# Operation and Control of PV System using Different Modulation Techniques

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*Abstract*— A high penetration of distributed solar photovoltaic resources is becoming a worldwide reality for many electricity distribution utilities. This paper present the design and analysis of PV module connected with D.C. Boost Converter and Perturb and Observe (P&O) algorithm that is used for maximum power point tracking (MPPT) to maximize the generated power and it is further connected to three phase inverter whose switches are controlled by different Pulse Width Modulation techniques i.e. Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM). In the A. C. systems quantity is not more important than quality. To improve the quality of output ac voltage in this system we are using two different techniques and also results are analyzed using FFT analysis to find out the total harmonic distortion (THD). MATLAB/SIMULINK environment is used to simulate the proposed system.

***Key words:*** PV, P & OSPWM, SVPWM, THD, SIMULINK

## I. INTRODUCTION

### A. *Motivation & Introduction*

Increasing fossil fuels cost, climate change sustainability and a political imperative for the energy independence that moves towards the interest and research in the uses of renewable energy resources to meet the demand of electricity. Uses of renewable energy resources make additional complexity to power system and makes them more challenging task to operate. The power quality is also a concern in power system operation and control.

These resources can be divided into two groups.

- First is the one having similar characteristics to the conventional power techniques which is predictable and controllable i.e. biomass, hydroelectric generation.
- And the second is the one which are intermittent and varying in nature i.e. solar and wind.

Through this paper we will focus on solar energy which has been the most concerned research field over the recent years.

Based on the analysis of Samimi (1997) [1] we figured out a way to get the optimal tilt angle and other aspects of PV modules in various climate. PV installation and size of PV module are the biggest challenge which was resolved by Soras (1998) [2].who developed a methodology for optimal size of PV to increase the coordination in load, we link PV system with the load using boost converter and MPPT [14-16]. To get the desired quality of output waveform we require sinusoidal PWM. But to get an enhanced result we require Space Vector PWM which decreases the THD to more than SPWM.

In the proposed scheme we design a PV module [3-6] which is connected to a boost converter [7-10] (to step up the PV module output voltage) which is further connected to a three phase inverter [11-13] (converts dc voltage to three phase ac voltage) whose switches are controlled by SPWM [17] and SVPWM [18].Both two method is used to control the operation of inverter. Then find out the THD [8] of both two methods and compare it[19-20]. After comparing THD, we find out that the SVPWM method reduces the THD more than SPWM by 10%.So we conclude that SVPWM is better method then SPWM.

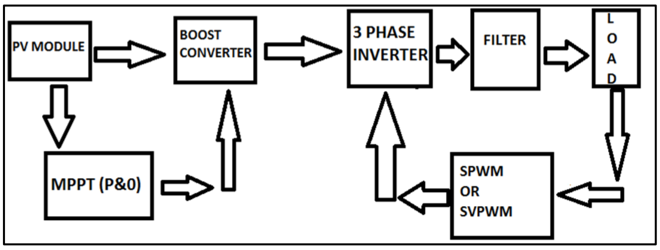


Fig. 1: Block diagram of proposed system

To verify the effectiveness of the system. The proposed system modelling and simulation is done on MATLAB/SIMULINK AND SIMPOWER SYSTEM TOOLBOX. The proposed system block diagram is shown in figure 1.

## II. SYSTEM DESCRIPTION & MODELING

### A. *Design & Equivalent circuit of PV Module*

The solar cell model consist of photocurrent, diode, parallel and series resistance which shown in figure 2.

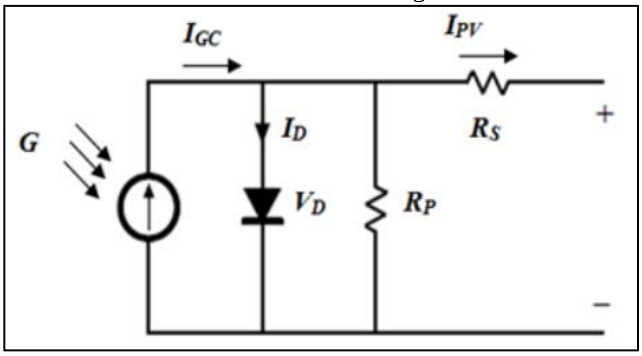


Fig. 2: Single diode PV cell equivalent circuit

Apply KCL on figure 2, we get the following equation

$$I_{PV} = I_{gc} - I_0\left[\exp^{\frac{ev_d}{KFT_C}} - 1\right] - \frac{V_d}{R_P} \quad (1)$$

Where

$I_{gc}$ Light generating current

$I_0$ Dark saturation current
e electric charge($1.6\times10^{-19}$ coulombs)
K Boltzmann's constant ($1.38\times10^{-23}$ J/K)
F Cell idealizing factor
$T_C$ Absolute Temperature
$V_d$ Diode voltage
$R_p$ Parallel resistance

The photocurrent is depending upon the temperature and solar irradiation. $I_{gc}$ Also express as follows

$$I_{gc} = [\mu_{sc}(T_c - T_r) + I_{SC}] + G \quad (2)$$

Where $\mu_{sc}$ the temperature coefficient of cell's short circuit current is, $T_r$ is the cell's reference temperature, $I_{SC}$ is short circuit current at 25* C and 1 kw/m$^2$, and G is the solar irradiation in kW/m$^2$.

