Mathematical Modeling & Performance analysis of Solar Power operated SPWM Inverter using MPPT controller

Akash Chouhan[1], Dr. Deepak Agrawal[2], Saurabh Vishwakarma[3], Dr. Shiv Kumar Sonkar[4]

[1,2,3,4]Department of Electrical & Electronics Engineering, Trinity Institute of Technology and Research, Bhopal

Abstract

In the proposed work, mathematical modeling of Solar power fed SPWM inverter is done using MPPT controlled Boost converter. The proposed circuit consists of MPPT controlled Boost converter at the input and output of which is given to SPWM inverter and further to 3-phase load. Performance characteristics of entire circuit is obtained and analyzed for varying value of load.

The I-V Characteristics of Solar PV array described how the output voltage varies with the value of Load resistance. Importance of boost converter in extracting the maximum power from PV array presented. Use of Solar PV array having Maximum Power Point Tracking explained using MATLAB simulink.

1. Introduction

As the solar PV array fed inverter is becoming popular in today's scenario. The proposed simulation circuit has two main important sections. First is MPPT Controlled Boost converter and second is SPWM Inverter. As the purpose of proposed method is to extract the maximum power from the Solar Panel and deliver it to AC Load through the SPWM Inverter. Due to which it is very necessary to connect the load which can consume near to maximum power same as that of solar panel maximum power rating. The electrical power generated from the solar PV panel is obtained as constant current up to a certain voltage level, after that particular voltage level the supplied current drops to zero. Near to the particular said voltage the solar PV array will extract the maximum power from the source of energy i.e. solar panel. The point hence named as maximum power point and explained in next section.

While using the Solar PV array as the source of electrical energy, the best way to take the maximum power from solar PV array is to interface the PV array with the Boost converter.

By changing the duty cycle of Boost converter depending upon the MPPT algorithm, one can achieve the Maximum Power point of PV array with the varying load resistance value. Boost converters are the dc to dc converters having the constant dc voltage input and having the step up output voltage higher than the input voltage.

2. Mathematical Modeling of Solar Power fed SPWM Inverter using MPPT controlled boost converter

The simulation circuit of solar power operated SPWM inverter operates at maximum power point is shown in fig. 1.In the concerned simulation circuit, the same is simulated for the 3-phase load of 60 KW for the input power of solar panel is 68 KW at the output voltage of 243 Volts.
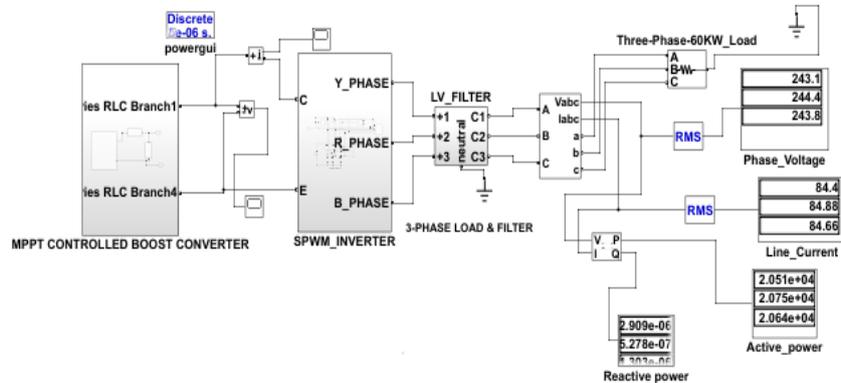
Fig. 1: Simulation circuit of Solar Power fed SPWM inverter using MPPT controlled boost converter

The entire simulation circuit of Solar Power fed SPWM inverter operates at maximum power point of solar PV array is divided into following sections mentioned below:

a) **Solar PV array as the source of entire circuit**
b) **MPPT controlled Boost Converter**
c) **SPWM Inverter**

