IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

# ACTIVE AND REACTIVE POWER CONTROL OF SERIES-CONNECTED INVERTERS USING D-Q FRAME CONTROLLER FOR DISTRIBUTED-GENERATION SYSTEM

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***Abstract:*** In this work, grid-tied series-connected (SC) inverter system is presented in order to improve the efficiency, overcome the redundancy-reliability problems and also to reduce the cost of solar panel. In this system, each photovoltaic (PV) array is interfaced with an inverter and a boost converter to boost up the PV panel output voltage. Maximum Power Point Tracking (MPPT) is used to maximize the solar power. Frequency of series connected-inverters is AC in nature. The output of inverters is connected in series to match with the utility grid voltage. Meanwhile, Synchronous reference frame (D-Q) control is used for the series-connected inverters to control the active power and the reactive power. MATLAB simulation is carried out to analyze the performance. In this work, the internal control method of inverter is implemented. By avoiding external control methods of inverter, larger number of conversion stages could be avoided and further results in reduction of losses. Bipolar SPWM (sinusoidal pulse width modulation) is used to provide switching sequences to the grid-tied inverter to minimize the switching losses. Simulation results shows the effectiveness of designed controller which is used to provide the active power from dc bus to grid. The proposed control strategy provides quality in output current and output voltage i.e they are having less harmonic distortion and voltage and frequency should be within limits.

***Index Terms* - Photovoltaic generation; Series-connected inverter; MPPT Algorithm; Utility grid; Boost converter; Synchronous D-Q reference frame control.**

## I. INTRODUCTION

Electrical energy demand is increasing rapidly and application of renewable energy systems play a major role in fulfilling the demand [1]. For the last few years, electrical world is moving towards harnessing energy from non-conventional sources of power generation. In this work, distributed photovoltaic generation system is being dealt with. Usage and implementation of micro grid enables us to utilize electrical energy from the non-conventional sources and helps us to maintain and sustain a better environment. Renewable energy is more reliable, flexible, simple, low maintained cost, and a onetime set up.

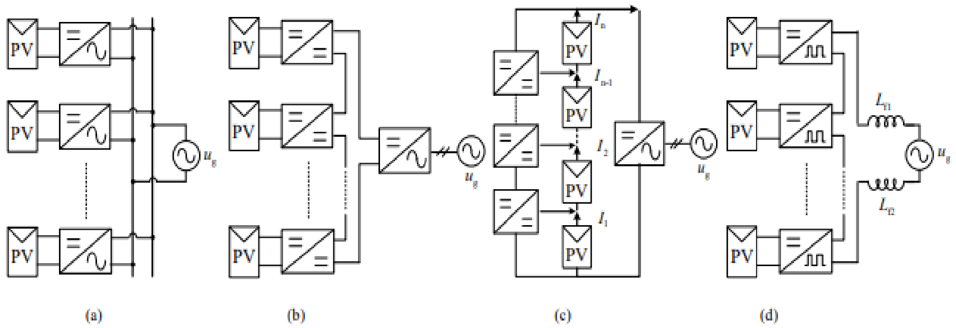


Fig. 1. Four architectures of a PV grid-tied system. (a) ac-module. (b) dc-module. (c) differential-power processing. (d) series-connected H-bridge [1]

