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# Current Controller Based Power Management Strategy for Interfacing DG Units to Micro Grid

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**ABSTRACT**

This paper proposes a power management strategy of parallel inveters based system, to enhance the power generation capacity of the existing system with distributed energy sources one has to choose DG source based inverter connected in parallel with the existing system.Two DG sources PV, Fuel cells feeds the DC voltage to two parallel inverters connected to the grid. Fixed band hysteresis current control with Instantaneous p-q power theory is adopted to create an artificial environment. Two parallel inverters are able to deliver the harvested power from PV, FC to grid and able to balance the load Without communication between parallel inverters this controller having the capability of load following, the harmonic components of currents at output of inverter are also very low; this will automatically reduces the circulating currents between parallel inverters. Simulation studies are carried out to investigate the results of PV, FC systems connected to the utility grid.



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## 1. INTRODUCTION

The world energy outlook 2016 report stated that “Renewable make very large strides in coming decades but their gains remain largely confined to electricity generation,” said Dr. Birol. “The next frontier for the renewable story is to expand their use in industrial, building and transportation sectors where enormous potential for growth exists” [1]. RES [Renewable Energy Sources] has been characterized as clean sustainable energy, capable to cater the demand of the electrical power, and can be easily delivered to remote sites. Regarding the merits of RES , the European renewable energy council stated that the share of RES in 2010 was 16.6% and it is estimated to enhance upto 50% by 2040 [2]. In Distributed Generation units and Micro Grid’s , the grid tied inverters are necessary interfaces to interconnect RESs and energy storage devices to micro grid [3],[4].

Many grid connected inverters are there in the literature, among all current controlled voltage source inverters are fundamental integrators to connect solar PV systems, fuel cells to the grid [5]. Hysteresis control technique is known to be fast and robust but has unwanted harmonics due to the continuous change in switching frequency [6]. PI controller has fewer harmonics when exactly tuned, but gives destitute dynamic performance. Moreover it depend upon the knowledge of the system to function well [6]. From the last twenty years many investigators seek to find a current controller that can give the advantages of both control techniques [7-10].

This paper describes the method of fixed band hysteresis current controller to parallel connected inverters applicable to distributed generation systems through simulation.The current control voltage source inverters are the fundamental integrators to connect any renewable energy sources to the grid, to enhance the generating capacity consistent option is parallel connected inverters. In this paper two DC sources PV, FC systems are considered as energy sources for two parallel inverters , in parallel connected systems there is no need of voltage control. Current control is sufficient to maintain the system effectively, Many current control schemes PI, ramp time, hysteresis control techniques are there in literature.

In order to get better AC power quality and high performance of the converters, it is preferable to directly control the magnitude and phase angle of three phase supply currents. Among the control techniques, the hysteresis current control has got much attention due to several advantages such as the simplicity of its implementation, its independence to changes in parameters of load power supply and ability on current limiting and fast current control response [11].

Hysteresis current controller is one of the most important PWM switching methods to produce reference currents [12]. On the other hand conventional hysteresis method includes some undesirable results, such as variable switching frequency that causes audio noises, high switching losses and injection of high frequency current components to the source current that makes it difficult to design suitable filters to remove these high frequency harmonics. In [12] [13] applied the fixed and adaptive hysteresis current controllers in active power filters. In [14] implemented the hysteresis current control technique to eliminate the harmonics and hence improved the power quality of micro grid system . In [15] a PV inverter with PI current controller is used to maintain constant voltage and to reduce harmonics . [16] shows the results of the PV,FC based grid connected system with PI, ramp time current controller methods. Identified the fixed band hysteresis current control technique is not applied to the parallel connected PV, FC feeded inverters, to avoid the limitations of conventional hysteresis current controller a fixed band hysteresis current controller with instantaneous PQ power theory is implemented for parallel connected inverters to reduce the harmonic components of current waveform and hence circulating currents of parallel inverters also get minimized.

This paper evaluates the performance of nonlinear current controller i.e fixed band hysteresis current controller with instantaneous p-q power theory. When compare with linear current controllers nonlinear current controller not require the information about the load and gives good dynamic response to the considered system. In this scheme, hysteresis bands for all phases are fixed throughout the fundamental period and the value of bandwidth is generally 5 to 10% of the adopted system current. Figure 1 shows the overall circuit diagram of the designed system.

