A New Simulation Approach Of 3-Φ Transformer-less Grid Connected PV Inverter Using Hysteresis Controller

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Abstract - This paper represents Grid connected Photovoltaic (PV) system with Hysteresis Current Control inverterwhich can be used to supplies electric power to the utility grid. This system uses two stage conversion processes. DC to DC stage which utilizes MPPT technique to extract the maximum power .DC to AC stage which is used to control the inverter output current by using Hysteresis current controller. The objective of controlling grid connected PV system is to provide boost constant DC link voltage, to control the harmonic injected intothe grid.Hysteresis Current Controller is capable of equal switching frequencies among the switching devices which is used to increase the output current waveform.By using this method we can reduce THD of inverter output voltage and current and also increase the system efficiency by using Hysteresis current controller. In this paper, by using MATLAB/SIMULINK we observed inverter output voltage,current and THD by using different controllers like Hysteresis Current Controller, Voltage controller, PI controllerfor Transformer less grid and comparison between these controllers.

Key Words: Grid connected PV system, MPPT, Hysteresis current control, transformer-less grid, inverter

1. INTRODUCTION

Solar power is considered a very promising source for electric power generation.Now days, the demand for renewable energy has been increasing significantly over the past few decades due to shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy andwind energy have become very popular and demanding due toadvancement in power electronic techniques. Electricity can be generated from sunlight either directly by employing the photovoltaic effect, or by using energy from the sun to heat up a working fluid that can be used to power up electricity generators. These two technologies are widely used today to provide power to either stand-alone loads or for connection to the power system grid.Photovoltaic power supplied to the utility grid is attaining more and more visibility, while theworld's power demand is increasing.Amongst the renewable source of energy, the photovoltaic power or solar systems[1] are gaining popularity,with heavy demand in energy sector and to reduce environmental pollution around caused due toexcess use non-renewable source of energy. Several system structures are designed for gridconnected PV systems.There are several grid inverter technologiesavailable such as centralized inverter, stringinverter, multi-string inverter and modular inverter
The main advantages of using a grid connected PV systems are: effect on the environment is low,the can be installed near to the consumer, thereby transmission lines losses can be saved, cost of maintenance in the generating system can be reduced as there are no moving parts.

The conventional stand-alone photovoltaic systems have the advantages of simplein orderto draw maximum power from PV arrays and store high amount ofenergy, battery banks are needed in these systems. Thesolar cell array produces only a small amount of current andvoltage. So, in order to meet a large load demand, the solarcell array has to be connected into modules and these modulesconnected into arraysPV array convert sunlight energy into DC electricity. Inpractice, PV array is connected to a maximum power pointtracker (MPPT) in order to allow the PV array to produce maximum power.The generated DC poweris then converted into AC power using inverter beforedelivered into the utility grid.Generally, the MPPT is built-in the inverter.The output voltage from PV array can bechangeable with solar radiation and also ambient temperature. So in order to interface with the electrical grid,PV array output voltage should be fixed and is converted to AC voltage compatible with the grid ac voltage.For that purpose grid inverter used.The grid inverter is different from a typical inverter thatused in stand-alone PV system. The main advantage ofthe grid inverter is that current drawn from the inverter isdelivered to the utility grid at unity power factor. Recently there are inverters capable of adjustable power factor.

2. MODELING THE SOLAR CELL

A simplifiedequivalent circuit of a solar cell consists of a current source in parallel with a diode variableresistor is connected to the solar cell generator as a load as shown in Fig 1. Theoutput of the current source is directly proportional to the light falling on the cell. Modeling of Solar PV array explained in [2,5]. When light strikesthe solar cell, the energy of the photons generates free charge carriers. Since the current is dependent upon the radiance,the current source produces the photoelectric current (photocurrent) Iph.

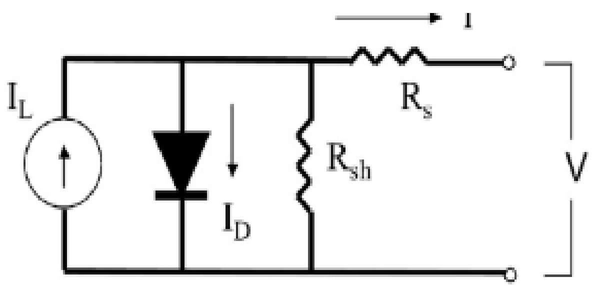

Fig-1: Circuit diagram of the PV model

The PV generator is a set of several photovoltaic cells which are connected in series and in parallel toproduce the requiring power. The density of power radiated from the sun at the outer atmosphere is 1.373 kW/m². Final incident sun light on the earth surface has the peak density of 1 kW/m2 at afternoon in thetropics. Solar cell can convert the energy of sunlight directly in to electricity.
The I-V characteristics equation of solar cell is given as

$$I = I_L - I_0\left\{\exp\left[\frac{q(V+IR_S)}{AKT_C}\right]-1\right\} - \frac{V+IR_S}{R_{Sh}}$$

Where

I_L is a light generated current or photo current (representing the current source),

I_0 is the saturation current (representing the diode),

R_S is series resistance,

A is diode ideality factor,

k is Boltzmann's constant (= 1.38×10^{-23} W/m²),

q (=1.6×10^{-19}C) is the magnitude of charge on an electron and

T_c is working cell temperature.