The saturation current is also depend upon the cell temperature

$$I_0 = I_{0\alpha}\left(\frac{T_C}{T_r}\right)^3 \exp\left[\frac{eV_g}{KF}\left(\frac{1}{T_r} - \frac{1}{T_C}\right)\right] \quad (3)$$

Where $I_{0\alpha}$ is the cell's saturation current which is expressed as

$$I_{0\alpha} = \frac{I_{sc}}{\exp^{\frac{(eVoc)}{KFT_C}}} \quad (4)$$

$V_g$ is the band gap energy of used semiconductor cell and $Voc$ is the cell open circuit voltage .

The equivalent circuit diagram of PV module is design in MATLAB/SIMULINK which is shown in figure 3.The various type of PV module is present in SIMULINK. We selected Canadian solar CS5P-220M module.

So the parameters are decide according to type of the PV module selected.

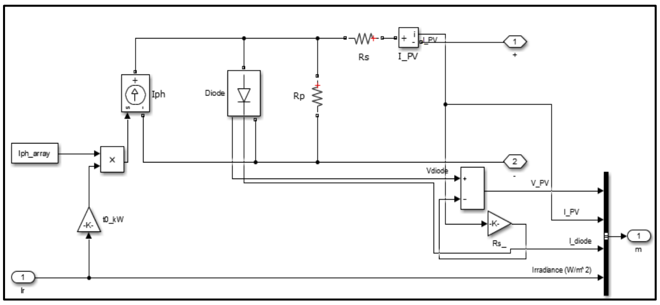

Fig. 3: Equivalent PV module in SIMULINK

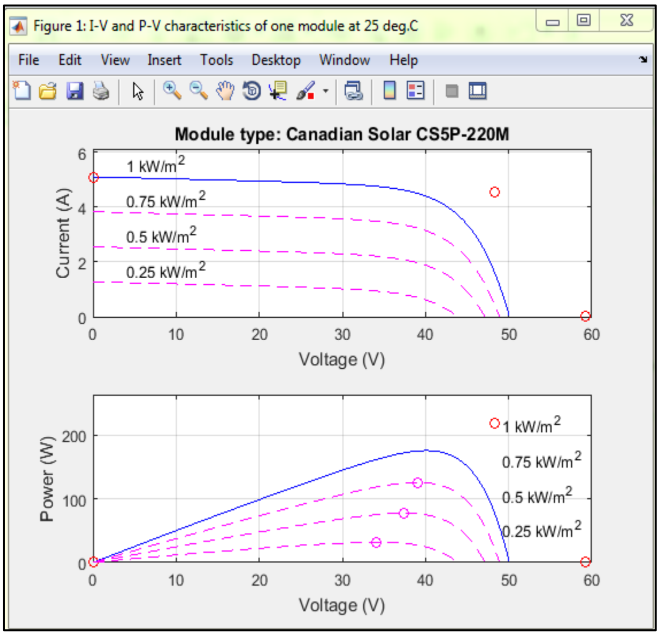

Fig. 4: I-V and P-V characteristics of one module

*B. Operation & Control of DC Boost Converter with P&O MPPT Technique*

The d.c.boost converter is connected in series with PV module. The switch of boost converter is controlled by perturb and observe (P&O) maximum power point tracking algorithm. The input of P & O algorithm is output voltage and current of PV module and the output of this system is duty cycle of the boost converter switch.

