SPACE VECTOR PULSE WIDTH MODULATION SCHEME FOR INTERFACING POWER TO THE GRID THROUGH RENEWABLE ENERGY SOURCES

Smt N. Sumathi M.Tech.,(Ph.D) [1], **P. Krishna Chaitanya**[2]

[1] *Assistant Professor, Department of EEE, JNTU Kakinada, Andhra Pradesh, India*
[2] *Student, M.Tech (EEE) in High Voltage Engineering, JNTU Kakinada, Andhra Pradesh, India*

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Abstract - ***This Paper presents the development of a control design that is required for inverters that are tied to Grid, which will take the power from renewable energy sources (RES). Space Vector Pulse Width Modulation (SVPWM) and Hysteresis Current Control (HCC) are performed in this work. The paper presents MATLAB simulation results, and the experimental results obtained will prove the ease and reliability of the control design. The transfer of Active power can be executed through a solar panel connected inverter that is interfaced to the Grid. As the DC link voltage increases, the power delivered to the grid will increase.***

Key Words: *Space Vector Pulse Width Modulation, Hysteresis Current Control, renewable energy, distributed generation, grid connection.*

1. INTRODUCTION

Electric power Generation systems interfaced Renewable energy source (RES) with significant Controllers is very difficult and uneconomical to handle the inconstancy in the power input. More over the distributed generation systems becomes popular to deal the situation of Black-out's. Hence the systems that are interfaced to the Grid raises a problem of power quality to the consumers if it is not standardized [1]. For an inverter-interfaced system, the power quality of the grid largely depends on the inverter's controller performance. Grid connected inverter systems broadly adopts Current monitored VSI in order to accommodate grid stability, active and reactive power control, power quality development [2]. The current-controlled PWM inverters have considerable advantages such as fast dynamic response, built-in current spike protection, better dc-link usage, and instantaneous current control. Control schemes using HCC and SVPWM are considered and discussed in a detailed manner [5, 10]. In HCC without the use a PI controller, power transmission into the Grid is accomplished. It is used for quick current tracking, and easy implementation. However, the bandwidth of the Hysteresis current Controller regulates the acceptable current shaping error. By modifying the bandwidth the user can restrict the grid connected inverter's average switching frequency and evaluate the performance for different values of hysteresis bandwidth. Here the output current of inverter is forced to follow the grid voltage in terms of time phase. The advantage of this method is that it will satisfy the fundamental conditions in order to achieve synchronization and it will be fulfilled by default [11]. On the other hand space vector PWM (SVPWM) is widely engaged for three-phase systems [4]. The SVWPM-based current controller is a kind of linear control VSI and in this, PI controller is used in a typical voltage balancer discussed in [7]. It has many benefits such as constant switching frequency, and good DC-link utilization. Hence in order to achieve the active power transfer to the Grid, the comparison of current control techniques have been introduced in this paper.

2. CUREENT CONTROL DESIGN FOR GRID CONNECTED INVERTER SYSTEM

A current controlled VSI is generally used to interface the utility grid with the DG system [9]. The design of current control for grid connected inverters which is shown in fig.1 plays an effective role in providing high quality power to the grids.

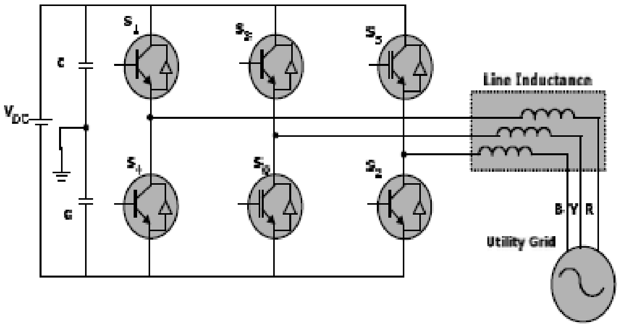

Fig 1. Three-Phase Inverter connected to utility Grid

3. ANALYSIS OF HYSTERESIS CURRENT CONTROL

In this proposed control design the Voltage source inverter (VSI) is connected to a RES (Solar panel) [12]. The DC link capacitor acts as an isolator in between the converters. The basic aspect of the control strategy has been discussed in [5]. The DC link transfers the power from the RES to the Grid. The control Design is shown in Fig 2.

