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MPPT Enabled SPWM based bipolar VSI design in photovoltaic applications

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Abstract

The depletion of fossil fuels and rising demand for energy has lead the search for various alternative sources of energy. Solar being inexhaustible provides sustainable power to the rural areas. The renewable energy system has been promoted worldwide because of the Kyoto agreement. The design and simulation of a single-phase two-stage photovoltaic system is proposed in isolated mode of operation. The maximum power point tracking is performed based on perturb and observe MPPT technique. A boost converter topology is used to obtain the constant DC voltage from solar photovoltaic system. The modeling and simulation of solar array, dc-dc boost converter, a voltage source inverter and an LC filter is done in matlab simukink. Perturb and observe based tracking of maximum power point and design of PI controller to control the voltage source inverter with PWM switching are the key feature of this work. Single phase inverter with bipolar voltage switching is used. The square wave output produced by the inverter is fed to a low pass filter to obtain a sinusoidal wave. The PV system is operated under isolated mode of operation. The Total Harmonic Distortion (THD) of load voltage is analyzed.

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Keywords: VSI, SPV, MPPT, SPWM,THD;

1. Introduction

Various renewable energy resources namely as solar, wind, tidal, hydro, biomass and geothermal are natural sustainable energy resources. The Kyoto Protocol restrictions for the generation of greenhouse gases along with the diminution of fossil fuels reserves make renewable energy a promising technology. The merits of distributed

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generation like higher reliability of service, better power quality, higher efficiency of energy and the environmental considerations such as no pollution has attracted the interest of whole globe. Due to the huge growth rate of power electronic techniques the photovoltaic system has embedded into many application domains. Modeling, simulation and control study of a PV generator system connected to the isolated load is proposed in this paper. Fig. 1 depicts a simple diagram of solar system with an isolated load. The PV system is controlled by a DC/DC boost converter using duty ratio control technique. It is used as the control means to track the maximum power point. The DC bus is supplied by the power generated by PV unit which in turn drives a voltage source inverter to supply the total generated power to the isolated load. The power electronic interfacing consists of a boost DC/DC converter and an inverter for power conversion.

2. System Specification and Modeling

Single phase PV system includes a PV array of 3.5KW power output, a dc-dc boost converter. A voltage source inverter is designed for converting DC into AC and to filter out unwanted harmonics produced by the power conversion system in the output current waveform, a LC filter is added at the output stage. Perturb and observe algorithm is used to track the maximum power from PV array. The SPWM inverter with bipolar voltage switching is used for DC to AC conversion and LC filter is used to mitigate harmonics content in order to get sine wave at the load terminal.

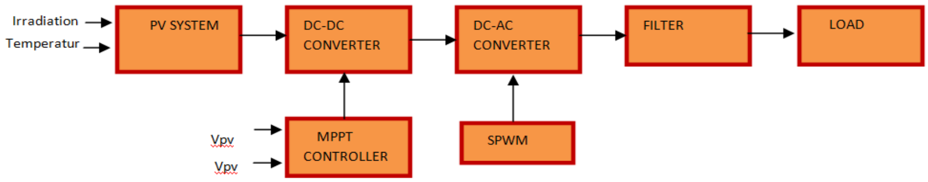

Figure 1: General block diagram of PV array

2.1 Modeling of solar PV system

The single-diode PV array model based on general equation is shown below in figure 2. Solar Panel is designed for constant irradiance. PV array is designed using series parallel combination of PV cells to generate an output of 3.5KW. As per the design six PV modules are connected in series and two modules are connected in parallel. The following equations are used to model solar PV system for the simulation.