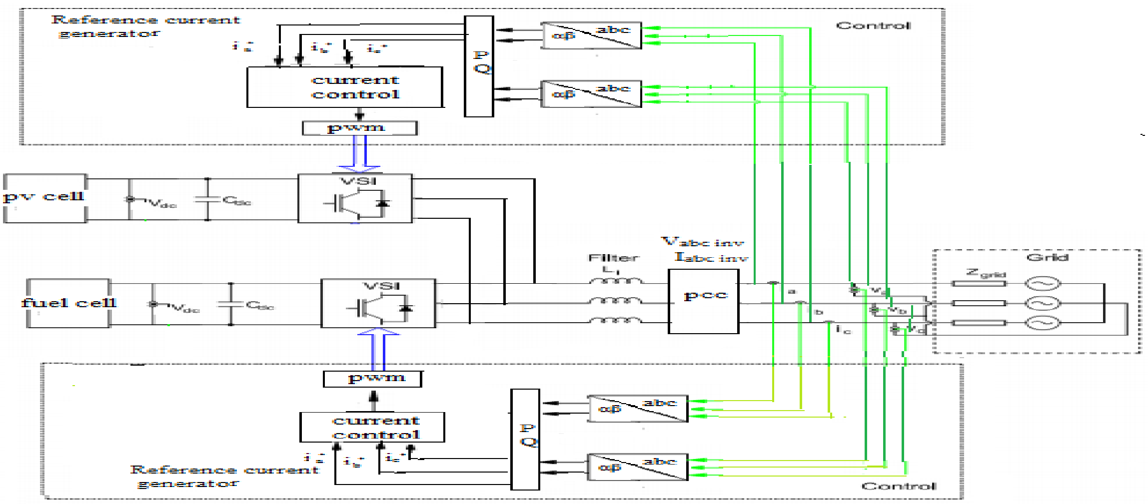


Figure 1. Over all circuit diagram of considered system

## 2. FIXED BAND HYSTERESIS CURRENT CONTROLLER

$$Ie = I - Iref \tag{1}$$

The error of every phase current is controlled by two level fixed band hysteresis current controllers, but to trigger the three phases logic is needed due to the coupling of three phases. Whenever Current error vector ‘Ie’ touches the edge of the hysteresis band, the switch logic has to choose next most optimal switching state with respect to the following [17].

1) The current difference ‘Ie’ should be moved back towards the middle of the hysteresis band as slowly as possible to achieve low switching frequency.

2) If the tip of the current error 'Ie' is outside the band, it should be returned to the hysteresis band as fast as possible.

$$V_{DC} = L\frac{dI}{dt} + e \tag{2}$$

$$\frac{dI}{dt} = \frac{1}{L}[V_{DC} - e] \tag{3}$$

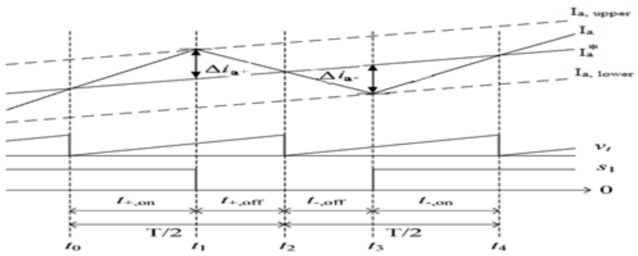


Figure 2. Timing diagram of fixed band hysteresis current controller

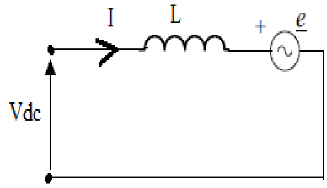


Figure 3. Load presentation

From equation (1) the current error deviation is

$$\frac{dIe}{dt} = \frac{dI}{dt} - \frac{dIref}{dt} \tag{4}$$

$$\frac{dIe}{dt} = \frac{1}{L}[V_{DC} - e] - \frac{dIref}{dt} \tag{5}$$

Assume $Vref = e + L\frac{dIref}{dt}$ (6)