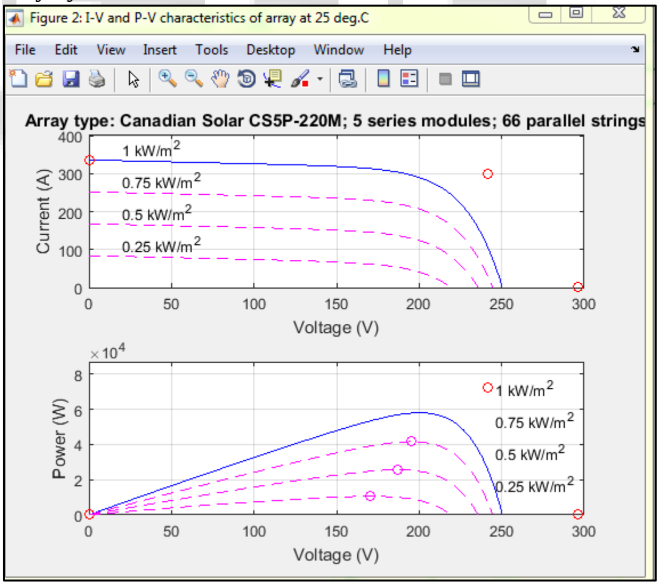

Fig. 5: I-V and P-V characteristics of Array

The flow chart of P&O algorithm for digital control of MPPT is shown in figure 8.

The output of P&O method is duty cycle which is given to the dc boost converter which is connected in series with PV module. The boost converter steps up the PV module output voltage. The circuit diagram is shown in figure 4.

 

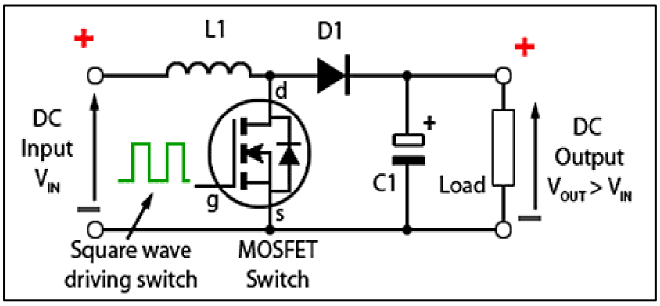


Figure 6. circuit diagram of dc boost converter

The boost converter is driven by the convention of the crick changes in inductor current.The energy is concentrated in inductor during the ON time of switch. And when switch is OFF, the concentraed energy in inductor tries to disintegrate.The inductor polarity is reversed in that condition and output voltage sum up with the input voltage.

The working of boost converter is as follows

When MOSFET switch is ON

$$\Delta i = \frac{(V_{IN} - V_{Trans})}{L} T_{ON} \quad (5)$$

When MOSFET switch is OFF

$$\Delta i = \left( \frac{(V_{out} - V_{in} + V_D}{L} \right) T_{OFF} \quad (6)$$

