Modelling and Simulation of 1 KW Solar Generation System to Grid Connected with use SPWM & SVPWM

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Abstract— This paper present solar photovoltaic (PV) generation system to gird-connected with low harmonic distortion in the output voltage. Solar generation system utilizes maximum power point tracking is achieved with perturb and absorb (P&O) Method. In three level diode clamped inverter implementation of sinusoidal pulse width modulation (SPWM) as well as Space vector pulse width modulation (SVPWM) techniques for pulse width modulation and generation of gate pulse. In this paper first a model for SPWM is made and simulated using MATLAB/SIMULINK software and its performance is compared with SVPWM. The simulation study reveals that SVPWM voltage more effectively and generates less Total harmonic distortion (%THD) when compared with SPWM.

Key words: Photovoltaic (PV) Cell, MPPT (P&O), multilevel inverter, SPWM, SVPWM, THD

I. Introduction

Renewable energy sources, such as solar, wind, tides, geothermal heat, biomass etc., are desirable for electrical power generate due to their environmental friendly nature and unlimited existence. Global warming and energy policies have become a hot topic on the international agenda. Developed countries are trying to reduce the greenhouse effect, [2]. In this situation, photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source.

The photovoltaic nature of solar panels, this current-voltage (IV), curves depend on temperature and irradiance levels. Therefore, the operating current and voltage which maximize power output will change with environmental conditions. There are a number of maximum power point tracking (MPPT) algorithms which track the optimal current and voltage in a fluctuating environment such as the perturbation & observation (P&O) method. Multilevel inverters put forward many benefits for higher power applications. In particular, these include ability to synthesis the voltage waveforms with lower harmonic content than three-level inverters and operation at higher DC voltages using series connected semiconductor switches. While many different multilevel converter topologies have been proposed, the three most common topologies are, the Cascaded Inverter H-Bridge Multilevel Inverter, Flying Capacitor Multilevel Inverter and Diode Clamped Multilevel inverter, [5]. The two most popular switching strategies for these multilevel inverter topologies are,

– Sinusoidal PWM (SPWM) and
– Space Vector PWM (SVPWM) modulation.

In SPWM the gating signals generated by comparing sinusoidal reference signal with a triangular carrier wave. In SVPWM rotating phase is obtained by adding all the three voltages. SVPWM technique is mostly used for multilevel inverters compared to SPWM, [8]-[11]. SVPWM technique was originally developed as a vector approach to PWM for three phase inverters, [9]-[10]. It is an advanced and computation method and it is quite different from other PWM methods.

$V_{max} = \frac{Vdc}{2}$: For Sinusoidal PWM

$V_{max} = \frac{Vdc}{\sqrt{3}}$: For Space vector PWM

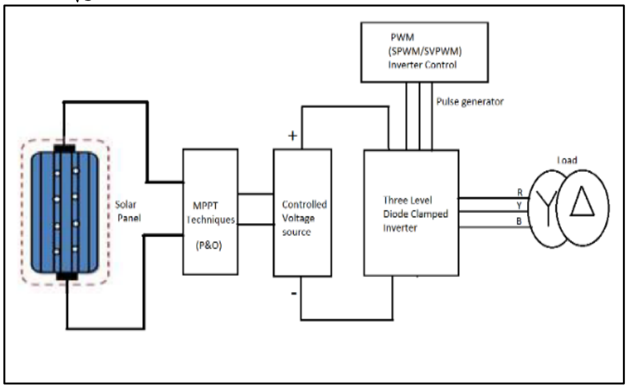

Fig. 1: Block Diagram of the representation system along with PWM (SPWM/SVPWM) technique.

II. Modeling Solar Photovoltaic Cell

The equivalent circuit shown in fig. (2) Can represent of the PV cell. It includes a current source, series and shunt resistance and diode, [1]- [13].