Figure 1, represents the four architectures of PV grid-tied system [1]. By seeing in figure 1(a), AC module called as module - integrated converter (MIC). Module – integrated converter is using as a plug-in device by the users without having good knowledge. If Module - integrated inverter is comparing with string inverters, Module - integrated converters cost is high and efficiency is low [2]-[4]. In MIC topologies, PV voltage is low, to boost up that voltage, transformer is used which is having high frequency. So ac module switching losses and the losses of transformer are the limitations for efficiency improvement. By seeing in figure 1(b), DC MODULE has dc–dc converters and centralized inverter [5], [6]. The current and voltage ratings of this Power Electronic devices such as inverter and dc-dc converters is limited and the string voltage means series connection of inverter voltage is also limited. So due to this reason, we cannot track the maximum power from each PV array due to mismatched conditions [7-11]. Dc module maximum power capacity depends on the centralized inverter. Scalability of the system is limited due to centralized inverter. By seeing in figure c, Differential power processing structure has DC-DC converters and centralized inverter. This centralized inverter can directly bypasses most of the power and there is a local mismatch due to low power converters to achieve Maximum power point [12-14]. By using centralized inverter in this Differential – power processing architecture, scalability of the system is limited. By seeing in figure d, series – connected H - Bridge has inverters which output is non - sinusoidal and to get sinusoidal output, here separate filters is used. Because of getting non – sinusoidal output, high ac power is generated at inverter side. Due to this over modulation problems and the power quality problems occur [15]. Synchronous reference frame control strategy for Series-connected inverters is proposed in this paper, in which the sharing of active power of inverters is depends on the load angle which is the angle between the inverter voltage and the grid voltage and also on frequency and current control is used to control active power, while the system reactive power can be controlled through any individual inverter by automatically controlling of modulation index. To overcome the redundancy and reliability and power quality and over modulation problems which are occurred in AC module, DC module, Differential power processing structure and series-connected H-bridge structures are replaced by series-connected inverter papers in this paper. In section II, System architecture is included and in section III, D-Q frame control strategy is proposed for series connected inverters. In Section IV, simulation results included and finally section V concludes the paper.

## II. SYSTEM ARCHITECTURE

The architecture of Grid – tied series – connected inverters system is shown in figure 2, where $u_{o1}$ to $u_{on}$ represent the each inverter output voltage. Point of common coupling (PCC) voltage i.e $u_{PCC}$, is the vector sum of each individual inverter voltage. $u_g$ represents the voltage of grid, and $Z_{Line}$ represents the impedance of line.

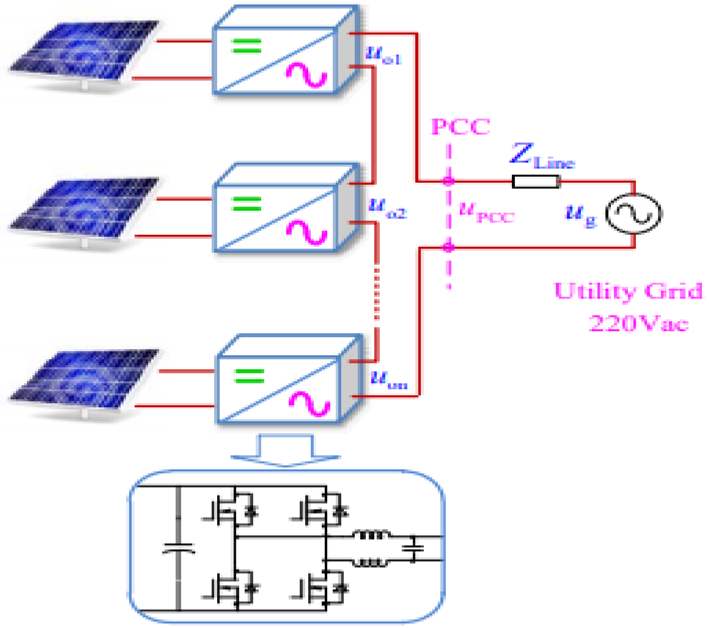


Figure 2: Architecture of Grid-tied series-connected inverters system [1]

In the grid-tied Series connected inverters system, each PV panel is interfaced with an individual inverter similar to the series connected H- Bridge inverter. Inverters outputs are connected in series to match up with utility grid voltage. Maximum power point tracking is used to maximize the solar panel power in each inverter. However, in the series- connected inverters system the output of series connected inverters at AC line frequency where as in series connected H- Bridge inverter the output of inverters at pulse width modulation frequency [1].