a) Solar PV array selected as the source of entire circuit: The solar PV array selected for simulation of MPPT controlled boost converter and SPWM inverter has the I-V characteristics as shown in fig.1. The renewable source of energy i.e. solar PV array of proposed method has the constant current up to the certain voltage Vp1@25ºC and Vp2@45ºC as shown in fig.1. The values of different parameters of fig.1 are shown in table 1.
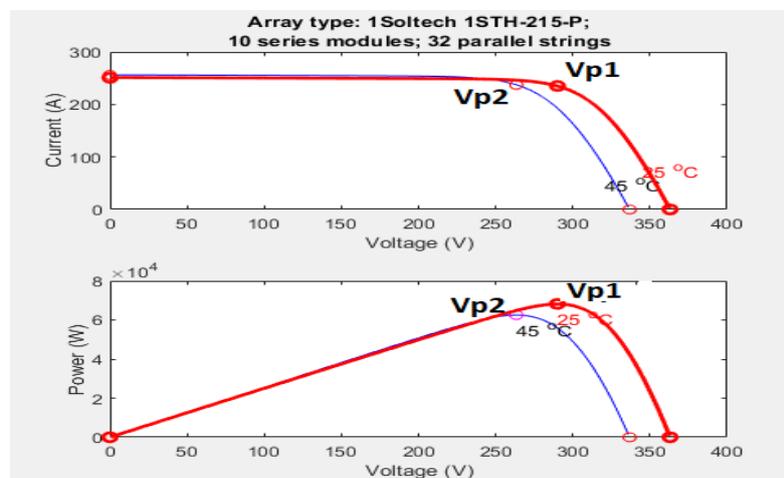

Fig.2: Graph showing the I-V/P-V characteristics of Solar PV array used in proposed strategy

Table 1: Variation of parameters of solar panel with its operating temperature

S. No.	Ambient Temperature	Voltage at Maximum power point	Maximum power output	Output Current
1	25ºC	Vp1 =290 Volts	68210 Watts	235.2 A
2	45ºC	Vp2=263.4Volts	62520 Watts	237.4 A

As the power output of solar PV array depends on two important factors i.e. ambient temperature and Irradiance. With the increase in the irradiance the power output increases and with the increase in the ambient temperature the power output decreases.

b) MPPT controlled Boost Converter

The important feature of MPPT (Maximum Power Point Tracking) controller is to achieve the duty ratio for getting the voltage output of solar PV array should be at a point in the P-V characteristic as shown in fig.1, such that PV array will deliver the maximum power to SPWM inverter and to the load. The simulation circuit of MPPT controlled Boost converter is shown in fig.2.
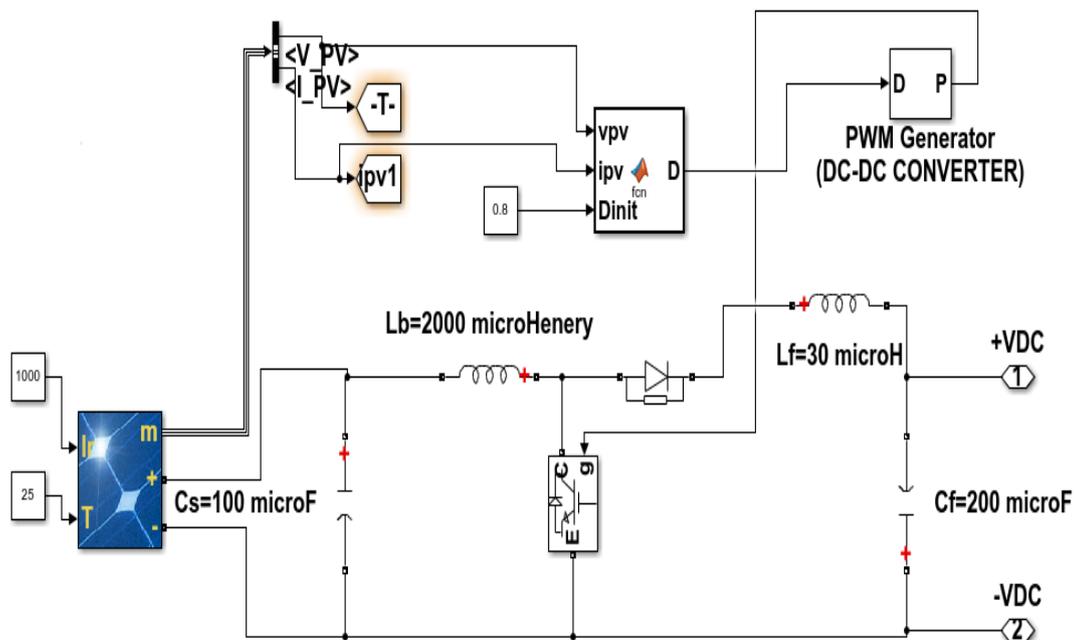

Fig.3: Simulation circuit of MPPT controlled Boost converter

In this circuit, Solar PV array is used in place of dc source, the voltage and current of solar PV array is used as input of MPPT controller, the output of which is the duty ratio. The value of duty ratio will drive the PWM generator and the output of PWM generator will follow the value of duty ratio.