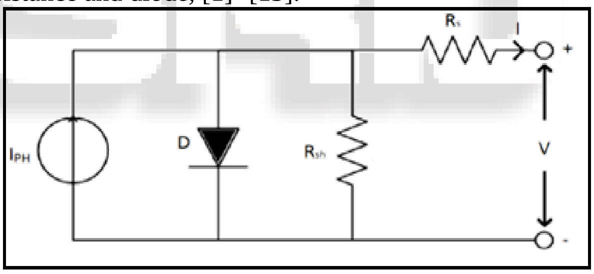

Fig. 2: Equivalent circuit of a solar PV cell

In the equivalent circuit, the current delivered to the external load equals the current I_{PH} generated by the illumination, less the diode current I_d. The output character of a single PV cell is show in eq. (1).

$$I = I_{PH} - I_S \left[\exp\frac{q(V+IR_S)}{NKT} - 1\right] - \frac{q(V+IR_S)}{R_{sh}} \quad (1)$$

This equation, I is the load current (A), I_{PH} is the photocurrent (A), V is the Cell terminal voltage (V), I_S the Short circuit current (A), q is the electron charge (1.602 x 10-19 C), N is the diode ideal factor, K is the Boltzmann constant (1.38 x 10-23 J/K), T is the cell temperature (K), R_S and R_{SH} is the series and shunt resistance respectively,[2]-[13]. So, the behaviour of a solar PV cell is completely dependent on these parameters.

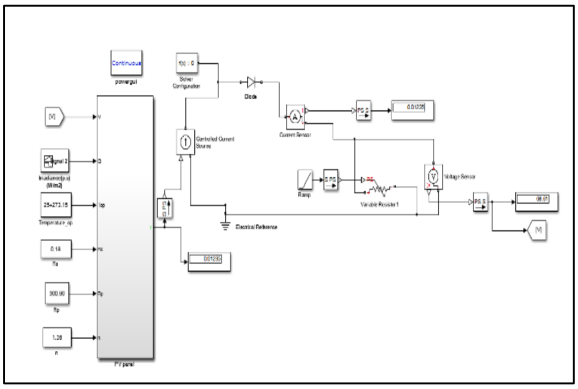

Fig. 3: Simulation model of solar photovoltaic (PV) cell

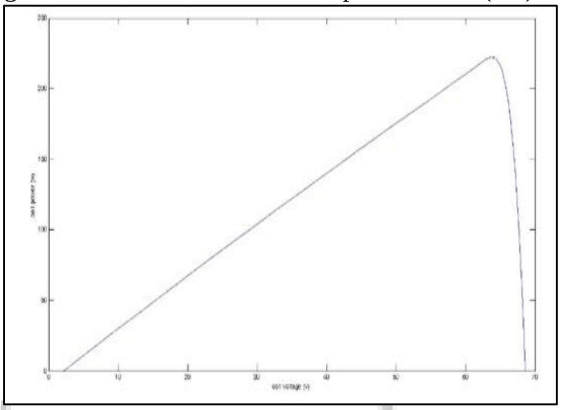

Fig. 4: P-V characteristics

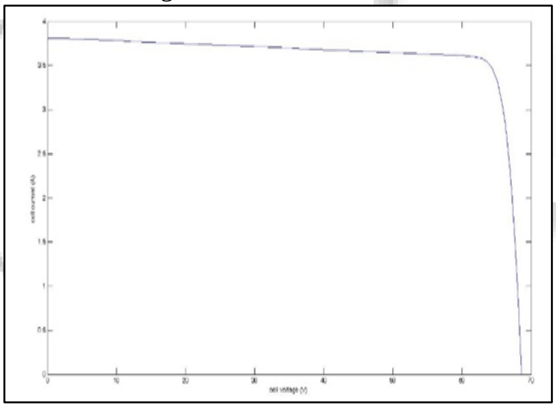

Fig. 5: I-V characteristics

Fig. 3 shows the Simulink subsystem for solar PV cell.

Fig.3 and 4 respectively generated output results in P-V and I-V characteristics curves are given.

In eq. (1) of them calculates the photocurrent IPH. The photocurrent IPH depends on the solar irradiance and cell temperature, [1]-[13]. The output of the PV module different solar irradiance level and constant temperature which can be obtained from the following eq. (2).

$$I_{PH} = [I_{SC} + K_i(T - T_{ref})]\,\frac{B}{1000} \qquad (2)$$

In this equation, ISC is the short circuit current (A), Ki is the temperature coefficient of short circuit current (A/0C), T is the cell temperature (K), Tref is the reference temperature (K) and B is the solar irradiation in W/m2.

Generation of I-V and P-V characteristics for different solar irradiances and constant temperature, [1]-[13].

Shows the I-V and P-V characteristics generated by the simulation for a constant temperature of 25°C (T=298°K) and different irradiance values = 400,600,800 and 1000 W/m2 .