In the grid tied series- connected inverter system, two inverters are connected in series taken as an example. The output voltages of two inverters vectors sum is equal to the point of common coupling voltage which as grid voltage. Synchronous reference frame control strategy for Series- connected inverters is proposed in this paper, in which the sharing of active power of inverters is depends on the load angle which is the angle between the inverter voltage and the grid voltage and also on frequency and current control is used to control active power, while the system reactive power can be controlled through any individual inverter by automatic controlling of modulation index. By controlling the reactive power, each inverter voltage is controlled.

## III. IMPLEMENTATION OF CURRENT CONTROL

*A.SYNCHRONOUS REFERENCE FRAME CONTROL*

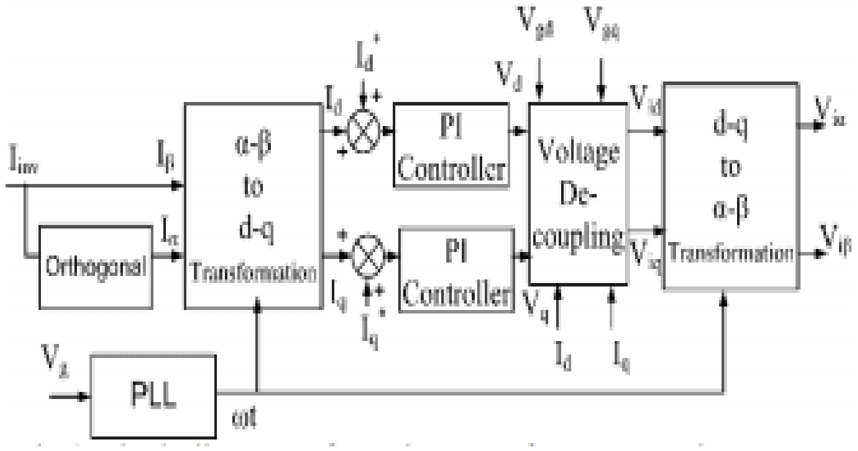


Figure 3: Block diagram of Synchronous reference frame control structure [16]

Figure 3, represents block diagram of synchronous frame control structure. In this Phase locked loop is providing phase angle and frequency. When the active power is flowing from renewable energy source to the grid, during which the current of inverter should be in phase with the voltage of grid. In this, an inverter current i.e the output current of series connection of two inverters and the grid voltage are converted from alpha- beta reference frame to d-q reference frame by using Parks transformation.

Where voltage decoupling circuit output equations are

$$Vid = Vgd - WLIq + L\frac{dId}{dt} \quad (1)$$

$$Viq = Vgq + WLId + L\frac{dIq}{dt} \quad (2)$$

Where $V_d$ and $V_q$ are the outputs of proportional integral controller and $V_{gd}$ and $V_{gq}$ are the outputs of grid in d-q form and $I_d$ and $I_q$ are the output currents of inverter and $V_{id}$ and $V_{iq}$ are the output voltages of voltage decoupling circuit and voltage balance decoupling equations are needed to send power from inverter to grid. Inverter current and the grid voltage are computed to transform from alpha-beta reference frame to d-q reference frame using Parks transformation and voltage decoupling outputs, $V_{id}$ and $V_{iq}$ are transformed from d-q to alpha-beta reference frame using inverse Parks transformation. $V_{id}$ and $V_{iq}$ are the inverter voltage dc components. These are transformed into alpha-beta voltages. $V_{ialpha}$ is fed to the bipolar SPWM. $I_d$ and $I_q$ are max values which are obtained from inverter.

*B. Bipolar SPWM*

Carrier wave and the reference wave or modulating wave both are passed through comparator. Comparator compares the two signals.

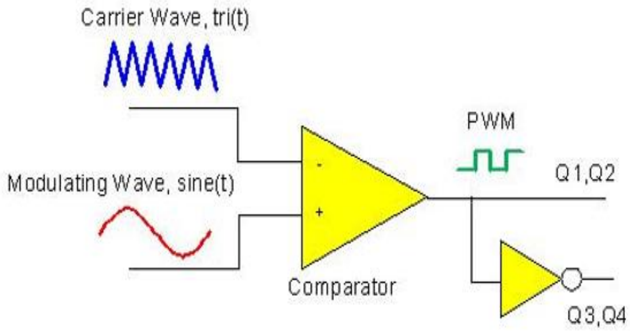


Figure 4: Bipolar SPWM circuit [16]

Figure 4, represents the block diagram of the bipolar SPWM. When Modulating wave or reference wave > Carrier wave, then Q1 and Q2 should on. When Modulating wave or reference wave < Carrier wave, then Q3 and Q4 should on.