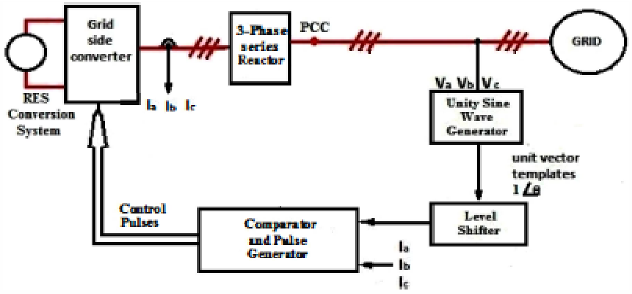

Fig 2. Control Design

In this control design, the inverter output current is forced to follow the grid voltage. By using a unity sine wave generator, the grid voltage is converted to a unit vector template and then this waveform is used as the reference current. The actual grid current is measured and compared with the reference current, and the pulses are generated according to the error between the actual current and the grid current [8]. The unity vector templates are obtained from the grid voltage, here the synchronizing angle **θ**, of the three phases is used to force the inverter output current to follow the grid voltage. The unit vector templates are represented as:

$$U_a = \sin(\theta) \quad (1)$$
$$U_b = \sin(\theta - 2\pi/3) \quad (2)$$
$$U_c = \sin(\theta + 2\pi/3) \quad (3)$$

These unit vector templates are sampled and fed to the microcontroller and compared with the actual grid currents I_a, I_b and I_c sampled from the grid directly

$$I_a \geq (U_a + h) \quad (4)$$
$$I_b \geq (U_b + h) \quad (5)$$
$$I_c \geq (U_c + h) \quad (6)$$

Where, h is the hysteresis band provided. If all the three conditions of equations (4), (5) and (6) are satisfied then the upper switches of the three phase inverter are switched on.

$$I_a < (U_a - h) \quad (7)$$
$$I_b < (U_b - h) \quad (8)$$
$$I_c < (U_c - h) \quad (9)$$

If the three conditions of equations (7), (8) and (9) are fulfilled, then the upper switches will be switched off and the lower switches will be switched on. In order to synchronize the RES to the grid, the magnitude, frequency and the phase of the voltages on the two sides should match [6]. The control scheme presented here easily manages these aspects. The reference current is obtained from the grid voltage. This helps the control scheme to generate switching pulses for the inverter such that the inverter output current is in the same phase and frequency as that of the grid voltage. As far as this control scheme is concerned the inverter output current is of the same phase as that of the grid current and also lags the inverter output voltage by an angle decided by the inductance in the circuit. Thus by default the inverter output voltage leads the grid voltage by the same angle. This makes the power transfer to the gird possible. The control design using these equations thus provides switching pulses to the inverter in such a way that the inverter output current is forced to follow the reference current strictly.

4. ANALYSIS OF SVPWM CURRENT CONTROL

SVPWM is employed to generate the desired output voltage vector V* in d-q reference frame for a 3-Ø VSI, using NPC is discussed in [3]. Hence there are totally eight possible switching patterns and each of them determines a voltage space vector.