The other PV cell model calculates the diode saturation current IS for different as a cubic function of the temperature and it can be expressed as the following eq., (3) [1]-[13].

$$I_s = I_{RS}\left(\frac{T}{T_{ref}}\right)^{\frac{3}{N}} e^{-\frac{qV_t}{NK\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}} \qquad (3)$$

In this equation, IRS is the diode reverse saturation current (A) and V_t is the thermal voltage (V). The cell reverse saturation current can be obtained from the eq. (4) given below.

$$I_{RS} = \frac{I_{sc}}{[e^{qv_{oc}/NKT}]} \qquad (4)$$

Thermal voltage V_t can be obtained from the following eq. (5).

$$V_t = \frac{KT}{q} \qquad (5)$$

III. MAXIMUM POWER POINT TRACKING (MPPT).

A typical solar panel converts only 30 to 40 percent of the occurrence solar irradiation into electrical energy. Maximum power point tracking (MPPT) technique is used to improve the efficiency of the solar panel. Maximum power point is achieved at single point in PV graph, tracking of maximum power point with continuously variations in radiation intensity and temperature is necessary to ensure the efficient operation of the solar cell array. MPPT enables an increase in the power delivered from the PV module to the inverter or load, as well as also increase the operating lifetime of the PV system, [4]-[14].

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1) Perturb and observe (Hill climbing method)
2) Incremental Conductance method
3) Fractional short circuit current
4) Fractional open circuit voltage
5) Neural networks
6) Fuzzy logic

In this work perturb & observe (Hill climbing method) which is on line method has been used.

IV. PERTURB AND OBSERVE METHOD

This method is the most commonly used algorithm to track the maximum power due to its simple configuration and less required parameters. This method finds the maximum power point of PV modules by means of iteratively perturbing, observing and comparing the power generated by the PV modules. It is broadly applied to the maximum power point tracker of the photovoltaic system for its features of simplicity and convenience. According to the structure of MPPT system the required parameters are only the voltage and current of PV array.

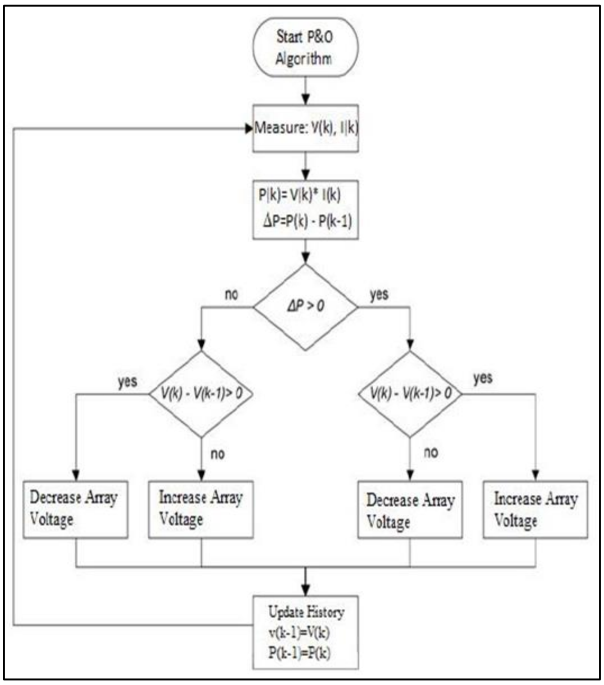

Fig. 5: The Flow Chart of the Perturb & observe method

The Perturb and Observe (P&O) system given in Fig. (5) Conditions that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we are going in the direction of MPP and we will keep on perturbing in the same direction. If the ΔP is negative than we will go away from the direction of MPP and the sign of perturbation supplied has to be changed, [14].

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

Table - 1: Summarized process of P&O method.

V. THREE-LEVEL DIODE CLAMPED INVERTER

Conventional simple two-level inverters are mostly used to generate an AC voltage from a DC voltage, the three phase three-level diode clamped multilevel inverter is the common multilevel inverter used for various applications. A three phase 3-level diode clamped multilevel inverter is adopted in this paper. Shown in fig. (6) It is obtained from a configuration of twelve switching devices and six clamping diodes, [5]-[6]-[7].