Photo current or light generated current, mainly depends on the solar insolation and cell working temperature, which is given as:

$$I_L = G\left[I_{SC} + K_I(T_C - T_{ref})\right]$$

Where

Isc is the short circuit current at 25°C and 1KW/m²,

K_I is the short circuit current temperature coefficient,

T is the reference temperature and

G is the solar insolation kW/m²,on the other hand, the cells diode current or saturationcurrent varies with the cell temperature which is given as:

$$I_0 = I_{RS}\left(\frac{T_C}{T_{ref}}\right)^3 \exp\left[\frac{qEG\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)}{KA}\right]$$

Where
I_{RS} is the cells reveres saturation current at reference temperature and a solar radiation,

E_G is the band-gap energy of the semiconductor used in cell.

The parameters of the Sun Power SPR305-WHT PV module are given in Table. The number of series connected strings or modules are 3 and the number of parallel strings is 2. The I-V and PV characteristics of the PV module are illustrated in Fig.2. The I-V and PV characteristics are highly nonlinear and the MPPT algorithm finds the maximum power point. Fig. 3 illustrates the I-V and P-V characteristics of PV array with varying solar irradiance.

Table-1: PV parameter specifications

Maximum power (Pmax)	305 W
Voltage at Pmax (Vmp)	54.7 V
Current at Pmax (Imp)	5.58 A
Short-circuit current (Isc)	5.96 A
Open-circuit voltage (Voc)	64.2 V

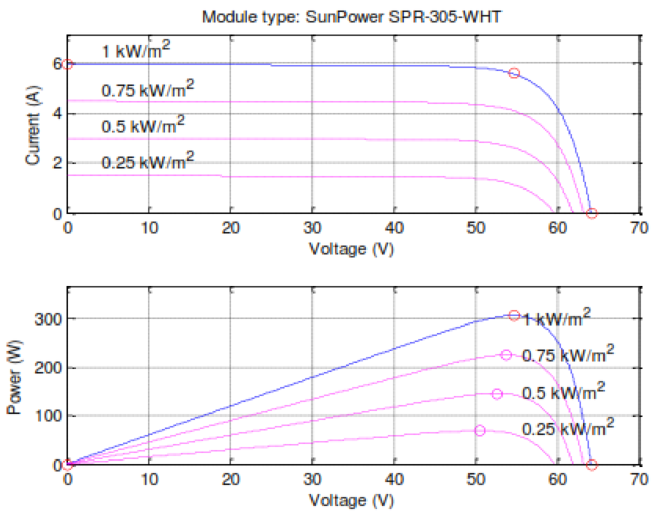

Fig-2: I-V and P-V characteristics of Sun Power SPR 305WHT module withvarying irradiance

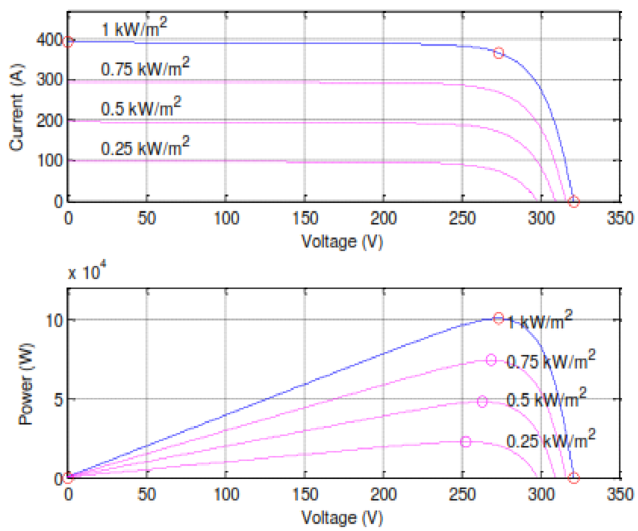

Fig-3: I-V and P-V characteristics of SunPower SPR 305WHT Array with varying irradiance

3. Boost DC-DC Converter

For grid-connected PV applications, two conversiontopologies for MPPT have been mostly used,known as one-stage and two-stage PV systems. In this paper,we selected the two-stage PV energy conversion system.when compared with the one-stageconfiguration, two stage PV energy conversion system offers an additional degree of freedom in operation of the system. Since the output voltage of PV cell is low, theuse of boost circuit will provide low-voltage PV array to beused, as a result, the total cost will be reduced. There are several topologies of direct single stage boost inverters [6,8]. A capacitor isgenerally connected between PV array and the boost circuit, which is used to reduce high frequency harmonics. The configuration of the boost circuit and its control system are illustrated in fig.4. DC-DC converters used to boost step-up the PV voltage to the level of the allowable maximum linevoltage and to the stable required DC level without storageelements as battery. DC-DC converter is controlled totrack maximum power point of the PV array.

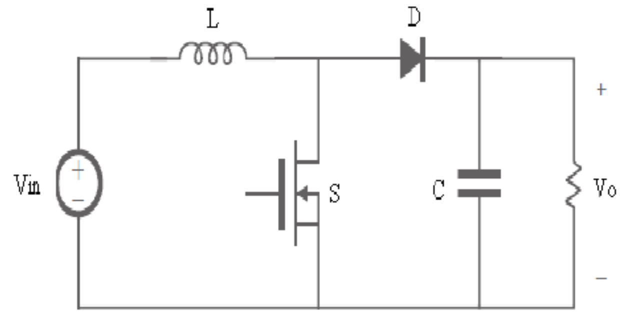

Fig-4: Boost converter

For Boost Converter, the Output Voltage , $V_{out} = \frac{V_{in}}{1-D}$

4. MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUE

MPPT techniques are used to control DC converters in order to extract maximum output power [3] from a PV array under a given weather condition. Three phase grid connected PV system reactive power compensation is possible by modified MPPT method [4].The DC converter is continuously controlled to operate the array at its maximum power point despite possible changes in the load impedance. Several techniques have been used but Perturb and Observe Method is best technique.The perturb and observe algorithm [7] is a simple technique for maximum power point tracking. It is based on controlling the duty cycle (D) of a DC-DC converter to adjust the PV array terminal voltage at the maximum power point. The power output of the array is monitored every cycle and is compared to its value before each perturbation is made. If a change (either positive or negative) in the duty cycle of the DC-DC converter causes output power to increase, the duty cycle is changed in the same direction. If it causes the output power to decrease, then it is reversed to the opposite direction.The performance of the algorithm is affected by the choice of the perturbation magnitude (Δd) of the converter switching duty cycle.