$$\frac{dIe}{dt} = \frac{1}{L}[V_{DC} - Vref] \tag{7}$$

Reference [18] explains why the decisive voltage for the current control is sum of the inner voltage and voltage across the inductance of load.From figure .1 the current waveform has been divided into two sections namely, positive half cycle ($t_0$-$t_2$) and negative half cycle ($t_2$-$t_4$) in one switching period.Here hysteresis band current controller is used to determine the time for turn on and turn off to get the required switching period in positive and negative cycles.In this paper Hysteresis controller scheme is used to predict the value of reference currents for each phase.

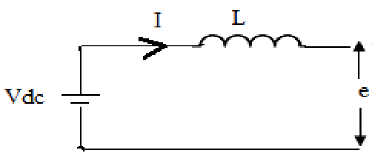


Figure 4. equivalent circuit of inverter when the switches are turned-on

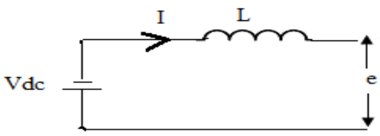


Figure 5. equivalent circuit of inverter when the switches are turned –off

For figure 4 the loop equation can be written as

$$V_{DC} - L\left(\frac{dI}{dt}\right)_{on} - e = 0 \tag{8}$$

$$\left(\frac{dI}{dt}\right)_{on} = \frac{V_{DC} - e}{L} \tag{9}$$

For Figure 5 the loop equation can be written as

$$-V_{DC} - L\left(\frac{dI}{dt}\right)_{off} - e = 0 \tag{10}$$

Equation (10) can be written as

$$\left(\frac{dI}{dt}\right)_{off} = \frac{-V_{DC} + e}{L} \tag{11}$$

Where $V_{DC}$ is the DC link voltage, e is the instantaneous grid voltage and L is the output inductance. Here in this paper to predict the value of reference current an assumption is made that reference current changes linearly over one switching cycle.

**2.1 Turn off criteria**

At $t_1$ , the inductor current and the reference current can be expressed as

$$I(t_1) = \left(\frac{dI}{dt}\right)_{on} * t_{+,on} + I(t_0) \tag{12}$$

$I^*$ is the reference current.

$$I^*(t_1) = \frac{dI^*}{dt} * t_{+,on} + I^*(t_0) \tag{13}$$

From equations (12)& (13)

$$I^*(t_1) - I(t_1) = t_{+,on}\left[\frac{dI^*}{dt} - \left(\frac{dI}{dt}\right)_{on}\right] + I^*(t_0) - I(t_0) \tag{14}$$

In Figure .2 at $t_0$ , $I^*(t_0) = I(t_0)$ In the positive section ($t_0$-$t_2$), the instantaneous slope of $I^*$ is given by

$$\frac{dI^*}{dt} = \left[\frac{dI^*}{dt}\right]_{on} + \frac{I^*(t_1) - I(t_1)}{t_{+,on}} \tag{15}$$

At $t_2$, the inductor current and reference current are expressed as

$$I(t_2) = \left(\frac{dI}{dt}\right)_{off} * t_{+,off} + I(t_1) \tag{16}$$

$$I^*(t_2) = \frac{dI^*}{dt} * t_{+,off} + I^*(t_1) \tag{17}$$

From equations (16) & (17)

$$I^*(t_1) - I(t_1) = t_{+,off}\left[\frac{dI^*}{dt} - \left(\frac{dI}{dt}\right)_{off}\right] + I^*(t_2) - I(t_2) \tag{18}$$

In figure 2 at $t_0$ $I^*(t_2)=I(t_2)$

$$t_{+,off} = \frac{I^*(t_1) - I(t_1)}{\left[\left(\frac{dI}{dt}\right)_{off} - \left(\frac{dI^*}{dt}\right)\right]} \tag{19}$$

By solving the equations (12) to (15)

$$t_{+,off} = \left[\frac{2V_{DC}}{L(I(t_1)) - I^*(t_1)} - \frac{1}{t_{+,on}}\right]^{-1} \tag{20}$$

The turn off time is estimated using the equation (20) with instantaneous feedback signals. The turn-off criterion is the time of I –I $^{*}$ in positive cycle that is equal to half the switching cycle as shown in Figure 2.

$$t_{+,off}+t_{+,on} \geq \frac{T}{2} \quad \text{and} \quad I - I^{*} \geq 0 \tag{21}$$

Where ‘ T’ is the switching period.
Based on equations (19) and (20), the controller can determine the turn-off action at the most suitable time.