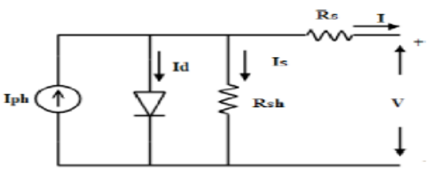

Figure 2: PV cell equivalent circuit

$$I_p = I_d + I_{sh} + I \quad (1)$$

$$I_d = I_0 * [e^{\frac{(q*(V+IR_S))}{KTA}} - 1] \quad (2)$$

$$I = I_p - I_0 * \left[e^{\frac{(q*(V+IR_S))}{KTA}} - 1\right] - \frac{V+IR_S}{R_p} \quad (3)$$

$$I = N_p I_l - N_p I_0 * \left[e^{\frac{\left(q*\left(VN_p + IR_s N_s\right)\right)}{N_p N_s R_p}} \right] - \left[\frac{VN_p + IR_{sN_S}}{N_S R_p}\right] \tag{4}$$

$$I_p = [I_{sc} + K_i * (T - 298)] * \frac{\beta}{1000} \tag{5}$$

$$I_0 = I_{rs} * \left[\frac{T}{298}\right]^3 * e^{\frac{\left(q*E_g\left(\frac{1}{298}+\frac{1}{T}\right)\right)}{KA}} \tag{6}$$

Here Isc represents short circuit current of the module and α is the temperature coefficient of I_{sc}. The voltage of PV cell V_{cell} was obtained using Equation (1) to (6)

Table 1. Solar panel Nomenclature

Details of the solar panel	Column A
Nominal Power (W)	280
Module Efficiency (%)	14.10
Voltage at maximum power V_{MPP} (V)	36.1
Current at maximum power I_{MPP} (A)	7.78
Open circuit voltage Voc (V)	44.5
Short circuit current Isc (A)	8.33
Series Resistance Rse (Ω)	2.2
Shunt Resistance Rsh (Ω)	415

2.2 Maximum Power point tracking

The amount of maximum power that can be extracted from the PV array always depends on the amount of available solar irradiance and the ambient temperature at any instant of time. Hence an MPPT algorithm is necessary to continuously track the maximum power point as the input variables are changing. There have been various MPPT techniques like the S.C Current and O.C Voltage method, Perturb and Observe methods, Incremental Conductance methods etc. Each of these methods vary with respect to convergence speed, stability, and tracking effectiveness. The P&O and IncCond method are two commonly used methods for tracking the maximum power. The P&O method is employed under speedy variation of solar irradiance.

The operating point corresponding to maximum power under different irradiation and temperature levels are determined by various MPPT methods available. This work makes use of perturb and observe algorithm to track the maximum power under varying irradiance and temperature. By measuring solar power along with voltage for two different instants reference current is obtained which is used as a control variable for the boost converter. Fast tracking, simple implementation and simple structure are key feature of this algorithm. The figure below shows the flowchart for perturb and observe MPPT algorithm.

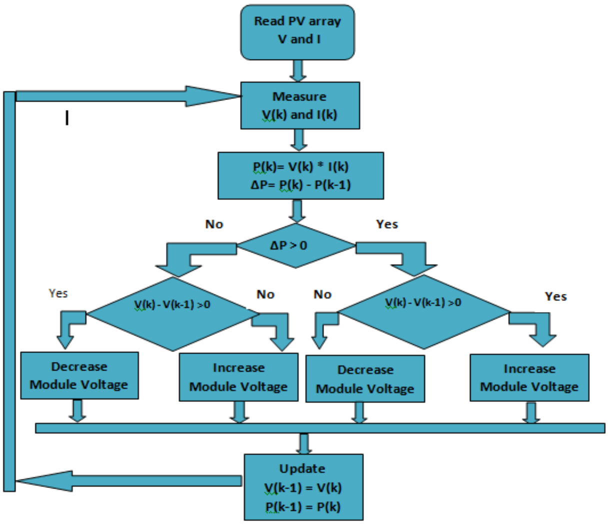

Figure 3: Flowchart of perturb and observe algorithm

2.3 Modeling of DC/DC Boost Converter

The Boost converter output voltage equation is as given below in equation (7)

$$V_o = \frac{1}{1-D} V_{in} \tag{7}$$

Where Vo is the boost converter output voltage, Vin and D are the input voltage and duty cycle of the converter respectively. The boost converter is designed to operate in the continuous conduction modes. The inductance value is designed to be higher. The minimum inductance required for operation in CCM is given below in equation 8.