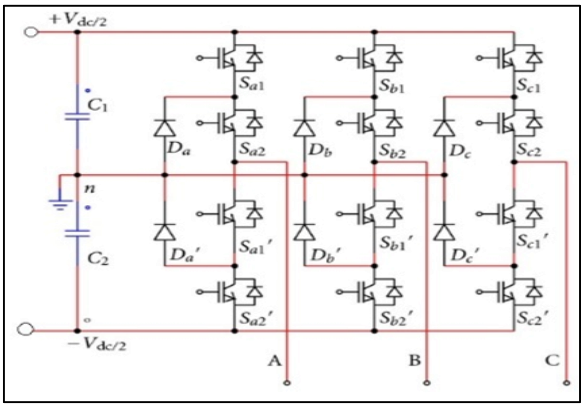

Fig. 6: Three level diode clamp inverter

In diode clamp or neutral point clamp topology, multilevel inverter diodes have been used as a clamping device to create required output voltage levels, [5]-[6]-[7]. The duty cycle for switches ON/OFF in three-level diode clamp inverter done as per Table. (2), [6]-[7].

Magnitude of voltage(Vdc)	No. of switches to be ON/OFF			
	S1	S2	S3	S4
+Vdc/2	ON	ON	OFF	OFF
0	OFF	ON	ON	OFF
-Vdc/2	OFF	OFF	ON	ON

Table - 2: Diode Clamped Inverter Switching Table

A. *Sinusoidal pulse width modulation (SPWM).*

Pulse Width Modulation method is a fixed dc input voltage is given to the inverters and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. The gating signal can be generated by comparing a sinusoidal reference signal with a triangular carrier wave and the width of each pulse varied proportionally to the amplitude of a sine wave evaluated at the centre of the same pulse, [8].

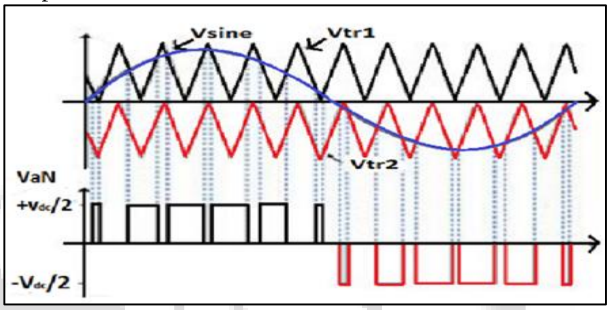

Fig. 7: Generation of Sinusoidal pulse width modulation

Explains Fig. (7) The generation of a sinusoidal PWM signal. SPWM order to output a sinusoidal waveform for three-level inverter at a specific frequency a sinusoidal control signal (Vsine). This specific frequency is compared with a (m-1) triangular waveform (Vtri) for three level inverter as shown in Fig. (); where, m is number of inverter level (2, 3, 4,..., etc), [8]-[11]-[12].. The inverter will use than the frequency of the triangle wave as the switching frequency which is basically kept constant.

The triangle waveforms (Vtr1, Vtr2) are at the switching frequency (fs) is this frequency controls the speed at which the inverter switches can turned on and off. The control signal (Vsine) is used to modulate the switch duty ratio and has a frequency f, which is known as fundamental frequency of the inverter output voltage. The output of the inverter is affected by the switching frequency. Here, it contains harmonics at the switching frequency. The duty cycle of the one of the inverter switches here is called as amplitude modulation ratio (Ma), [11]-[12].

When, Vsin > Vtr1 = +Vdc/2
When, Vsin < Vtr2 = -Vdc/2
When, Vtr2 > Vsine = 0

The switches S+ and S- are controlled based on the comparison of signals Vsine and Vtri. Here, The two switches are never gets off at the same time which results in the output voltage fluctuating between +/- Vd/2 and the remaining switches will be output as 0,