**2.2 Turn –On Criteria:**
In the negative section ($t_2$-$t_4$), the instantaneous slope $I^*$ is given by

$$\frac{dI^{*}}{dt} = \left(\frac{dI}{dt}\right)_{off} + \frac{I^{*}(t_3) - I(t_3)}{t_{-,off}} \tag{22}$$

Based on the slope $t_{-,on}$ is predicted as

$$t_{-,on} = \frac{I^{*}(t_3) - I(t_3)}{\left(\frac{dI}{dt}\right)_{on} - \left(\frac{dI^{*}}{dt}\right)} \tag{23}$$

By using equations (11)&(12)

$$t_{+,on} = [\frac{2V_{DC}}{L(I^{*}(t_3) - I(t_3))} - \frac{1}{t_{+,off}}]^{-1} \tag{24}$$

From equation (25) the turn-on time is estimated with instantaneous feedback signals. The turn on criteria is the time of I-I$^{*}$ in negative cycle and is equal to half switching cycle as shown in Figure 2.

Thus: $$t_{-,off} + t_{-,on} \geq \frac{T}{2} \quad \text{and} \quad I - I^{*} \leq 0 \tag{25}$$

Based on equations (24) & (25) the controller can be designed.The switching function for phase A is derived from the above turn-on and turn-off criteria, for other two phases B and C reference currents for those phases has to consider to solve the switching function.

## 3. INSTANTANEOUS P-Q POWER THEORY

The regular reference current evocation theory is the instantaneous p-q power theory in three phase circuits. Real and reactive power theory considers the three phase system as a unit not as a superposition or sum of three single phase circuits. Clark’s transformation technique is used to convert three phase voltages and currents from a-b-c co-ordinates to α-β-0 co-ordinates. In other words this Clarks transformation converts natural three phase coordinate system into a stationary two phase reference frame.
Assume a three phase load with the instantaneous voltages as $v(t)=[v_a(t) \; v_b(t) \; v_c(t)]^t$ and the instantaneous currents $I(t)=[I_a(t) \; I_b(t) \; I_c(t)]^t$ . By using Clarks transformation:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{27}$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{28}$$

$I_0, I_\alpha, I_\beta$ are the zero sequence current, α axis current, β axis current.

This Clarks transformation is used to analyze the healthy and weak portion ,according to the output PWM pulse is generated and fed to the inverter section because of this the DC is again converted to three phase AC more pulse is profuced in weak portion phase and hence more power is injected towards the transmission lines through the transformer and hence power factor compensation is obtained.

Consider zero sequence current is equal to zero, thus instantaneous p & q can be calculated as:

$$\begin{bmatrix} p(t) \\ q(t) \end{bmatrix} = \begin{bmatrix} v_\alpha(t) & v_\beta(t) \\ -v_\beta(t) & v_\alpha(t) \end{bmatrix} \begin{bmatrix} I_\alpha(t) \\ I_\beta(t) \end{bmatrix} \tag{29}$$

P(t) and q(t) can be separate into average parts and oscillating parts, from literature it is well known that the average real power can produce from fundamental harmonics of the load current positive sequence component .
Accordingly in order to compensate harmonics and instantaneous reactive power reference currents can extracted as:

$$\begin{bmatrix} I_\alpha^*(t) \\ I_\beta^*(t) \end{bmatrix} = \begin{bmatrix} v_\alpha(t) & v_\beta(t) \\ -v_\beta(t) & v_\alpha(t) \end{bmatrix}^{-1} \begin{bmatrix} -\tilde{p}(t) \\ -\tilde{q}(t) \end{bmatrix} \tag{30}$$

$$\begin{bmatrix} I_a^*(t) & I_b^*(t) & I_c^*(t) \end{bmatrix}^{-1} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}^{-1} \begin{bmatrix} 0 & I_\alpha^*(t) & I_\beta^*(t) \end{bmatrix}^t \tag{31}$$