The algorithm represented in fig 5.

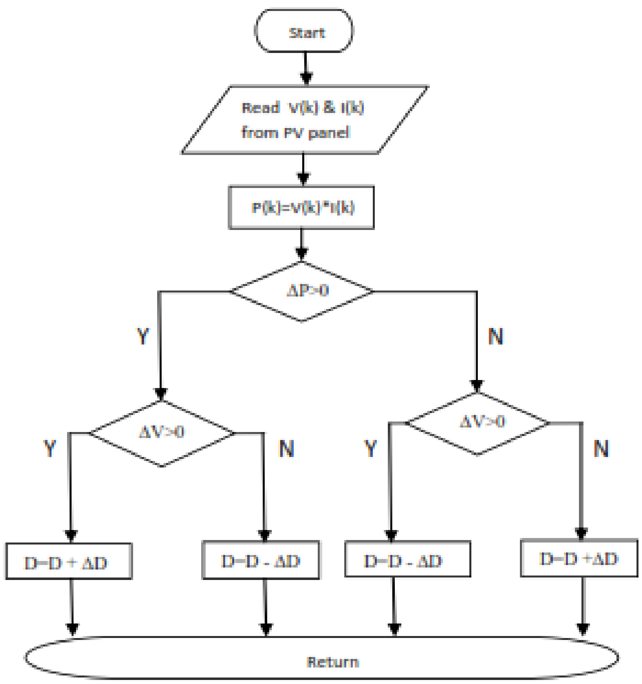

Fig-5: Flowchart of the perturb and observe algorithm

5. HYSTERESIS CURRENT CONTROLLED INVETER

The grid side inverter has six IGBTs as switching devices. It has inductor L, harmonic filter at itsterminal to reduce the current distortion. The inverter must act as a power controller between the DC link and the utility grid.

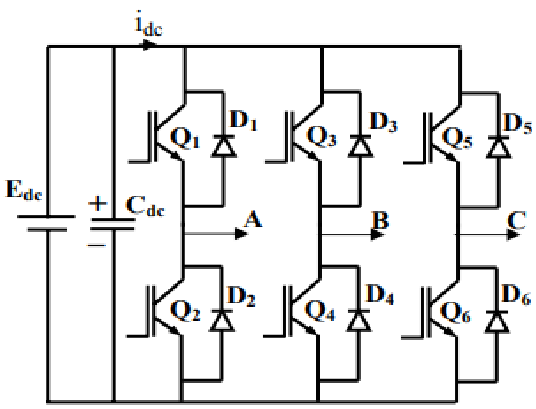

Fig-6: Voltage Source Inverter

The Hysteresis current controller provides generation of the switching signals for theinverter. Hysteresis-band PWM is basically an instantaneous feedback current control method of PWM [9] where the actual current continually tracks the command current within a specified hysteresis-band.

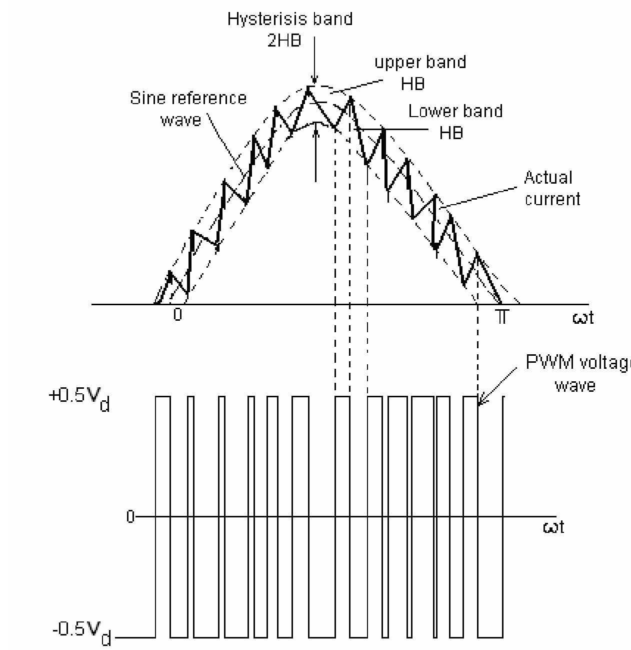

Fig-7: Principle of Hysteresis band current control

The control circuit generatesthe sine reference current wave of required magnitude and frequency, and it is compared with the actual phase currentwave. The inverter becomes an essential current source with peak to peakcurrent ripple, which is controlled within the hysteresis band irrespective of V_d fluctuation. The peak-to peak currentripple and the switching frequency are related to the width of the hysteresis band. Optimized control of grid connected inverter system is observed [10].The inputs to Hysteresis current controller are three phase current errors and outputs are switching patterns to the PWM inverter.