In this $V_{ialpha}$ is multiplied with $2/V_{dc}$ and is given to PWM block like modulating wave.

The real and reactive power of inverter are controlled by using below formulas

Active power $P = 0.5 * Vgd * Id$ (3)

Reactive power $Q = -0.5 * Vgd * Iq$ (4)

$V_{gd}$ is the maximum grid voltage and $I_d$ and $I_q$ are the maximum inverter currents

## IV.SIMULATION RESULTS

Grid-tied PV generation system based on series-connected inverters is proposed in this paper. Synchronous reference frame control strategy is implemented in MATLAB SIMULATION platform to control active and reactive power of inverters. The inverters input voltage is taken as 400 volts. In the grid tied series- connected inverter system, two inverters are connected in series taken as an example. The output voltages of two inverters vectors sum is equal to the point of common coupling voltage which as grid voltage. Synchronous reference frame control strategy for Series- connected inverters is proposed in this paper, in which the sharing of active power of inverters is depends on the load angle which is the angle between the inverter voltage and the grid voltage and also on frequency and current control is used to control active power, while the system reactive power can be controlled through any individual inverter by automatic controlling of modulation index. By controlling the reactive power, each inverter voltage is controlled.

*DC Voltage waveform:*

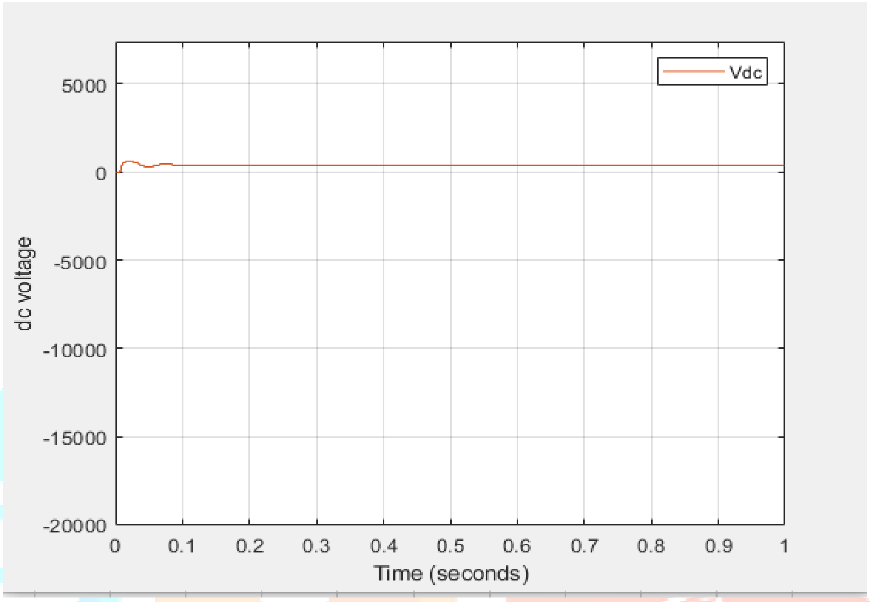


Figure 5: Wave form of DC voltage

Figure 5, represents the waveform of dc voltage (400 volts) which is given to the inverters. DC voltage has very low ripples and is within limits.

Synchronous reference frame control strategy done for inverter current and the grid voltage, when the load is considering as R-load and RL –load and RC- load as shown in below figures and figure 5, figure 6 and figure 6 represents the waveform of active and reactive power of inverters when the load is R-load and RL-load and RC-load and x-axis represents time and its units are in seconds and y-axis represents real and reactive powers in watts and figure 7 represents waveform of the two inverters voltages and grid voltage and in figure 7,y- axis represents voltage in volts and x- axis represents time in seconds.