## 4. SIMULATION RESULTS AND ANALYSIS

PV cell, Fuel cells are the two DC voltage sources used as DG units in this system, to change these two DG's output voltage to the desired inverter input voltage and smooth the two DG's output current need is there to adopt a DC/DC boost converter. Each 35kw rated PV, Fuel cells are adopted for this study, the PV, Fuel cell output voltage is 400 volts , boost up to 700 volts using DC/DC converter, Here the controller for the converter is used to regulate the DC bus voltage with in a desirable range. The output voltage of the DC/DC boost converter is fed to DC/AC inverter. Through the point of common coupling the inverter is connected to the grid, two RL loads are connected at the point of common coupling. The inverter is always maintains the output voltage according to the reference value and at the same time inner current control loop is used to avoid the circulating currents of both the parallel inverters.

Figure 6 shows the DC bus voltage of the PV cell. Maximum power point tracker is continuously tracing the optimal voltage from 0 secs to 0.1 secs, finds the optimal voltage at 0.1 secsdue to the slow tracing speed. Figure. 7 shows the DC bus voltage of fuel cell, with in 0.03 secs th fuel cell able to set the optimal voltage.
Figure 8 shows the load voltages and currents of two different RL loads, 20 kw real, 0.5 kvar reactive load is there from 0 sec to 0.5 sec to check the performance of the controller at variable load condition suddenly another load is added from 0.2 sec to 0.3sec but the control technique shows better performance and is able to follow the load quickly and after switch off the load it may come back with a short span of time.
Phase locked loop is not used to compute the reference current, even though the phase locked loop is not used the designed system is able to track the reference current.

Figure 9 shows the load current in amps at 0.2 sec the current consumed by the load is increased due to addition of another load with a slight distortion the considered technique may able to compensate the load it may observe in the waveform from 0.2sec to 0.3sec the current supplied to the load is increased to 90 amps.