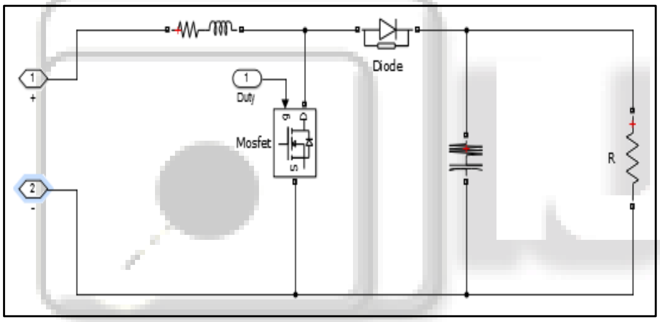


Fig. 7: Design of boost converter in SIMULINK

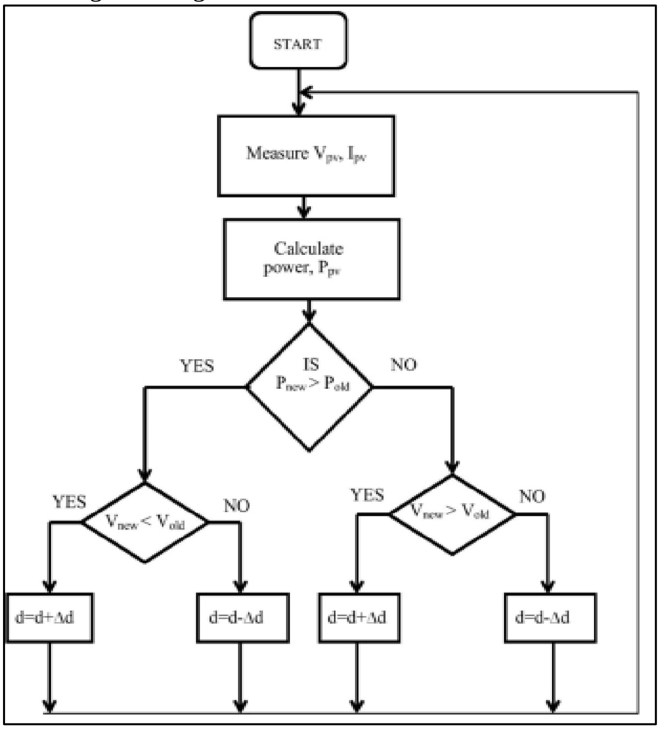


Fig. 8: control flow chart of P&O method

*C. Design and Control of 3 Phase Inverter with SPWM and SVPWM*

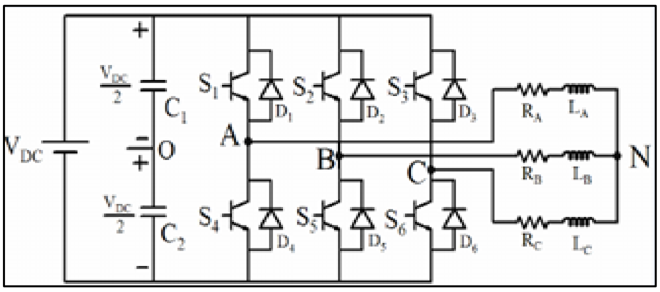


Fig. 9: Three Phase Inverter Circuit Diagram

The above figure 9. Shows the circuit diagram of three phase inverter which converts dc voltage to three phase ac voltage. The inverter is connected in series with the dc boost converter. The inverter's six switches are controlled by the two different techniques i.e. SPWM and SVPWM.

*1) Sinusoidal Pulse Width Modulation*

In the SPWM technique we produce sinusoidal waveform by varying the width of filtered output pulse waveform. To obtain better filtered sinusoidal waveform we can use a high switching frequency and also by varying the amplitude and frequency of reference and modulating voltage. It maintains pulses in different widths instead of maintaining in equal widths as in multi pulse width modulation where the distortion factor (DF) and lower order harmonics are significantly reduced.

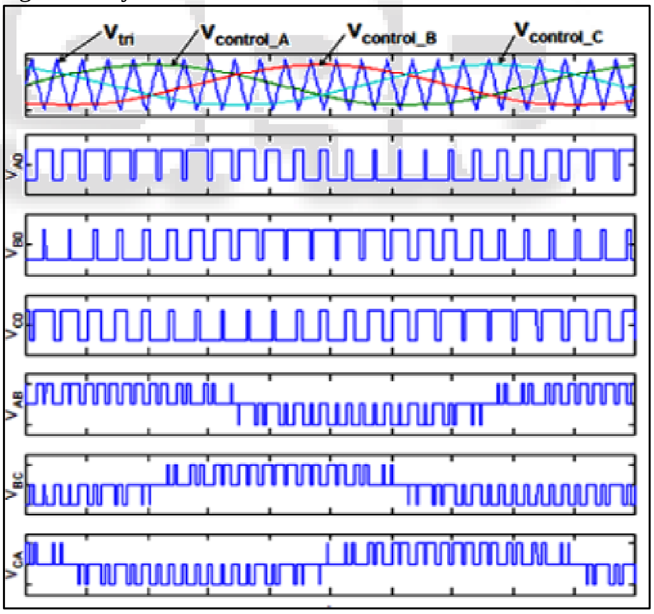


Fig. 10: Output waveform using SPWM

The frequency modulation ratio is defined as the ratio of frequency of carrier wave to frequency of reference signal.

$$m_f = \left( \frac{f_c}{f_0} \right) \quad (7)$$

Where $f_c$ is carrier signal frequency and $f_0$ is the frequency of reference signal.

### *2) Space-Vector Pulse Width Modulation*

The other method of switching in proposed system is SVPWM. The Space-vector pulse modulation method reduces the THD of output and increases the output voltage as compared to SPWM.SVPWM uses the rotating synchronous reference frame. This method increases the fundamental up to 26% when compared to SPWM. In SVPWM the voltages in abc reference is converted into stationary dq reference frame. The switching sequence of upper switches of inverter refer to special switching sequence.