$$L_{1,min} = \frac{(1-D)^2 \, D \, R}{2 f_s} \tag{8}$$

where R and *fs* are the load resistance and switching frequency of the MOSFET respectively. The output voltage ripple is maintained within limit by properly selecting the capacitance. The equation below gives minimum capacitance required for minimum output voltage ripple.

$$C_{min} = \frac{D}{R \, f_s \, V_r} \tag{9}$$

Hence the output voltage is maintained constant by controlling the duty cycle even under the variation of load or input voltage.

2.4 Modeling of Voltage Source Inverter

A full-bridge inverter with MOSFET switches are used with switching frequency of 5 KHz. A bipolar SPWM technique is used for switching. The inverter circuit uses switches and corresponding driving circuit for the AC conversion. A comparator is used to compare between the reference voltage waveform and the triangular carrier signal in order to generate the bipolar switching signal. The inverter is triggered with the help of pulses generated by comparing a sine wave of frequency 50 Hz with 5 KHz frequency of triangular waveform. Then the output is fed to LC filter to reduce the distortion and obtain output as per IEEE1457 standard. The table 2 shows the various switching states of single phase voltage source inverter.

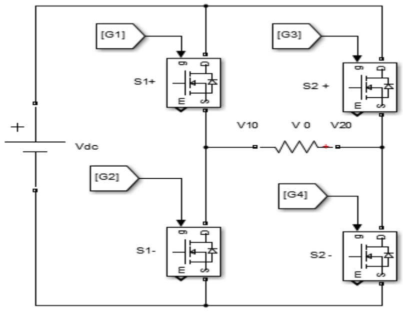

Figure 4: SPWM driven single phase VSI

The table 2 shows the various switching states of single phase voltage source inverter. Here S_{1+} and S_{2+} indicates top devices of the two legs and S_{1-} and S_{2-} indicates bottom devices of the inverter legs.

Table 2: Switching states of single phase VSI

Sl No	On States	Off States	V_{10}	V_{20}	V_0
1	$S_{1+}\ S_{2-}$	$S_{1-}\ S_{2+}$	$V_d/2$	$-V_d/2$	V_d
2	$S_{2+}\ S_{1-}$	$S_{1+}\ S_{2-}$	$-V_d/2$	$V_d/2$	$-V_d$
3	$S_{1+}\ S_{2+}$	$S_{1-}\ S_{2-}$	$V_d/2$	$V_d/2$	0
4	$S_{1-}\ S_{2-}$	$S_{1+}\ S_{2+}$	$-V_d/2$	$-V_d/2$	0

3. Proposed work and result

Solar panel of 3.2 KW, 200V is used to obtain an output DC voltage. This is given as an input to the boost converter which in turn used to maintain a constant DC voltage for any fluctuation in the solar panel. Then inverter used converts the DC to AC which is fed through LC filter obtain 400V, 50Hz. Here LC filter is designed to obtain the THD as per IEEE 1457 standard. Parameters for the Boost converter are as follows: Inductance value, L=5.75mH, Capacitance value, C= 2.16µF. The parameter for LC filter is: inductance value, L= 99mH, Capacitance value C=85 µF. The simulink diagram of PV module and boost converter are shown in figure 5 and figure 6 respectively. The I - V and P -V characteristic are shown in figure 7 and figure 8 respectively. The output of boost converter is around 400 V and shown in figure 9. The four gating pulses required for full bridge topology are generated under bipolar switching scheme and are shown in figure 10. The inverter output voltage before the filter and after passing through the filter are shown in figure 11 and figure 12 respectively.