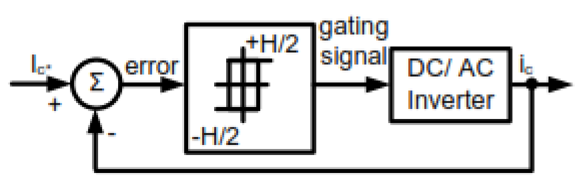

Fig-8: Block diagram of hysteresis band current control technique

Hysteresis band current control technique used to control the inverter output current. By usingthis method we set a zone around reference current to keep output current of inverter within this zone. The hysteresis band current control switching pulses and duration of pulse for one of the phase summarized as follows:

- If the output current of inverter reaches the upperlimit of zone, then the upper switch is OFF and the lower switchis ON.
- If the output current of inverter reaches the lowerlimit of zone, then the upper switch is ON and the lower switch isOFF.

By using Clark transformation (a-b-c coordinates reference system to a-ß coordinatesreference system), we can calculate the reference currents in a-b-c coordinates system given following equation

$$\begin{bmatrix} i_{c,a}^* \\ i_{c,b}^* \\ i_{c,c}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c,\alpha}^* \\ i_{c,\beta}^* \end{bmatrix}$$

6. SIMULATION AND RESULTS:

Simulation diagram of three phase grid connected PV system using Hysteresis band currentcontrol inverter discussed below.

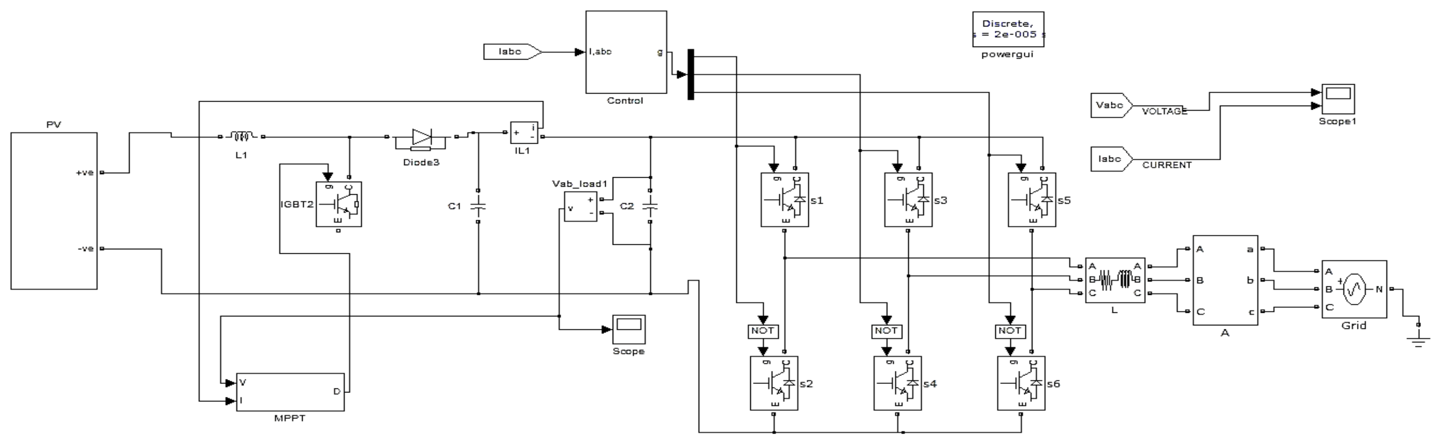

Fig-9: Simulation diagram of grid connected PV system using Hysteresis current controller

The Solar PV system uses SunPower SPR305-WHT module .The total power of Solar PV system is 1.8 kW. In above diagram, Boost Converter provides DC link voltage 500V.Here RL filter is used and values as R=10 ohms, L=0.1H.The grid voltage of 400V, 50Hz frequency used. The output voltage of Boost Converter is 500 V

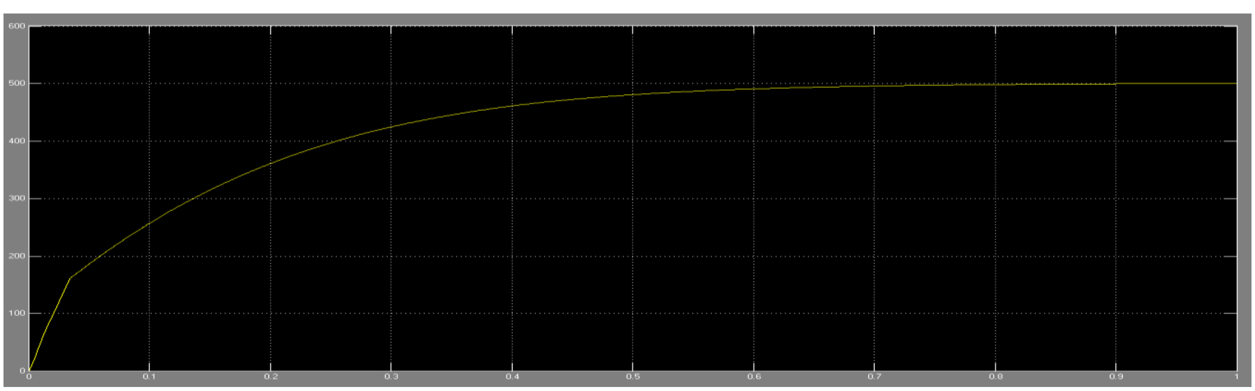

Fig-10: Output waveform of DC link voltage

For Hysteresis Current Control, RMS value of inverter Output voltage is 383.3 V and RMS value of inverter Output current is 4.64A. The Output waveforms of inverter given below:

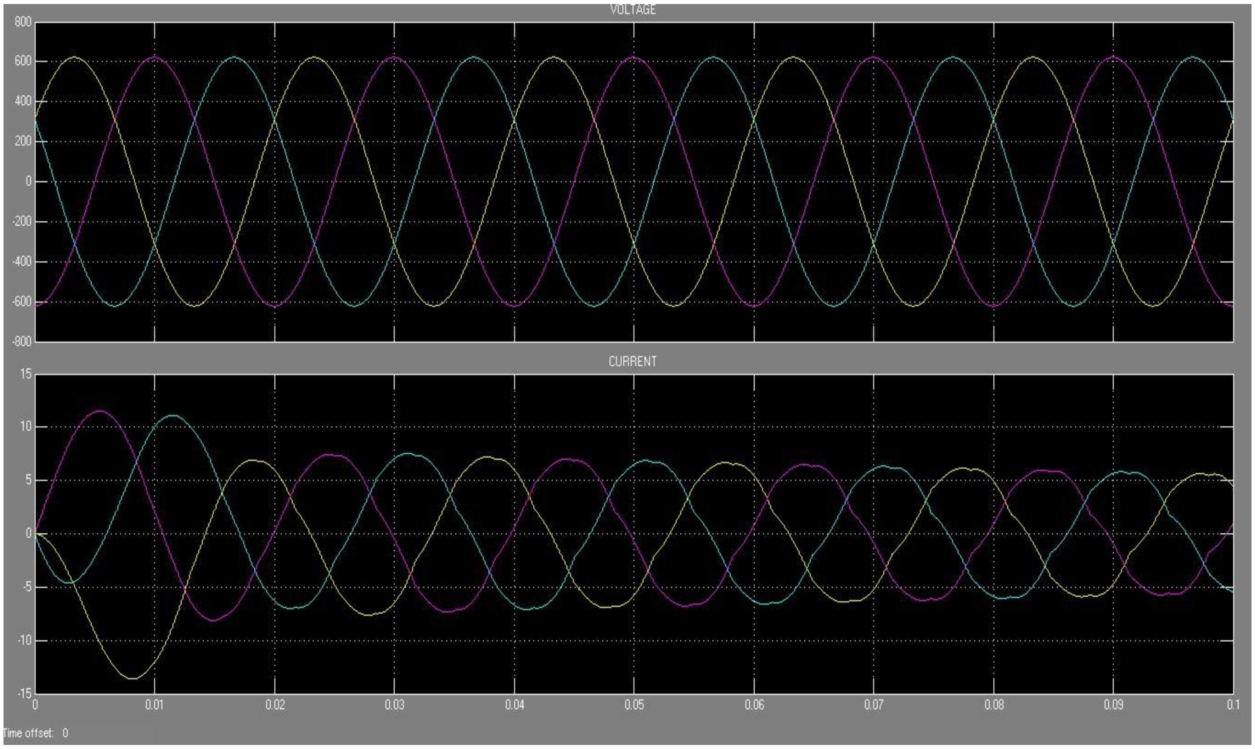

Fig-11: Output Voltage and Current of Hysteresis Current Control inverter

For Hysteresis Current Control inverter:

FFT Analysis for Voltage:

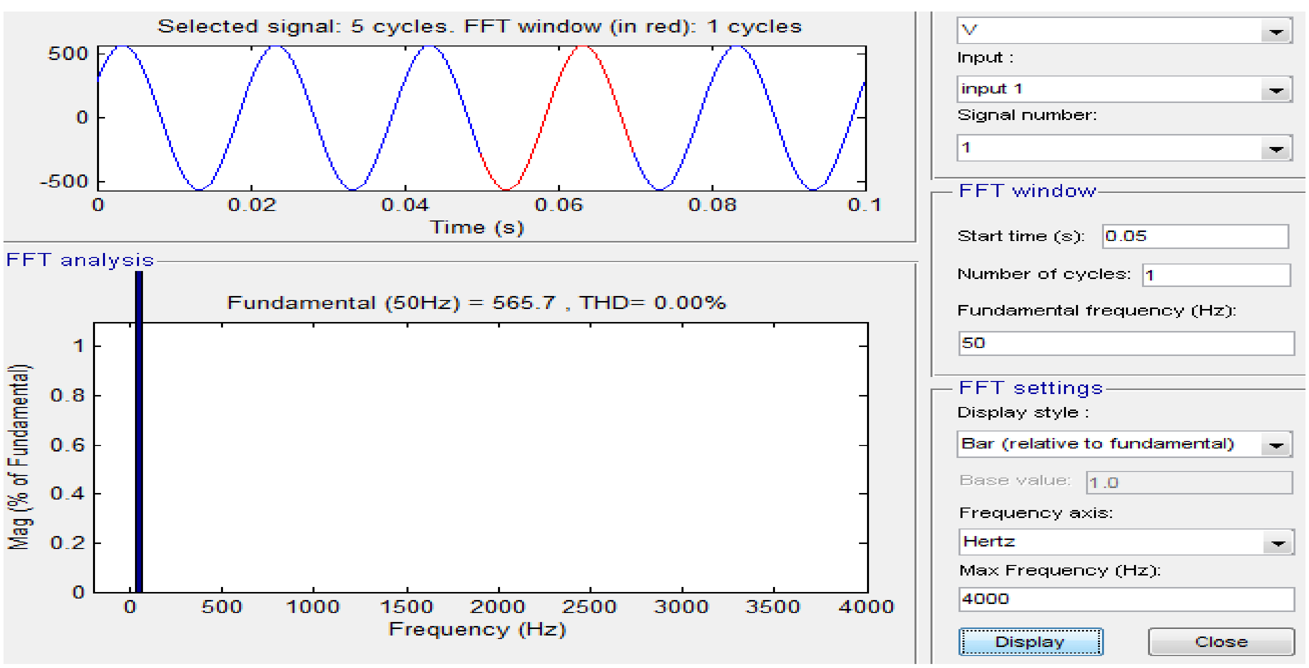

Fig-12: THD of inverter output voltage for Hysteresis Current controller

FFT Analysis for Current:

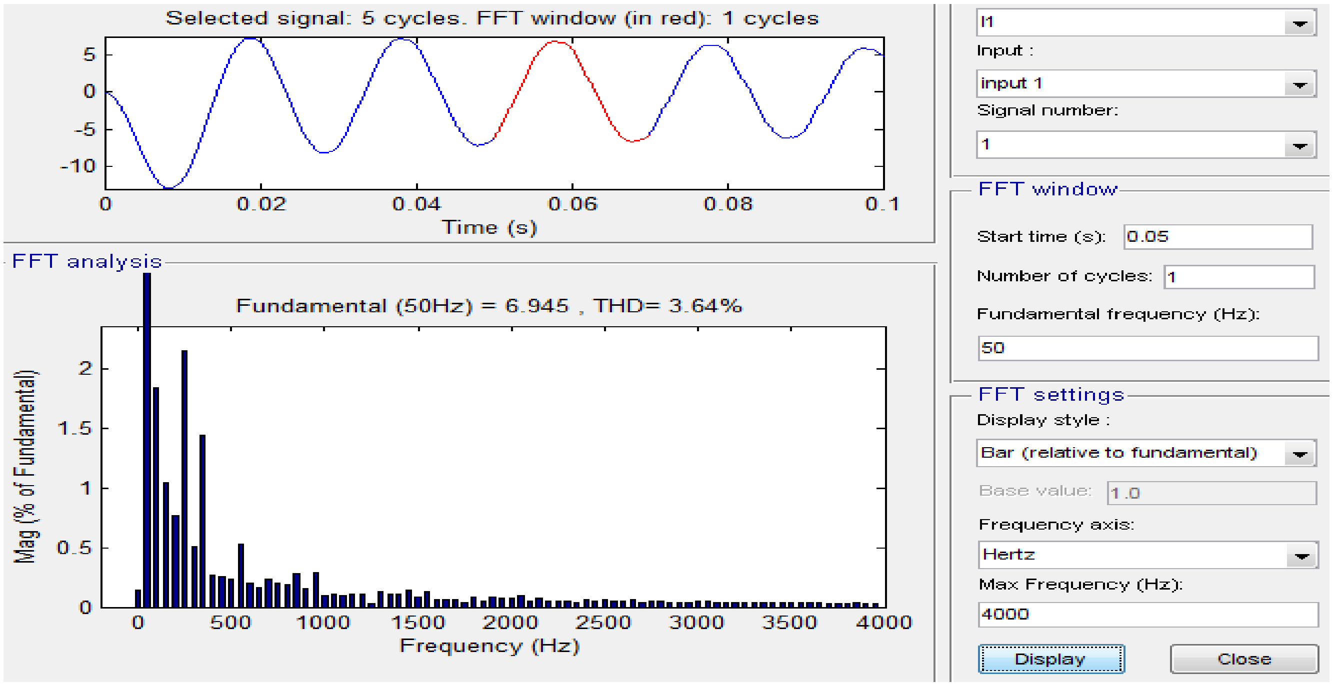

Fig-13: THD of inverter output current for Hysteresis Current controller

For Hysteresis Voltage controller, RMS value of inverter Output voltage is 383.3 V and RMS value of inverter Output current is 16.61 A.The inverter output voltage and current waveforms given below

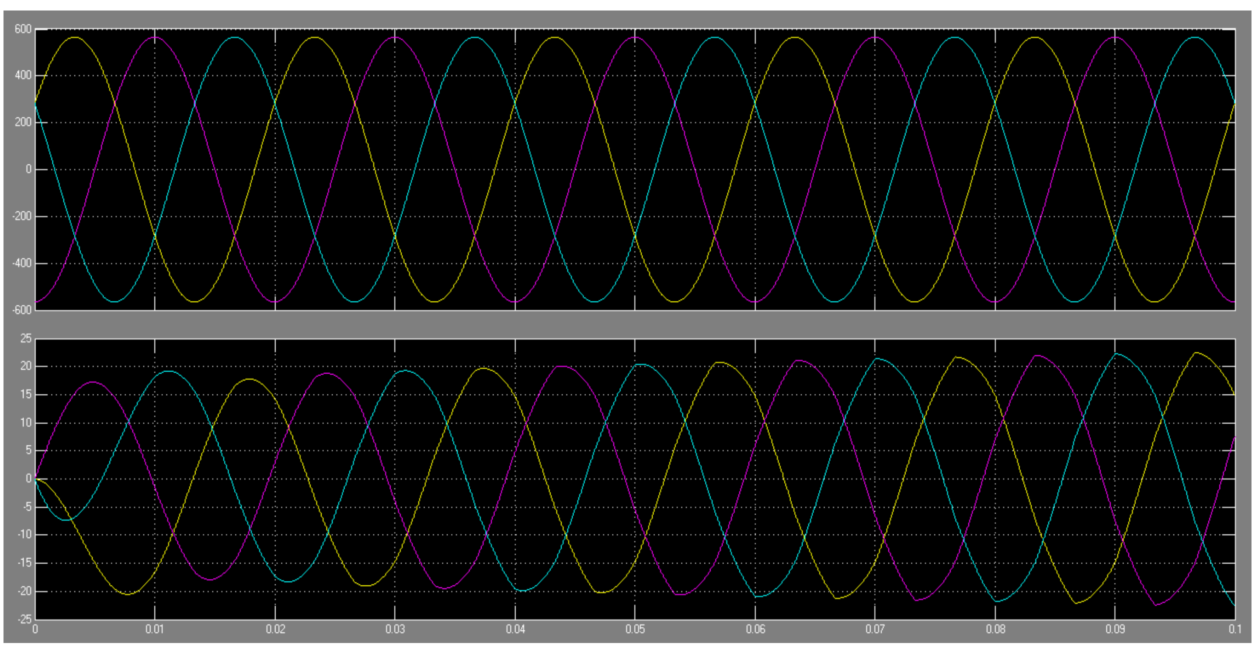

Fig-14: Output Voltage and Current waveforms of inverter for Hysteresis Voltage controller