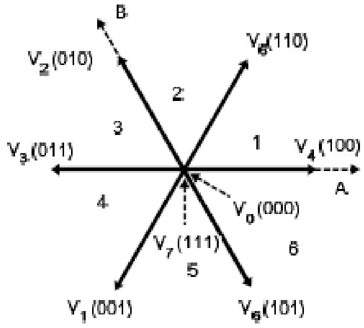

Fig 3. Voltage space vector of three phase VSI

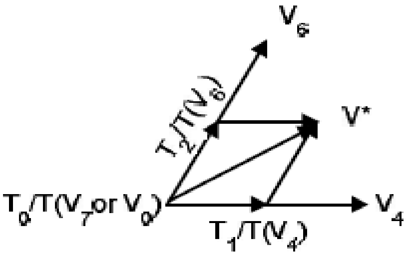

Fig 4. Arranging of voltage vector using adjacent vector

As shown in fig. 3 eight voltage space vectors divides the unified space vector into six sectors, namely V1 ~ V6. All other active space vectors except two zero vectors, V0 and V7 will have the same magnitude of (2/3) V_{dc}. According to the phase angle of the reference voltage vector in the d-q coordinates and the grid angle indicating the relative position of the d-axis to the Q-axis, the sector location in which reference voltage vector can be easily found out. In SVPWM, the reference voltage vector should be synthesized by the adjacent vectors of the located sector in order to minimize the switching times and to minimize the current harmonics. An example of the incorporating procedure in Sector 1 is described above in fig. 4. Where T is the PWM period, T1 and T2 are time durations of two active vectors in each PWM cycle, T0 is the time duration of zero active vectors in each PWM cycle and equals to (T0-T1-T2). After T1, T2 and T0 are established, the three-phase PWM pulses are generated by one of symmetrical methods. This method makes each switching component switch once in one carrier period, bringing all of them to a fixed switching frequency, and with the proper placement of zero vectors, the entire voltage vector is split into ripple frequency to the double of switching frequency.

5. SIMULATION RESULTS AND DISCUSSION

Computer simulation has been carried out using MATLAB/Simulink environment in order to validate the performance of the hysteresis and SVPWM current control strategies for three phase grid connected inverter system. For that 55 V is considered as phase-phase Rms voltage of the grid system with the frequency of 50 Hz. 110 V and 190 V has been considered as dc-link voltage taken from Solar panel for Hysteresis and SVPWM current controllers respectively.