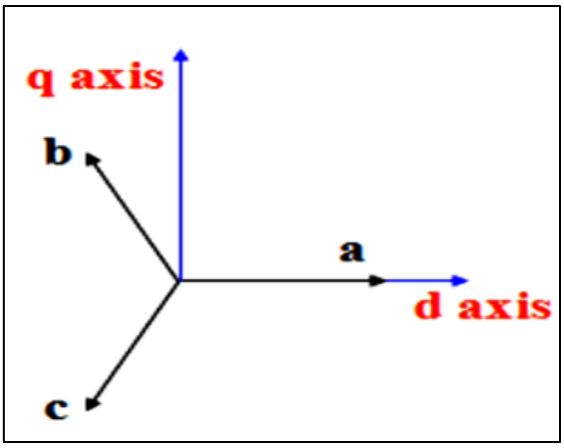


Fig. 11: Relation between abc and dq reference frame

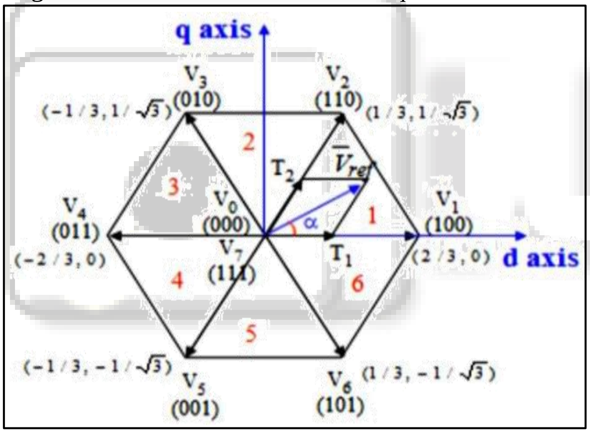


Fig. 12: Basic Switching Vectors

SVPWM main objective is reach approximate to reference voltage vector using eight switching patterns. By using sectors, SVPWM can identify the location of reference vector and also identify the switch which can be operated as per sector identified.

## III. DESIGN AND SIMULATION OF PROPOSED SYSTEM

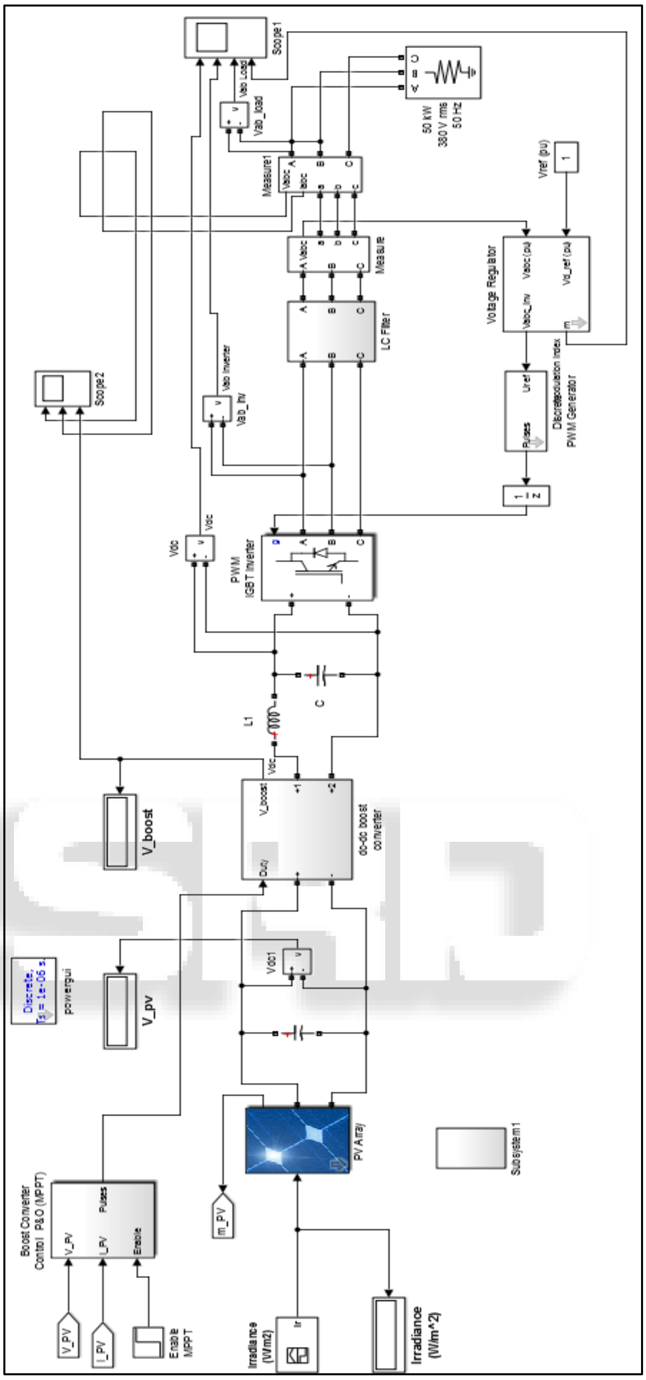

Fig. 13: Proposed System with SPWM

The figure 13 shows the design of simulation of proposed system using SPWM. And figure 14 shows the simulation of proposed system using SVPWM. The simulation consists of PV module, P&O MPPT controller, D.C. Boost Converter, Three Phase Inverter, SPWM and SVPWM switching, filter and resistive load.