The value of parameters of simulation circuit of MPPT controlled boost converter as shown in fig.2 are mentioned below in table 3. Here the value of duty ratio will be selected by the MPPT controller depending on the load connected at the output of SPWM inverter.

Table 2: Values of parameters selected for MPPT controlled Boost converter

S. No.	Name of parameter /element	Value selected for simulation
1	Vs(Input Voltage)	As per table 1
2	Maximum power point of Solar PV array	68210 Watts @ 290 Volts at 25ºC & 62520 Watts @ 263.4 Volts at 45ºC
3	Capacitor across the solar panel	100 μF
4	D(Duty ratio)	Automatically decided by the MPPT controller
6	f(Switching frequency) of	5000 Hz
7	Boost inductor, Lb	2000 μH
8	Filter inductor Lf	30 μH
9	Filter Capacitor Cf	200 μF

c) SPWM Inverter & Low Pass filter for delivering the maximum possible power to 3-phase Load

The simulation circuit of SPWM inverter connected at the output of Boost converter is shown in fig. 4.
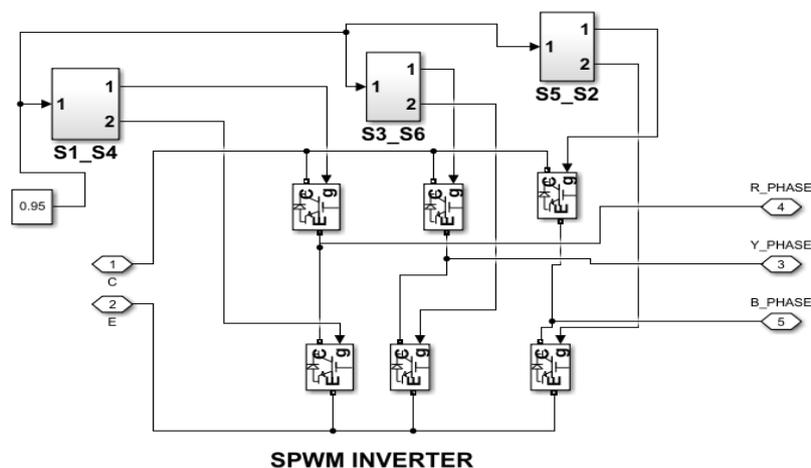

Fig. 4: MATLAB simulation circuit of SPWM inverter

The Sinusoidal PWM inverter used to convert the dc power supply at maximum power point from the boost converter into ac power by SPWM inverter for delivering the 3-phase load. The carrier frequency of triangular wave is 2100 Hz and the frequency of reference wave is 50 Hz resulting frequency modulation index (mf) is 42. The value of amplitude modulation index selected is 0.95. The simulation circuit of Low pass filter connected at the output of SPWM inverter is shown in fig. 5. The cutoff frequency of Low pass filter is 200 Hz.
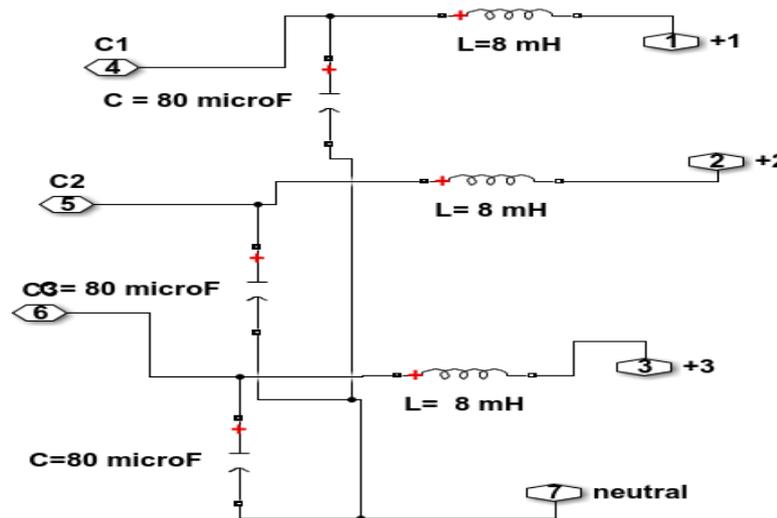

Fig. 5: Simulation circuit of Low Pass Filter for improving the THD of output line current

3. Simulation Results

As proposed simulation circuit is set to operate in such a way that it operates at maximum power point, hence the load which should be connected at the output of inverter should be of such a value that it can consume the maximum power which is extracted from the solar panel. From the table 1, the maximum power generated from the solar panel is 68210 Watts@25ºC and 62520 Watts@45ºC.