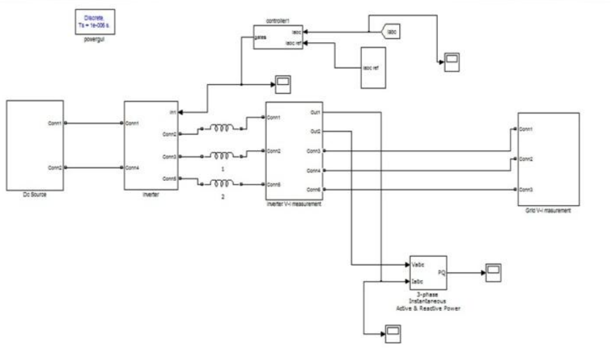

Fig 5. Modelling Of Simulink For HCC

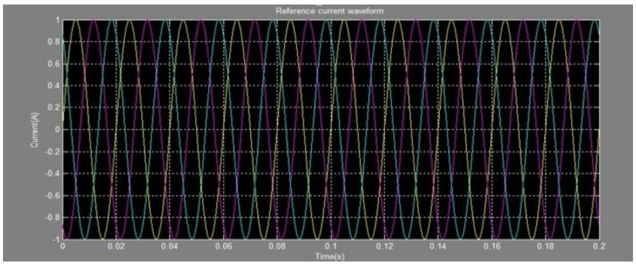

Fig.6 Simulation Results for Reference current

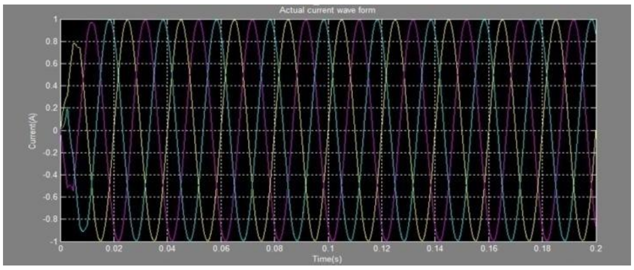

Fig 7. Simulation Results for Actual current

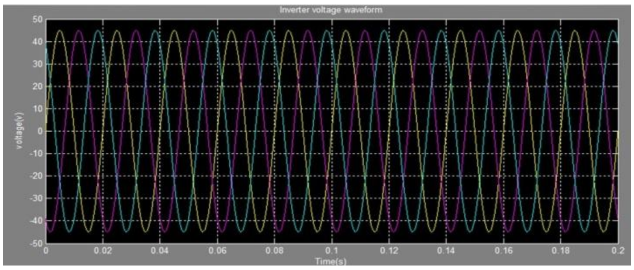

Fig 8. Simulation Results for Inverter Voltage

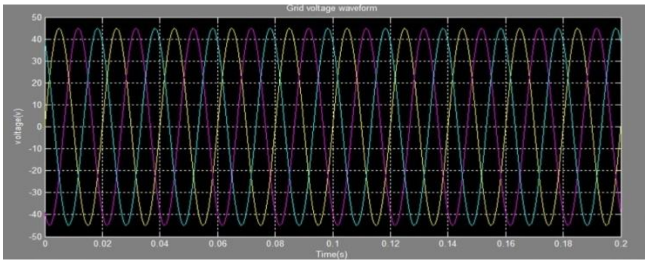

Fig 9. Simulation Results for Grid Voltage

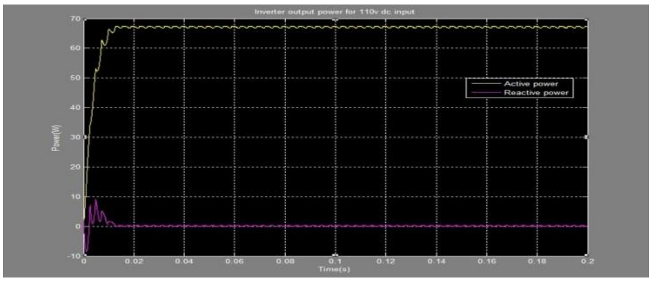

Fig 10. Simulation Results for Active and Reactive power

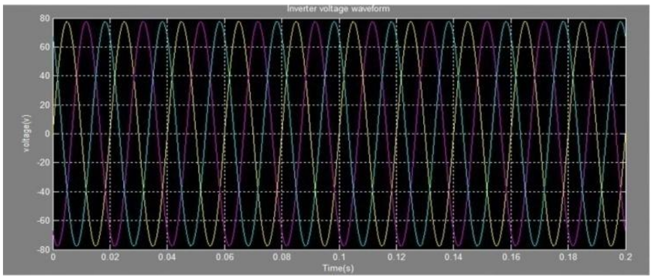

Fig 11. Simulation Results for Inverter Voltage

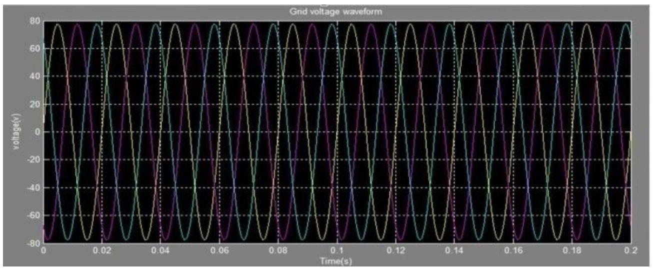

Fig 12. Simulation Results for Grid Voltage

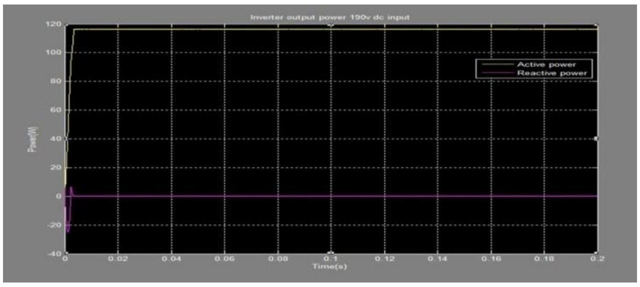

Fig 13. Simulation Results for Active and Reactive power

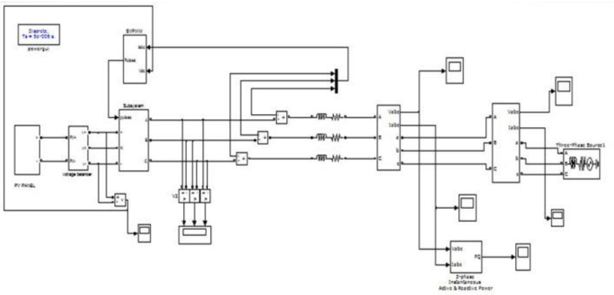

Fig 14. Modelling Of Simulink For SVPWM

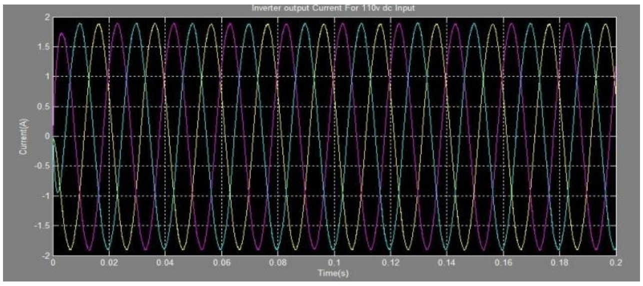

Fig 15. Simulation Results for Inverter Output current

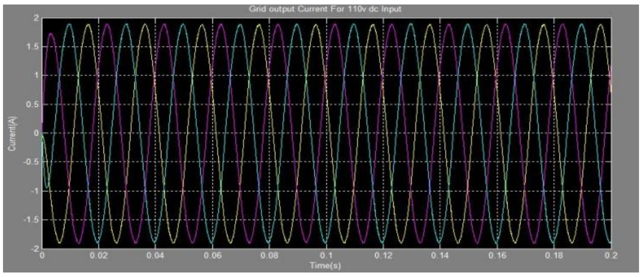

Fig 16. Simulation Results for Grid Output current

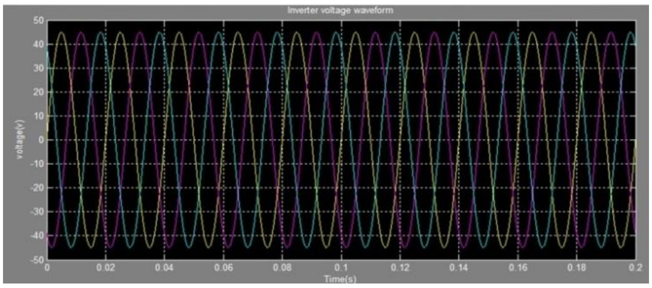

Fig 17. Simulation Results for Inverter Output Voltage

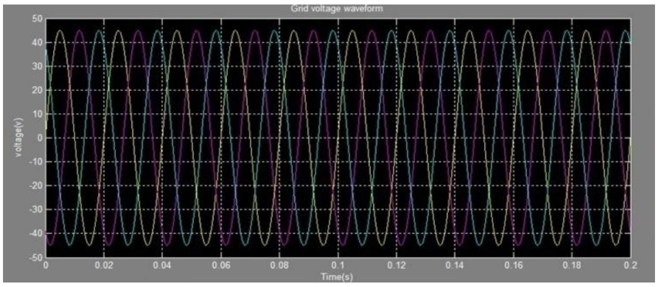

Fig 18. Simulation Results for Grid Output Voltage

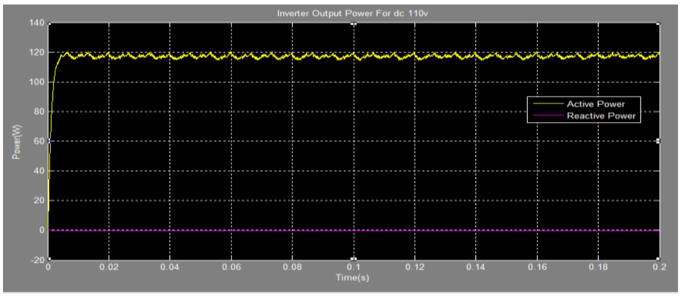

Fig 19. Simulation Results for Active and Reactive power

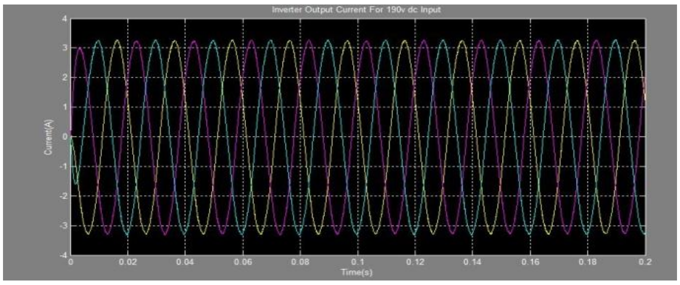

Fig 20. Simulation Results for Inverter Output current

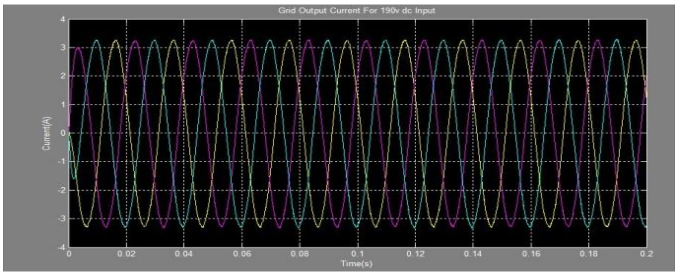

Fig 21. Simulation Results for Grid Output current