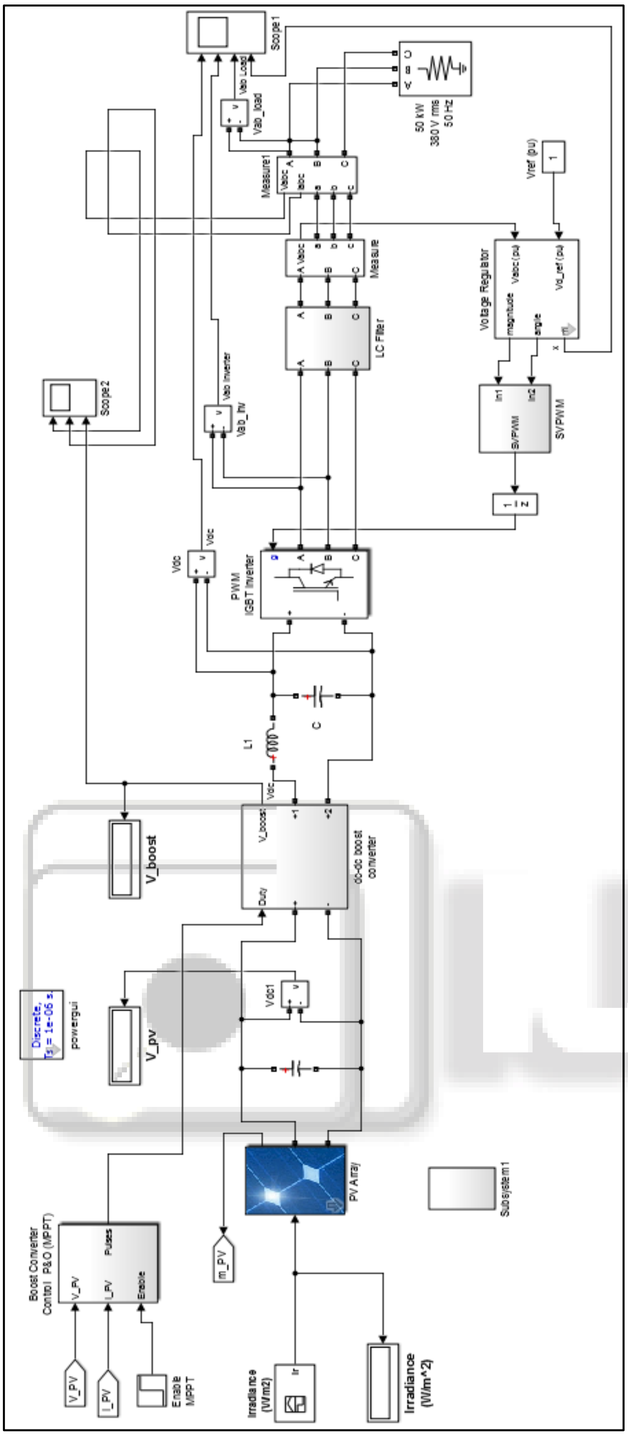

Fig. 14: Proposed System with SVPWM

## IV. RESULT & DISCUSSION

After simulating the above simulation we find out the following results

| Switching Method | THD (After Inverter) | THD (After Filter) |
|---|---|---|
| SPWM | 62.24% | 4.26% |
| SVPWM | 54.5% | 1.8% |

Firstly we discussed the result of proposed system using SPWM switching

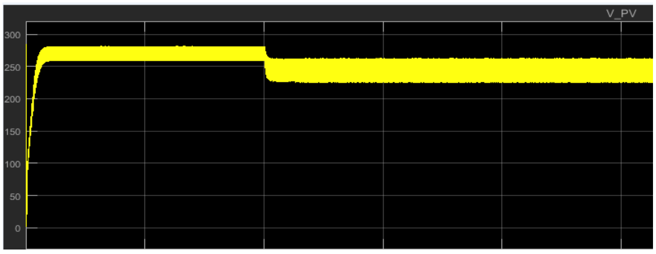


Fig. 15: PV Module generated Voltage

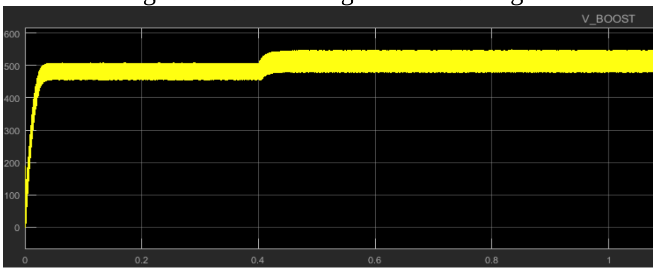


Fig. 16: Boost converter output voltage

The output voltage of PV module is shown in figure 15.The value of PV module output voltage is 280 Volts.It is boosted by dc boost converter and output boost voltage is 520 Volt which is shown in figure 16.