Case 1: The simulation results of solar power operated SPWM inverter are firstly described for the parameters shown in table 3 for pure resistive load. For the present case, the load assumed is 3-phase, 50 Hz, resistive load and it is rated for 240 Volts (phase to neutral) and ambient temperature of solar panel is 25ºC.

Table 3: Trends showing the variation of output voltage of inverter with the decrease in the load

S. No.	Load Connected at the output of Inverter	Duty cycle set by the MPPT Boost converter	Power Output at the load	Output Voltage across the load	DC Output Voltage of Boost converter
1	69 KW	0.6999	61.81 KW	227.1V	919 V
2	66 KW	0.7037	61.91 KW	232.5 V	910 V
3	60 KW	0.7063	61.90 KW	243.8V	904 V
4	56 KW	0.7221	61.91 KW	256.6 V	924 V

5	45 KW	0.722	61.92 KW	281.0 V	949.7
6	36 KW	0.726	61.92 KW	313.2 V	989.5
7	15 KW	0.8	61.91 KW	343.8 V	1377

It is observed from the above table 3 that as the name indicates the Maximum power point tracking SPWM Inverter; hence the load variation range is less for getting the particular accepted output voltage range i.e in the current case the load variation range is from 69 KW to 60 KW. Also it can be observed that the output power delivered to load is constant irrespective of output load variation. Hence it can only be used at the site which always has the almost constant load requirement. It is also observed that in all the cases of table 3, the %THD of line current and phase voltage is of the order of 1% to 2%.

Case 2: As it is well known that with the increase in the ambient temperature, the maximum power rating of solar PV array is decreased. Here in this section, simulation results obtained for ambient temperature of 45⁰C and mentioned in table 4. It is important to note that the load connected at the output of inverter as mentioned in column 1 of table 4 is rated at 240 V ac.

Table 4: Trends showing the variation of output voltage of inverter with the decrease in the load

S. No.	Load Connected at the output of Inverter	Duty cycle set by the MPPT Boost converter	Power Output at the load	Output Voltage across the load	DC Output Voltage of Boost converter
1	60 KW	0.7253	56.1 KW	232.2 V	853.0 V
2	57 KW	0.726	56.1 KW	238.5 V	902.0 V
3	51KW	0.7259	56.1 KW	252.0 V	883.0 V
4	36 KW	0.725	56.1 KW	300.0 V	948.0 V
5	9 KW	0.8477	56.1 KW	586.0 V	1631.0 V

As from the table mentioned above, the range of load variation is from 60 KW to 51 KW slightly less than the case 1. Also efficiency of system is maximum when load connected at the output of inverter is 57 KW.

Case 3: The most important feature of proposed circuit is that it can also fed power to inductive load, the simulation results obtained for different RL type of load and the same is mentioned in table 5.

Table 5: Trends showing the variation of output voltage of inverter with the decrease in the load

S. No.	Load Connected at the output of Inverter	Duty cycle set by the MPPT Boost converter	Power Output at the load	Output Voltage across the load
1	P=69 KW Q=69 KVAr	0.8001	Po=60 KW Qo=60 KVAr	225 V
2	P=63 KW Q=69 KVAr	0.8260	Po=60 KW Qo=65 KVAr	235.2 V
3	P=60KW Q=60 KVAr	0.7900	Po=60 KW Qo=60 KVAr	240 V

4. Conclusions

The important feature of proposed simulation circuit is that it has to be used under full load condition. Hence it is most suitable for grid connected system in which case it can supply as maximum as possible power to load. The solar operated SPWM inverter is used fed constant power drive. The efficiency of the proposed circuit is above 90% in all the cases mentioned from table 3 to table 5. In all the cases, as load power output increases, the voltage across the load decreases.

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