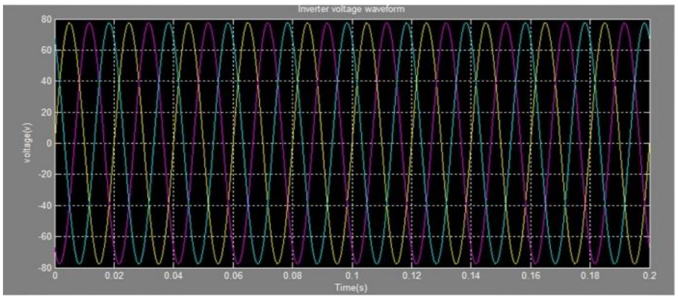

Fig 22. Simulation Results for Inverter Voltage

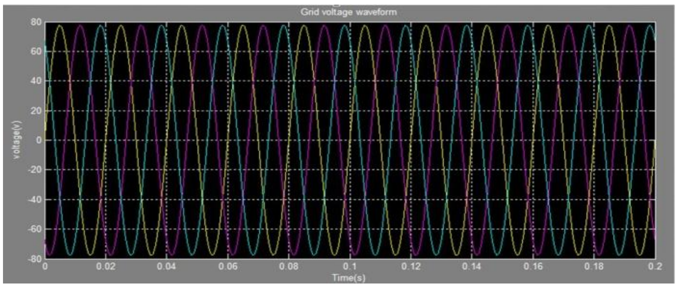

Fig 23. Simulation Results for Grid Voltage

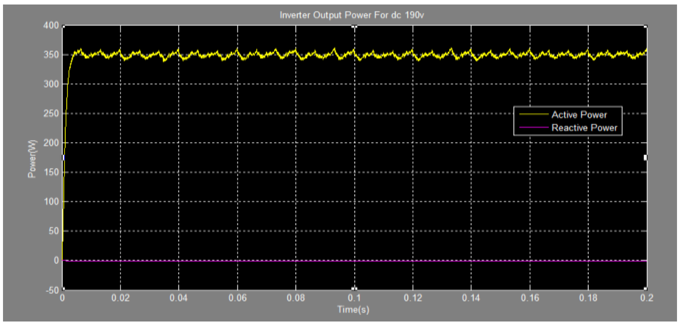

Fig 24. Simulation Results for Active and Reactive power

The Fig.5 shows the simulink diagram of HCC. Fig.6 and Fig.7 shows the current wave forms of HCC in which the reference current controls the actual current to a dc input of 110v and 190v from RES and a magnitude of 1Ampere has been obtained to each phase for a time period of 0.2 seconds and constant amplitude had been maintained in them. Fig.8 and Fig.9 shows the voltage waveforms of HCC for Inverter and Grid to a dc input of 110v from RES for which 45volts had been obtained to each phase for a time period of 0.2 seconds and more over constant amplitude had been maintained in them. Fig.10 shows the active and reactive power waveform of HCC for Inverter to a dc input of 110v, an active power of 68watts had been obtained for a time period of 0.2 seconds that will be injected to the Grid. Fig.11 and Fig.12 shows the Voltage wave forms of HCC for Inverter and Grid to a dc input of 190v from RES for which 78 volts had been obtained to each phase for a time period of 0.2 seconds. More over as the input increases the voltage had been increased and constant amplitude had been maintained in them. Fig.13 shows the active and reactive power waveform of HCC for Inverter to a dc an input of 190v, an active power of 118watts had been obtained for a time period of 0.2 seconds and that will be injected to the Grid.