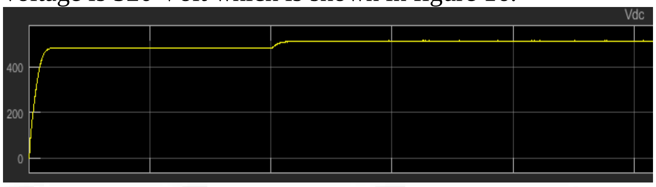


Fig. 17: PV module voltage after filter

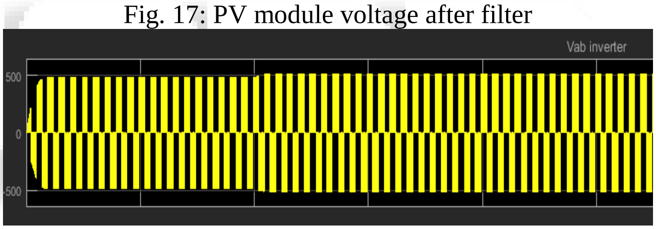


Fig. 18: Inverter output voltage (SPWM)

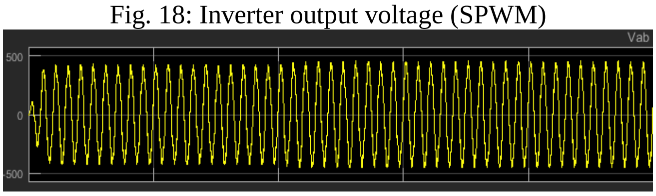


Fig. 19: After filter Inverter output voltage (SPWM)

Figure 17 shows the filter output of dc boost converter. It is further applied on inverter whose switches are controlled by SPWM. Figure 18 show the output of Inverter: the magnitude of voltage is 520 Volts.

After applying the filter on inverter output voltage we find out the output voltage waveform that tends to sinusoidal waveform. The THD of inverter output voltage before filter is 62.43% and after applying filter on it, the THD becomes 4%.These results are found when we use SPWM technique for switching.

 

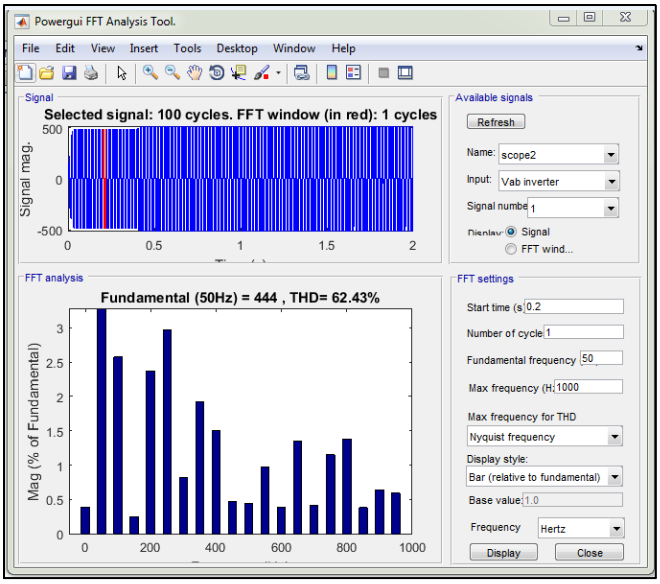


Fig. 20: THD of Inverter output voltage before filter (SPWM)

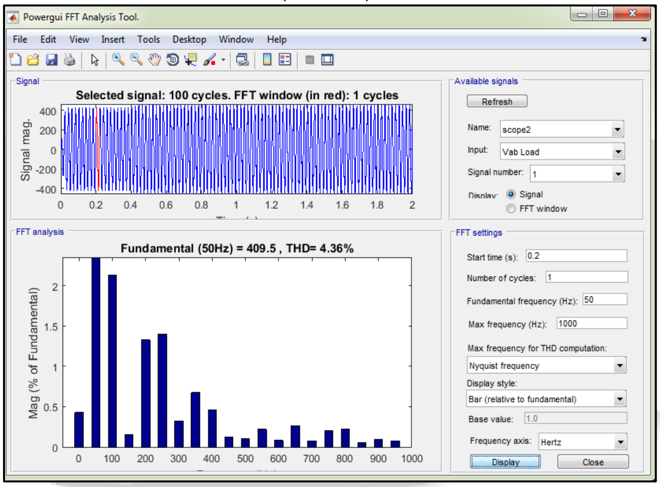


Fig. 21: THD of Inverter output voltage after filter. (SPWM)

After this we discussed the proposed system result using SVPWM switching technique. In this case the PV module output voltage and dc boost converter output voltage are same as the waveform shown if figure 15 and 16. (Because the switching method are applied on Inverter).Thus this section covers the comparison of both SPWM and SVPWM technique results.