*When the load is R – load: (P=1600W and Q=0 VAR)*

*Active and reactive power waveforms:*

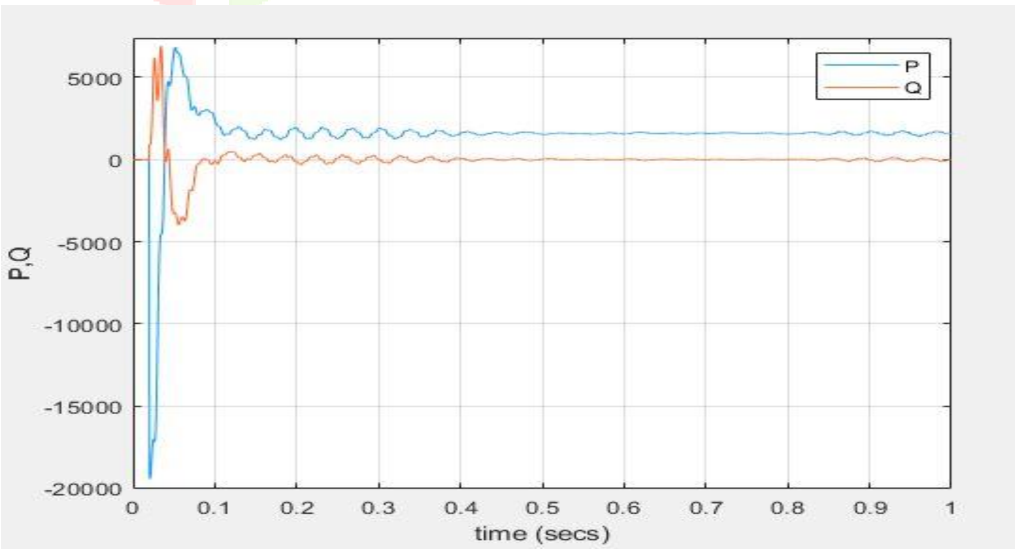


Figure 6: Active and reactive power waveforms for R-load

From figure 6, we can say that the active power is 1600 watts when $i_{dref}$ = 9.428 amps and $i_{qref}$ = 0.This active power is supplied from dc bus to grid. We can say that the reactive power of inverter is zero when $i_{qref}$ = 0. Here inverter current is in-phase with the grid voltage.