Therefore in HCC it is observed that for any range of input the current will be constant and the voltage will get increased. Hence it is the best controller to control the current there by injecting quality power to Grid.

The Fig.14 shows the simulink diagram of SVPWM. Fig.15 and Fig.16 shows the current wave forms of SVPWM in which the Grid voltage controls the Inverter current to a dc input of 110v from RES and a magnitude of 1.8 Amperes has been obtained to each phase for a time period of 0.2 seconds and it is observed that constant amplitude had been maintained in them. Fig.17 and Fig.18 shows the Voltage waveforms of SVPWM for Inverter and Grid to a dc input of 110v from RES for which 45volts had been obtained to each phase for a time period of 0.2 seconds and as the input increases the voltage had increased and constant amplitude had been maintained in them. Fig.19 shows the active and reactive power waveform of SVPWM for Inverter to a dc an input of 110v, an active power of 120 watts had been obtained for a time period of 0.2 seconds and that will be injected to the Grid. Fig.20 and Fig.21 are the current wave forms of SVPWM in which the Grid Voltage controls the Inverter current to a dc input of 190v from RES and a magnitude of 3.2 Amperes has been obtained to each phase for a time period of 0.2 seconds. Fig.22 and Fig.23 are the voltage waveforms of SVPWM for Inverter and Grid to a input of 190v from RES for which 78 volts had been obtained to each phase for a time period of 0.2 seconds. More over as the input increases the voltage had been increased. Fig.24 is the active and reactive power waveform for dc an input of 110v an active power of 350 watts had been obtained for a time period of 0.2 seconds and that will be injected to the Grid.

Therefore in SVPWM it is observed that for any range of input the current and voltage will be considerably increases and Inverter power will increases.

Table 1: Comparison of HCC AND SVPWM

	Voltage (V)			Current (A)		Active power (W)
	Input	Inverter	Grid	Inverter	Grid	
HCC	110	45	45	1	1	68
	190	78	78	1	1	118
SVPWM	110	45	45	1.8	1.8	120
	190	78	78	3.2	3.2	350

However current cannot be controlled in SVPWM but it can reduce the switching losses there by which it can increase the power compared to HCC and the comparison of both the controllers with results are shown in Table 1.

6. CONCLUSION

The Solar panel interfaced to the Grid has been tested and the power discharge was found to be decent. A DC link voltage control using a PI controller can control the active power flow effectively, thus the system accuracy had been increased. Though by using the HCC some disadvantages such as zero voltage vector switching losses had been occurred and it reduces the Active power that is injected to the Grid. Hence to incur the above disadvantage caused by the HCC technique it is concluded that SVPWM technique is found to be given the satisfactory results by reducing the switching losses, and provides the communication between the three sinusoidal signals and thereby increasing the Active Power that is to be injected to the Grid.

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