse signals having 180° of phase shift are generated to operate the switches, which is fed to IGBTs (Insulated Gate Bipolar Transistors) of the VSI. One signal is sent in pair to IGBTs S2 and S5. The other signal is sent in IGBTs S3 and S4. This signal is fed like this as IGBTs S2 and S5 remain on for some period and S3, S4 remain OFF for that time and vice versa. It affects the system efficiency and regulation
characteristics. Fig shows the topology of VSI and controller schematic.

The output signal from this full-bridge VSI is a pulse waveform which contains the desired output waveform along with frequency components at or around harmonics of the switching frequency. A low-pass filter is here utilized to extract the desired output voltage (50 Hz fundamental frequency) by separating it from the switching frequency.

D. PI Voltage Controller

To get good quality output voltage from a VSI a reasonably smooth dc voltage is required at input side, however this cannot be guaranteed always so a PWM control technique at VSI side is used to overcome this problem. Fig. 5 shows the block diagram of the PI controller. An instantaneous voltage error is fed to a proportional integral controller. The integral component in this controller improves the tracking by reducing the instantaneous error between the reference and the actual voltages. The resulting signal is compared with a triangular carrier signal and the error is forced to remain within the band defined by the amplitude of the triangular waveform [9]. Thus it generates switching pulses for VSI.

V. SIMULATION DIAGRAM OF SYSTEM

VI. RESULTS

1. The variation of solar power wrt temperature

2. The variation of solar voltage, current, power

3. The variation of output voltage and current

VII. CONCLUSION

The solar energy is the ultimate source of lasting energy on the earth surface which has the wide potential to meet our all needs so proper technologies has to be implemented to use it to meet our energy demands. In this paper a stand-alone solar power system for home needs is being designed and implemented using a fly back converter followed by a battery system along with MPPT controller followed by a voltage source inverter.

REFERENCES