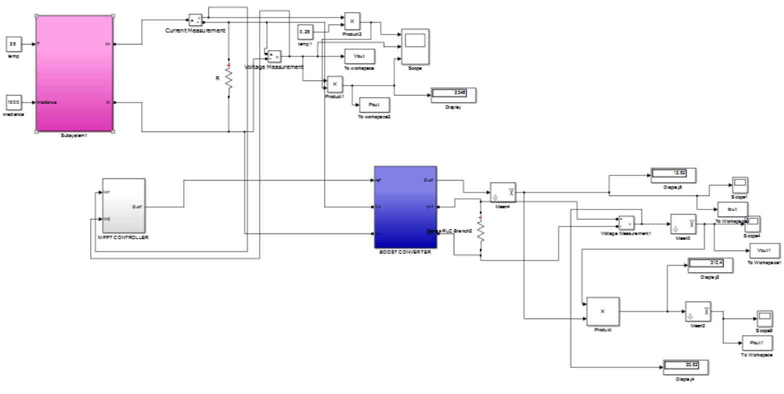
Figure 5: Simulink diagram of PV module

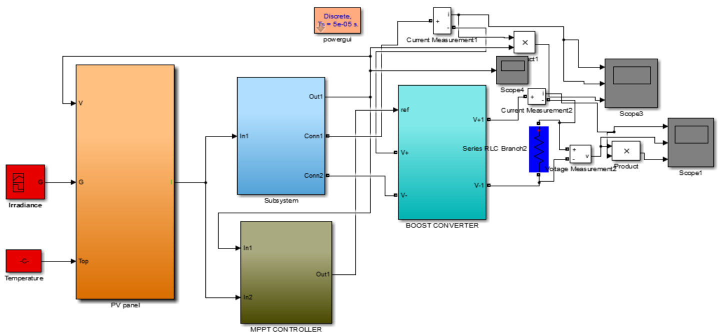

Figure:6 Simulink model of PV and Boost converter with P&O algorithm

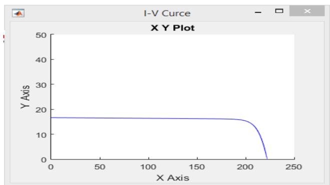

Figure:7 Current –voltage characteristics of PV array

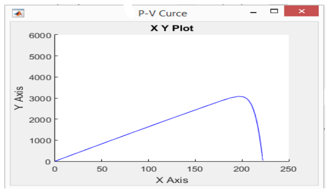

Figure:8 Power- Voltage characteristics of PVarray

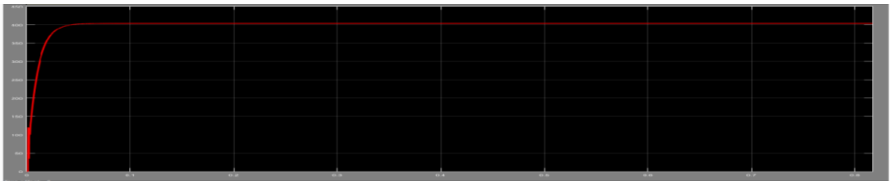

Figure 9: Output Voltage of Boost Converter

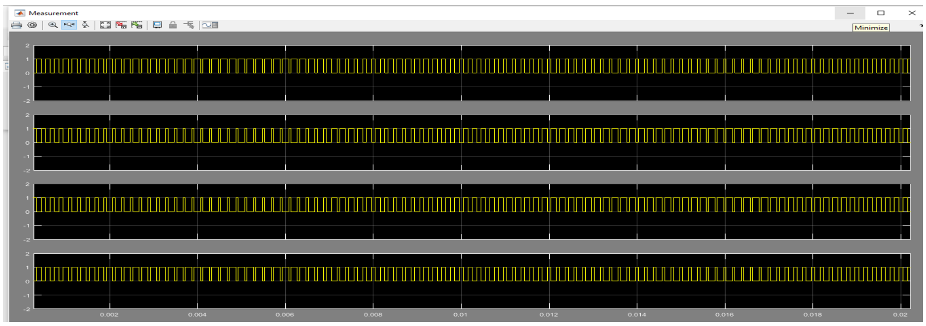

Figure 10: SPWM based gating pulses for VSI

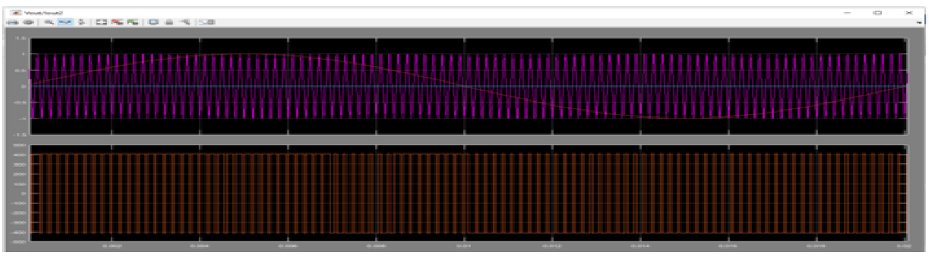

Figure 11: Output voltage of single phase inverter without filter

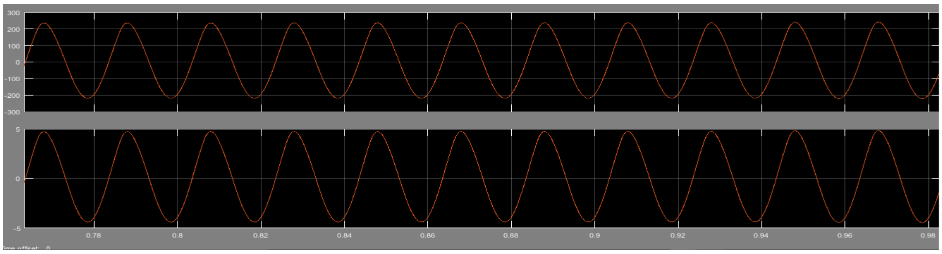

Figure 12: Filtered Inverter output waveform