*When the load is RL-load: (P=1000W and Q=2000VAR)*

*Active and reactive power waveforms:*

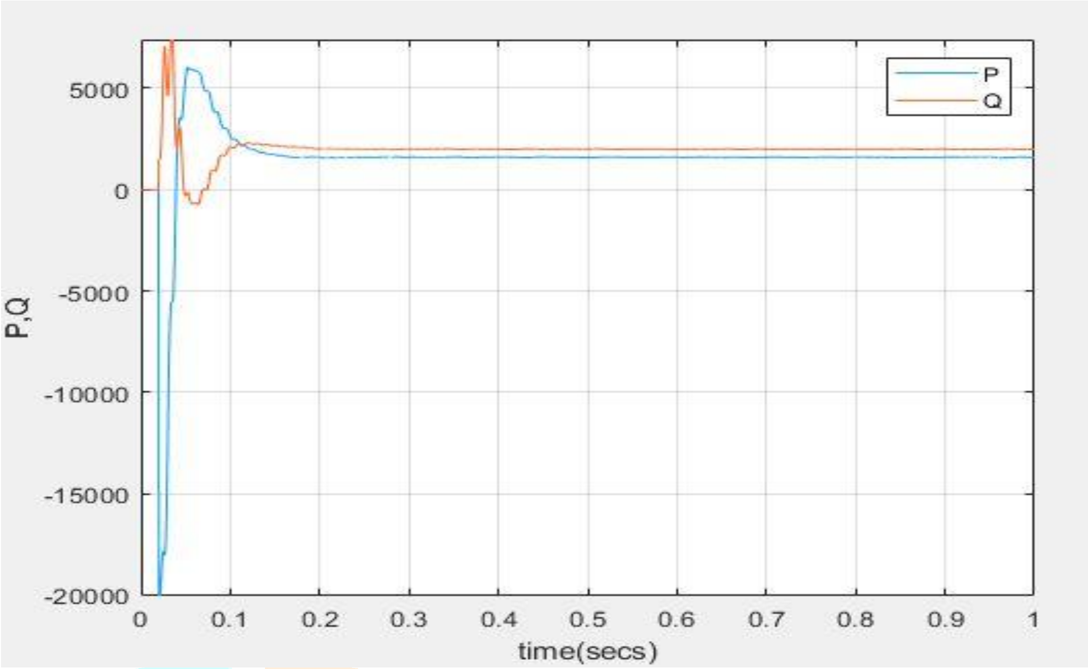


Figure 7: Active and reactive power waveforms for RL-load

From figure 7, we can say that the active power is 1600 watts for $I_{dref}$=9.428 amps and that reactive power is 2000vars when $i_{qref}$=-11.78 amps and from figure 7, power 1 represents real power and power 2 represents reactive power. Here inverter current lags the grid voltage.

*When the load is RC-load: (P=1000W and Q=-2000VAR)*

*Active and Reactive power waveforms:*

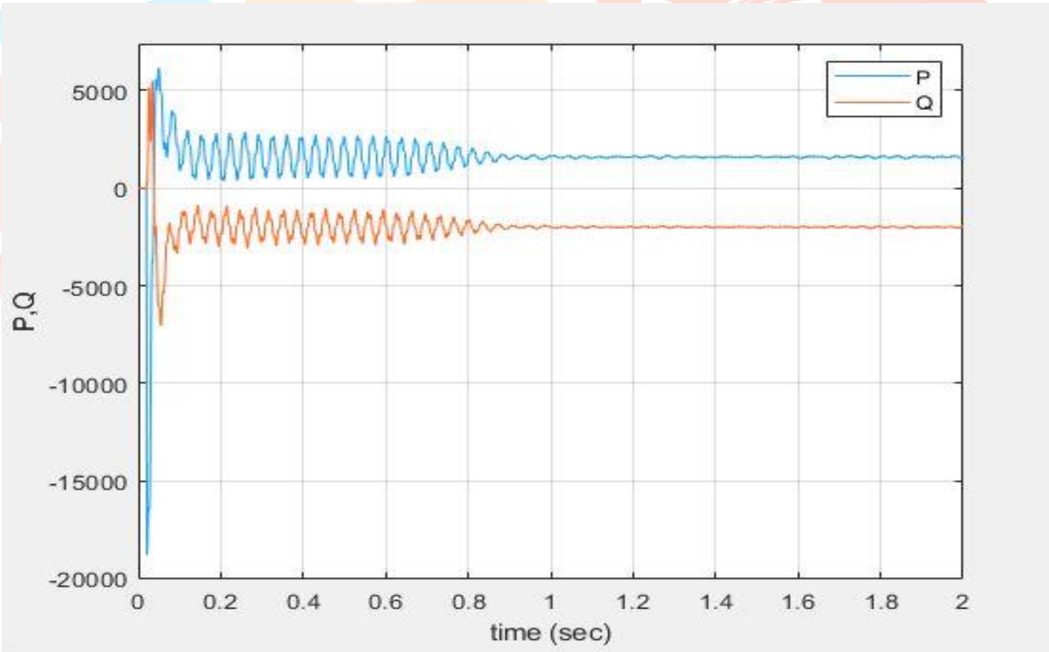


Figure 8: Active and Reactive power waveform for RC-load

From figure 8, active power is 1600 watt when $i_{dref}$ = 9.428 amps which is supplied to the grid from dc bus, and the reactive power is -2000var when $i_{qref}$=11.78 amps. Here inverter current is leading the grid voltage.