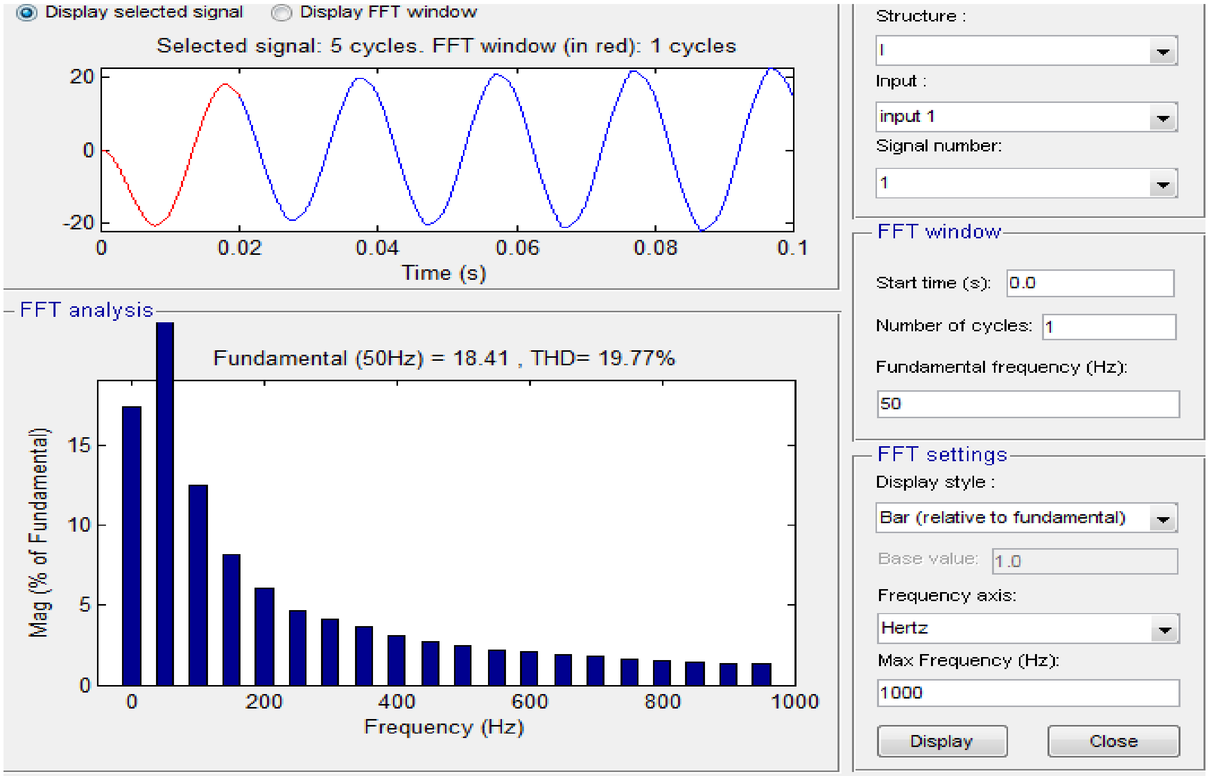

Fig-15: THD of inverter output current for Hysteresis Current controller

For PI controller, RMS value of inverter Output voltage is 383.3 V and RMS value of inverter Output current is 8.15 A.The inverter output voltage and current waveforms