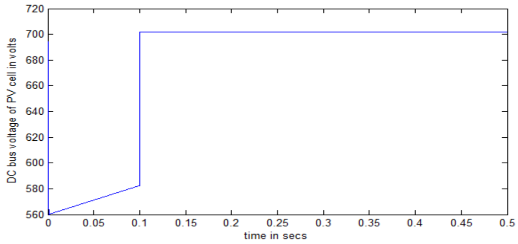


Figure 6. DC bus voltage of PV panel in volts

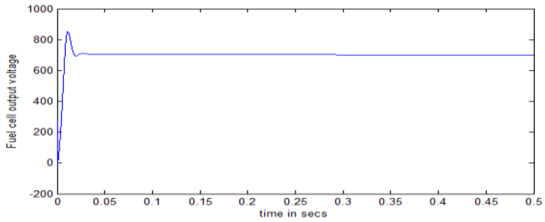


Figure 7. DC bus voltage of fuel cell in volts

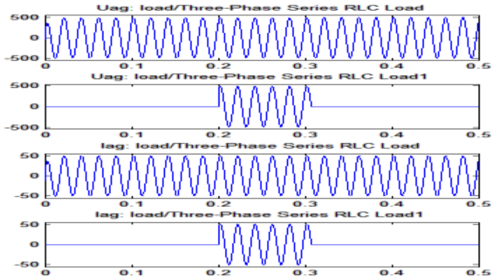


Figure 8. RLC load , RLC load1 voltage and current

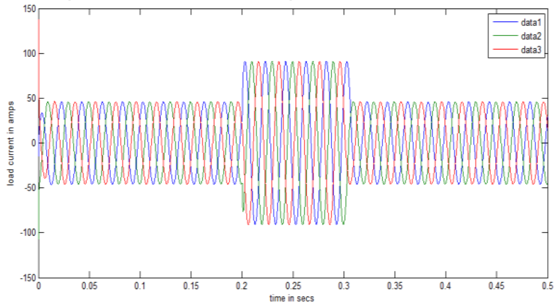


Figure 9. load current in amps

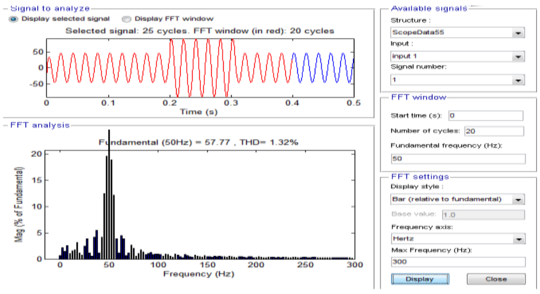


Figure 10. harmonic distortion of load current

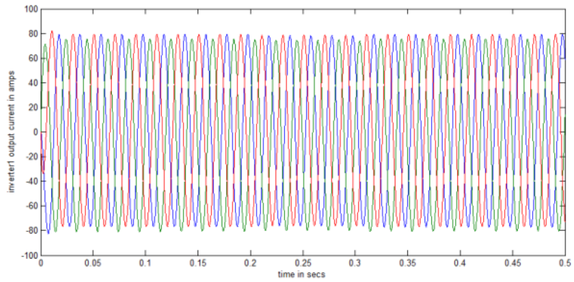


Figure 11. Inverter1 output current in amps

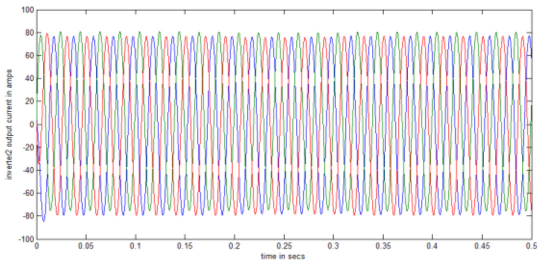


Figure 12. inverter 2 output current in amps

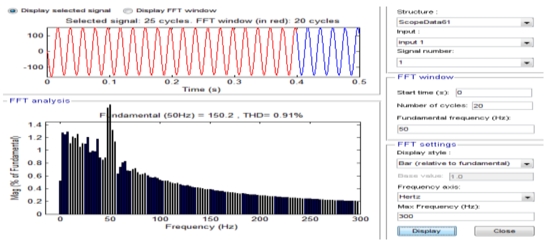


Figure 13. THD of inverter output current

Figure 10 shows the harmonic distortions of the load current for the first 20 cycles i.e from 0sec's to 0.4sec's is 1.32% which is very less value. Figure 11 and Figure 12 shows inverter1 and inverter2 output current in amps because the two sources are having the same capacity so the current supplied by both the sources are same and both inverters are connected in parallel so there is no need of voltage controller automatically for the parallel coneected system the voltage will become same. Figure.13 shows the total harmonic distortion of inverter output current for the first 20cycles period the harmonic distortion is very less i.e 0.91%.