*Inverter and grid voltage waveforms:*

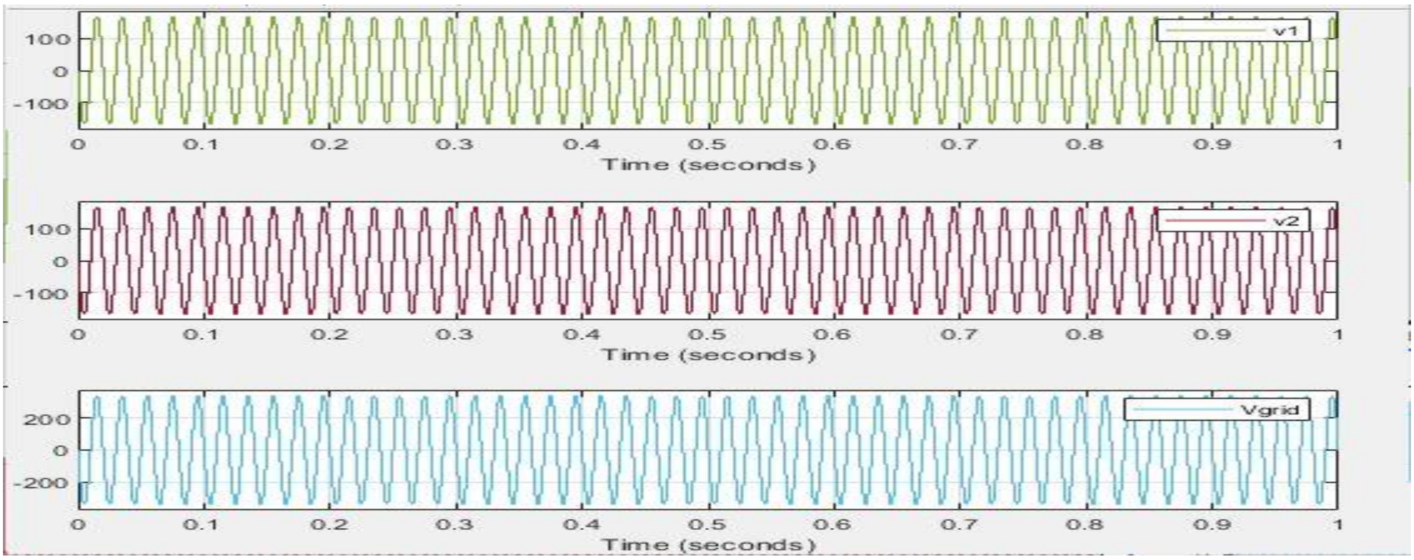


Figure 9: inverter voltages (v1 and v2) and grid voltage ($V_{grid}$)

From figure 9, output voltages of two inverters vector sum is equal to the total inverter voltage which is equal to the voltage of the grid which is 240 volts in rms. When the voltage of grid and inverter voltage are same then one of the synchronization condition is satisfied.

## V.CONCLUSION

Synchronous reference frame control technique is proposed for the grid-tied Series - connected inverter PV generation system and both the active and reactive power of each inverter is analyzed and presented. Simulation results demonstrates the following.

The output voltage of each inverter is almost in phase with the grid voltage. Synchronous reference frame (Current) control is provided for the inverter to control active and the reactive power of series connected inverters. By doing this control, active power is supplied to the grid. Voltage and frequency and phase of inverter and grid is matching. Synchronism conditions are satisfied. Bipolar SPWM is used to provide switching sequences to the grid- tied inverter to minimize the switching losses. The simulation results shows the effectiveness of designed controller which is used to provide the active power from dc bus to grid and reactive power is controlled automatically by the changing of modulation index when current control technique applied to the control active power. This proposed control strategy provides quality in output power means it has less harmonics and voltage and frequency should be within limits. By doing Synchronous reference frame (D-Q) control, active power is provided to the grid from the dc bus and Simulation results show the effectiveness of the D-Q frame control strategy.

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