B. Simulation Modal and results of SPWM

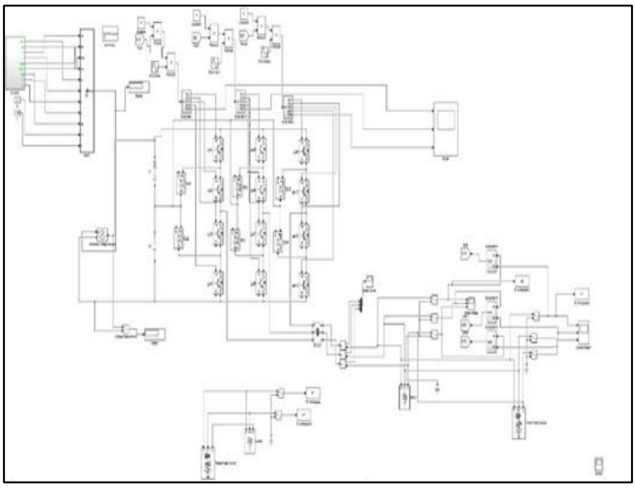

Fig.8: Simulation model for SPWM

C. Output Current Waveforms

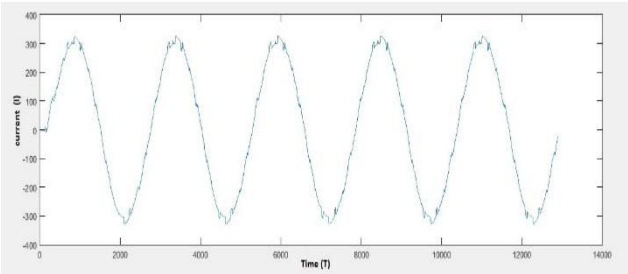

Fig. 9: Simulation results of Phase current

D. GATE Pulses

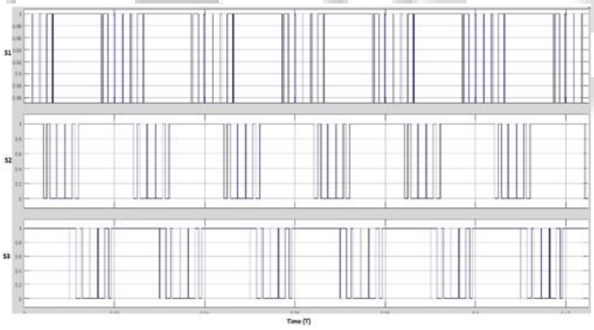

Fig. 10: Simulation results of GATE Pulses for inverter

E. Total harmonic distortion (%THD) analysis for SPWM

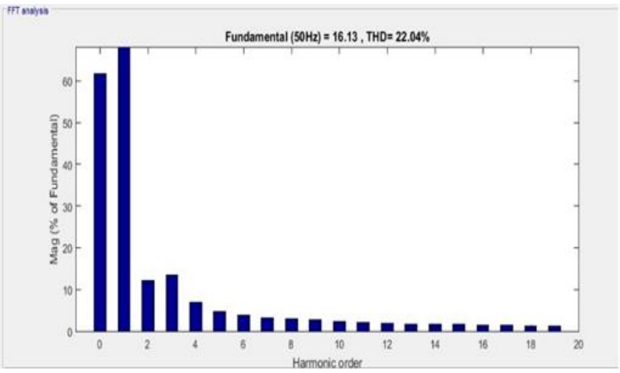

Fig. 11: Simulation results of Total harmonic distortion (%THD) analysis for SPWM.

VI. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

Space Vector Modulation (SVM) was originally developed as vector approach to Pulse Width Modulation (PWM) for three phase inverters. It is a more sophisticated technique for generating sine wave that provides a higher voltage to the load with lower total harmonic distortion. The main aim of any modulation technique is to obtain variable output having a maximum fundamental component with minimum harmonics. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application.

The inverter can be thought of as three separate push-pull driver stages which create each phase waveform independently. SVPWM treats the inverter as a single unit. Specifically the inverter can be driven to twenty seven switching states for 3-level inverter in SVPWM, [9]-[10]-[15].

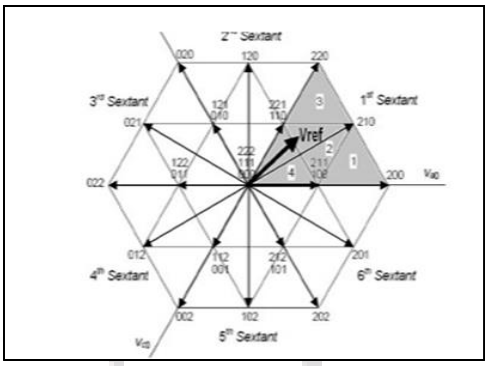

Fig. 12: Voltage vector of 3 level inverter system

Voltage vectors	Switching vectors		
	A	B	C
V0	0	0	0
V1	1	0	0
V2	1	1	0
V3	0	1	0
V4	0	1	1
V5	0	1	1
V6	1	0	1
V7	1	1	1

Table - 3: Switching patterns and output vectors

Modulation is accomplished by switching the state of inverter. SVPWM is a digital modulation technique where the objective is to generate PWM load line voltages. This is done in each sampling period by properly selecting the switching states of inverter and calculation of the appropriate time period for each state, [9]-[10]-[15].