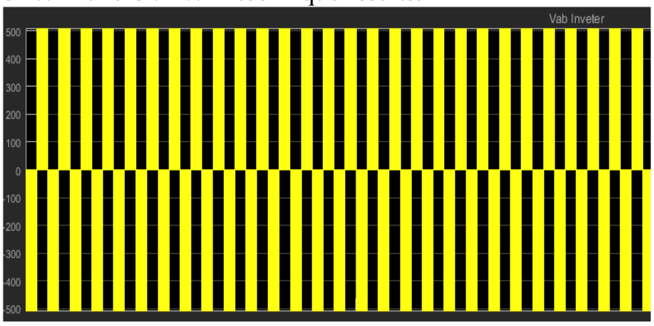


Fig. 22: Inverter output voltage (SVPWM)

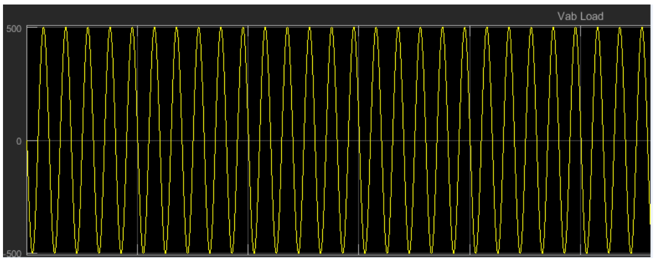


Fig. 23: Filtered Inverter output voltage (SVPWM)

The both above figure 22 and 23 show the result of proposed system using SVPWM switching technique. The output of inverter is 520 volts.

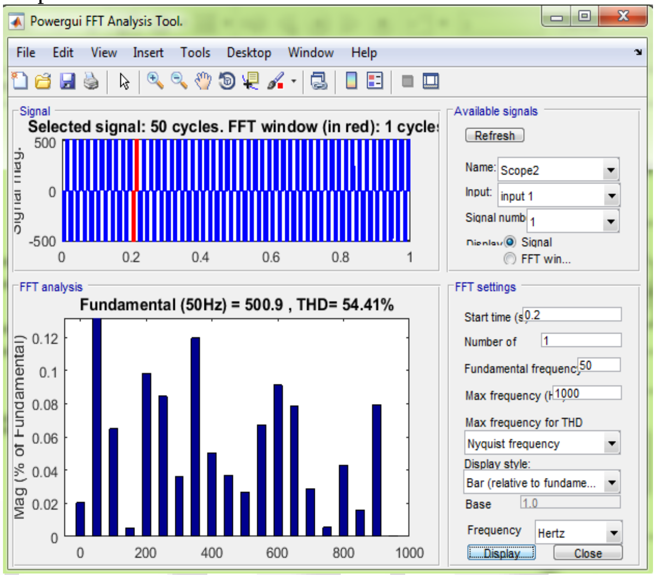


Fig. 22: THD of Inverter output voltage before filter (SVPWM)

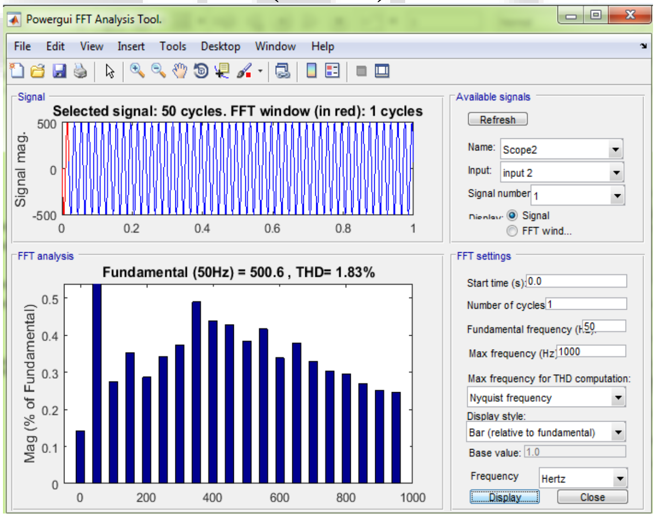


Fig. 23: THD of Inverter output voltage after filter (SVPWM)

## V. CONCLUSION

This paper brings us to the conclusion that whatever scheme we propose our motto should be fulfilled: that is using renewable energy resource for development purpose. Output achieved by SVPWM is far better than SPWM technique. In future we would be able to achieve more efficiency, what we just need is to keep digging for methods that can make us more reliable on renewable energy resources rather than rapidly depleting the conventional energy resources.

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