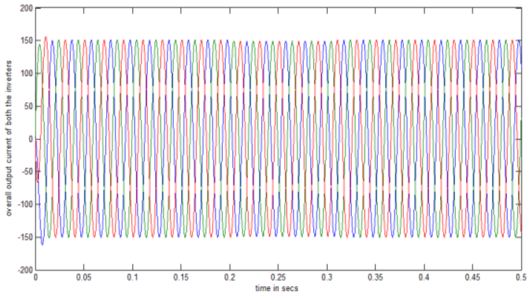


Figure.14 Total current of both the inverters in amps

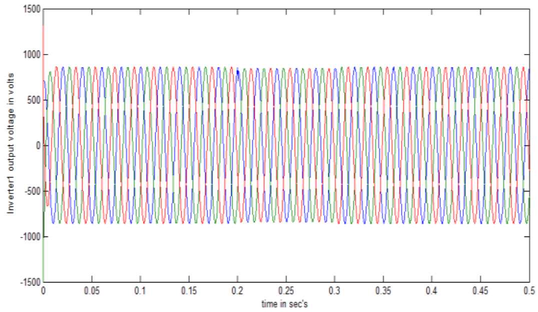


Figure. 15 Inverter1 output voltage in volts

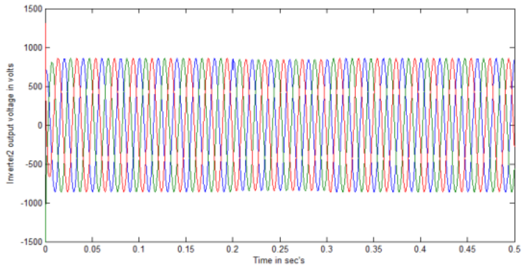


Figure. 16 Inverter2 output voltage in volts

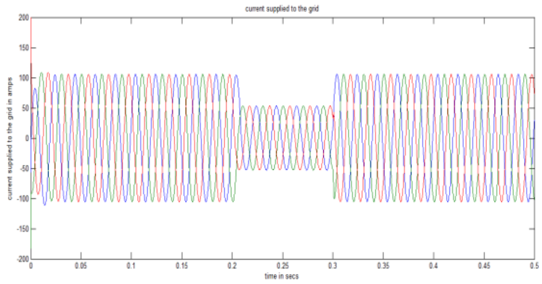


Figure.17 Current supplied to the grid

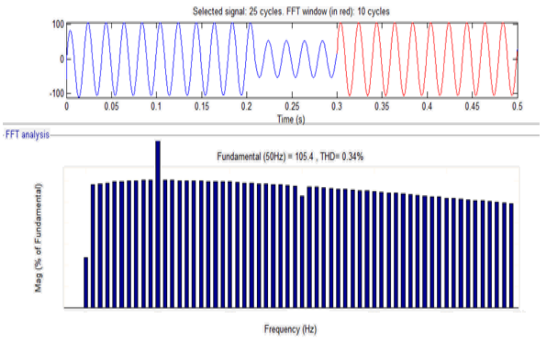


Figure 18. THD of current supplied to the grid

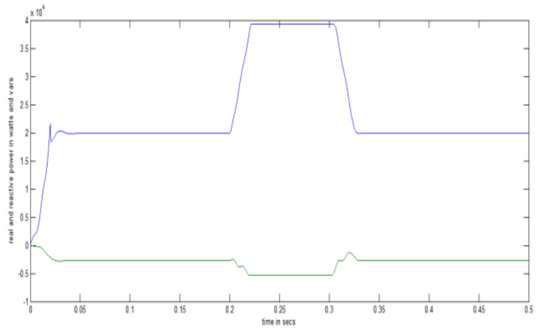


Figure 19.Real and reactive power consumed by load

Figure 14 shows the output current of both the inverters in amps.Figure 15 and Figure 16 show the output voltage of both the inverters in volts. Figure 17 shows the current supplied to the grid in amps to test the stability and tracking capability of the considered controller the load is increased from 0.2 secs to 0.3sec during that time the current supplied to the grid is reduced instantly. Figure 18 shows the THD of current supplied to the grid for the first 15 cycles is 0.34%. Figure 19 shows the real and reactive powers consumed by the load.

## 5. CONCLUSION

From literature it is observed there is a scope to apply both linear and nonlinear current control methods for parallel connected DG based inverters. This paper evaluates the performance of nonlinear current control method i.e fixed band hysteresis current control method without PLL for the parallel connected DG based system. The conclusions that can be drawn from this paper are:

1. A novel PV, FC based parallel connected system interfaced to grid is proposed.
2. Fixed band hysteresis current control with PQ power theory is proposed for the parallel conncetd systems.
3. To test the stability and tracking capability while determining the reference current a variable load condition is applied and observed the results.
4. Due to the incorporation of L filter at the inverters output side higher order harmonic current contents has been eliminated as a result circulating currents of both the inverters get controlled.

5. Total harmonic distortion at load current is 1.32%, at inverter output current is 0.91%, at current supplied to the grid is 0.34% after the condition of variable load, at the time of load varying the THD in current supplied to the grid is 1.48%.

The effectiveness of the proposed controller has been demonstrated through the results and the results shows that the proposed controller is suitable for parallel connected DG based systems.

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