A. Simulation Modal and results of SVPWM

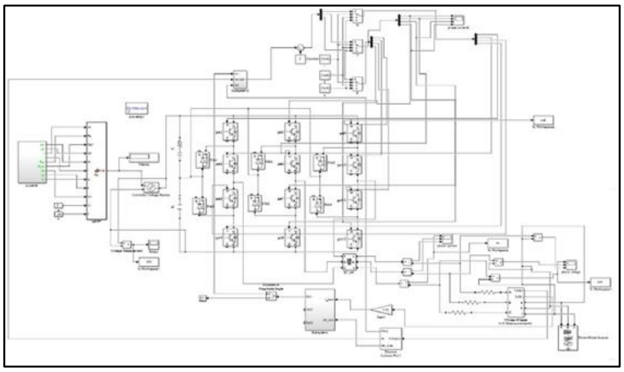

Fig. 13: Simulation model for SVPWM.

B. Output Current Waveforms.

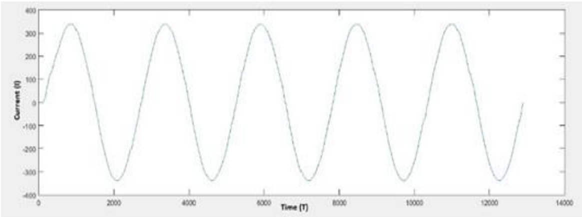

Fig. 14: Simulation results of Phase current.

C. GATE Pulses

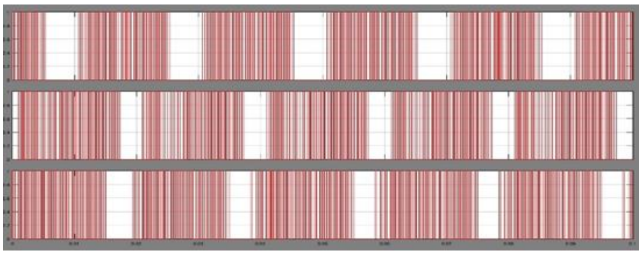

Fig. 15: Simulation results of GATE Pulses for inverter.

D. Total harmonic distortion (%THD) analysis for SPWM.

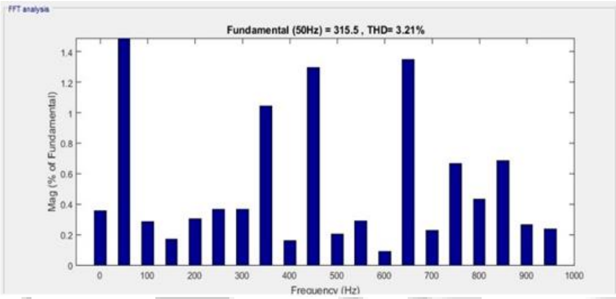

Fig. 16: Simulation results of Total harmonic distortion (%THD) analysis for SVPWM.

VII. COMPARISON

This results it is observed that the generated output voltage and current waveforms are smoother and very much increased of SVPWM system than SPWM. Generated Gate pulses from SVPWM are more in proper manner than SVPWM system. The THD measurement of SPWM and SVPWM are 22.04% and 3.21%. This show the THD is highly reduced. The THD levels of proposed SPWM and SVPWM are compared in Tab.4.

Total harmonic distortion(%THD)	SPWM	SVPWM
	Current	Current
%THD	22.04%	3.21%

Table - 4: Total harmonic distortion (%THD) analysis report

VIII. CONCLUSION

The paper has study the harmonic profile of Grid connected PV system with MPPT by using SPWM & SVPWM modulation techniques on MATLAB/SIMULINK. Simulink results we can conclude that SVPWM technique is more efficient by giving improved and smoother output waveforms than SPWM technique. As well as the %THD of line voltage and current are less in the system in which SVPWM technique is being used. The THD measurement of SPWM and SVPWM are 22.04% and 3.21%. This show the THD is highly reduced. The THD levels of proposed SPWM and SVPWM are compared in Tab.4.Therefore SVPWM technique is more suitable than SPWM technique for the proposed system.

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