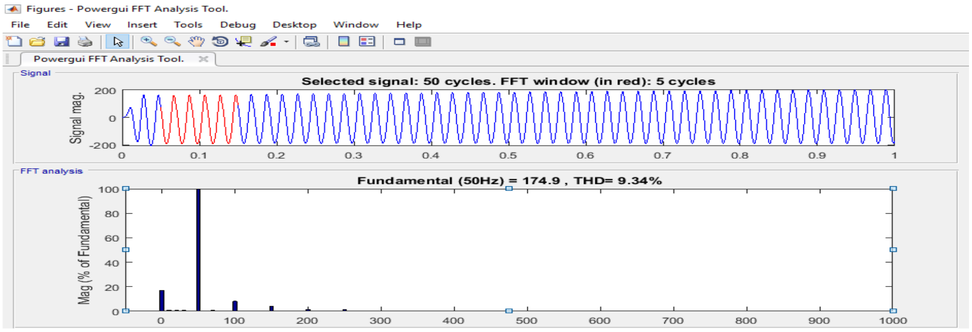

Figure 13: FFT analysis with filter

4. Conclusion

The design and modeling of solar array, DC/DC converter and SPWM based single phase voltage source inverter were done with the help of Simulink/Matlab. Using perturb and observe based maximum power point tracking algorithm the maximum power is tracked and the controlling of duty cycle to obtain desired boosting is achieved. This reference value is used by PWM generator to trigger the MOSFET switch in boost converter, thereby obtaining a constant DC voltage. . Also using suitable mechanism the control of output voltage of VSI to the desired value is successfully attained. The THD of output voltage improved through LC filter**.**

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