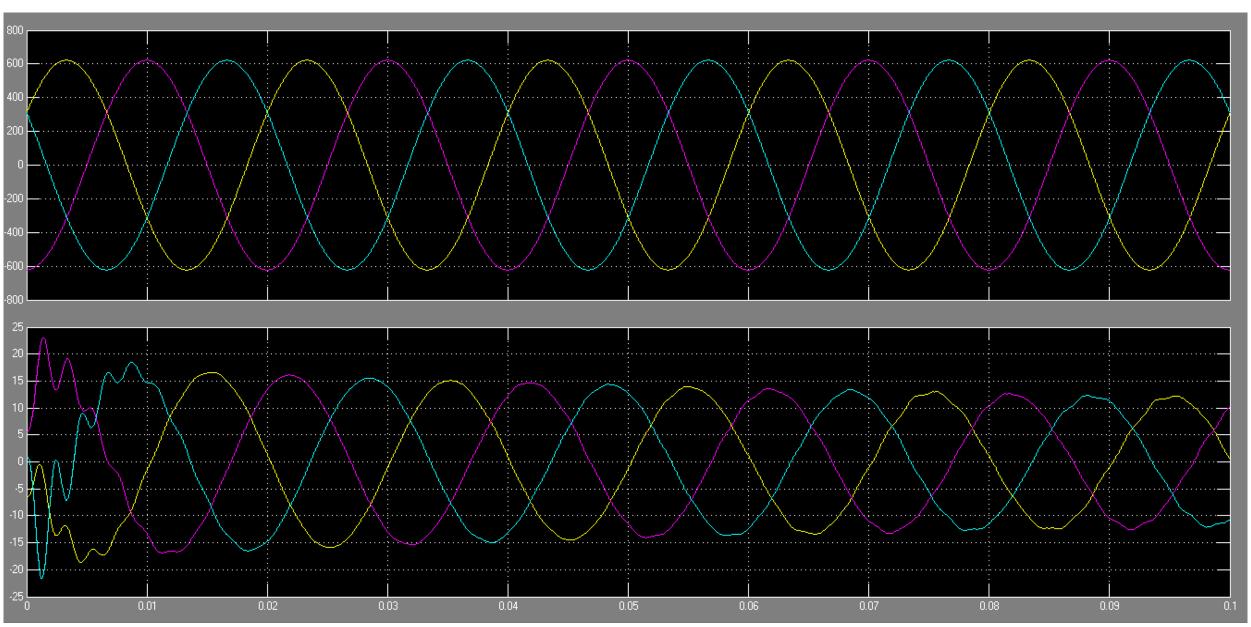

Fig-16: Output Voltage and Current waveforms of inverter for PI controller

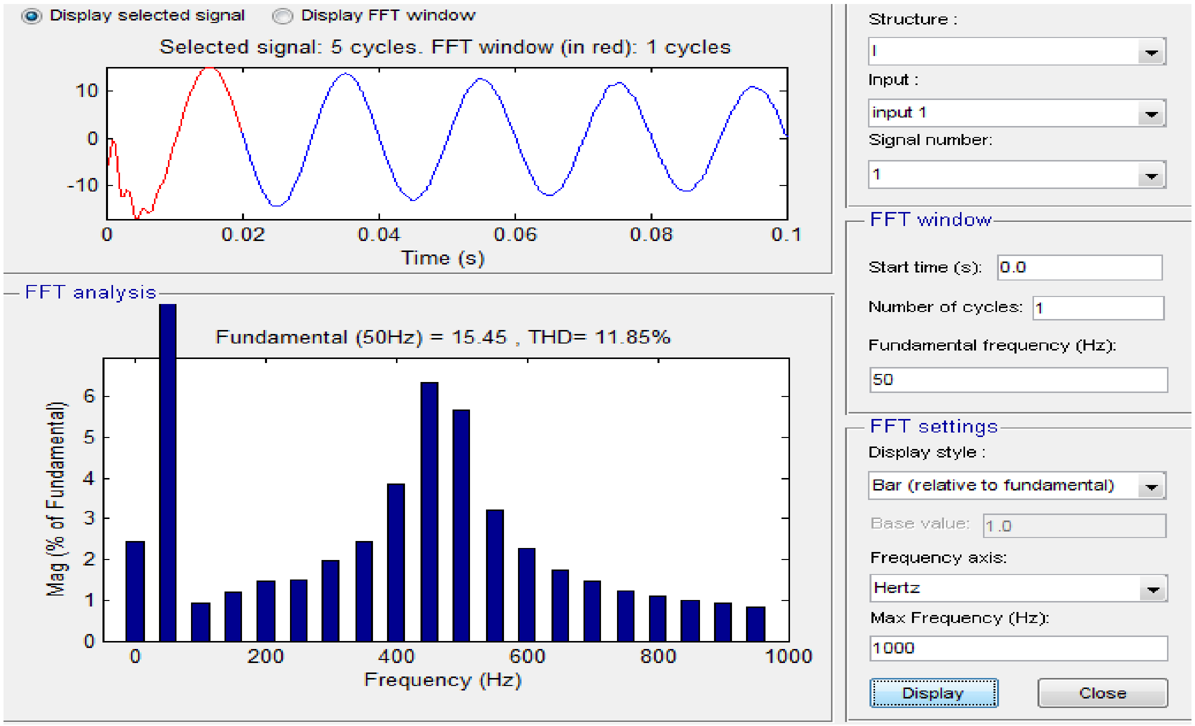

Fig-17: THD of inverter output current for PI controller

So we observed that for Hysteresis Current Controller, Voltage controller, PI controller the THD of inverter Output Voltage is 0%.But THD of inverter Output Current for these controllers is varying. The Current THD analysis is expressed in

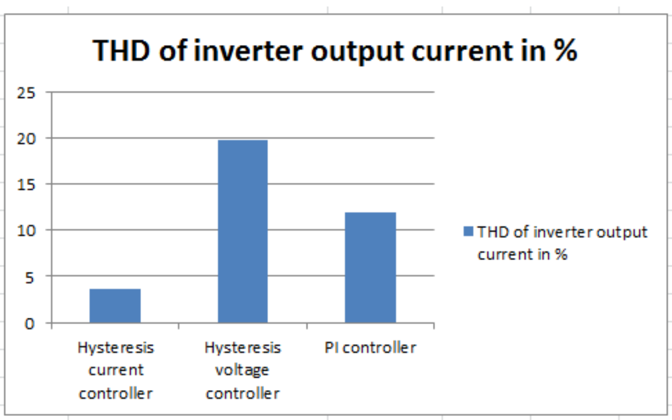

Fig-18: THD of inverter output current for various controllers

7. CONCLUSION:

This paper represents a three phase grid connected PV system with hysteresis current control inverter which has advantages such as fast dynamic response, transient response and simple control loop implementation when compared to other controllers. Here PV system gives input supply to the grid connected inverter. By using MPPT technique Boost converter extracts maximum power and provides DC link voltage. From Simulation results, we observed that Hysteresis current control inverter provides better output waveforms with less than 5% THD. It gives improvement of voltage and current waveforms with less distortion and increases system efficiency compared to Hysteresis voltage controller, PI controller. Due to use of transformer-less grid, size and cost of the system has been reduced.

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