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Comparative analysis of hysteresis and ramp type current controllers for Grid connected VSI

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***Abstract*:** Connecting distributed power generation system to the utility grid requires high quality control in order to improve the power quality problem in system. Vector control scheme is developed in virtual grid flux oriented reference frame for controlling grid connected PWM inverter. A hysteresis current control and ramp type current control is used in inner control loop to control the current flowing in to the grid. Also describe the decoupling control of active and reactive power flowing into grid. The control scheme has been developed and analyzed in simulation environment. Performance of the grid connected VSI has been evaluated in detail.

Keywords: vector control; ramp type current controller; hysteresis current controller; PWM inverter; virtual grid flux

I. INTRODUCTION

Power plays a great role wherever man lives and works. The living standard and prosperity of a nation vary directly with the increase in the use of power. The electricity requirement of the world is increasing at an alarming rate due to industrial growth, increased and extensive use of electrical gadgets. As human needs know no bounds, today most of the nations worldwide have been passing through a phase of power deficit. The crisis is more critical among the developing nations. The increased power demand, depleting fossil fuel resources and growing environmental pollution have led the world to think seriously for other alternative sources of energy. Basic concept of alternative energy relates to issues of sustainability, renewability and pollution reduction. In Reality alternative energy means anything other than deriving energy via fossil fuel combustion.

Various forms of Alternative energy sources are solar, wind, biogas/biomass, tidal, geothermal, fuel cell, hydrogen energy, small hydropower etc. Solution to long-term energy problem will come only through Research and Development in the field of alternative energy sources. Distributed power generation System is an alternative source of energy to meet rapidly increasing power demand, however due to intermittent power production by DPGS, they can't be directly connected to the utility grid which causes power quality problems[1].

The increased number of DGPS networks with integration of renewable energy systems in to grid, which lead to energy efficiency and reduction in emissions. With the increase of the renewable energy penetration to the grid, power quality of the system is becoming a major area of interest [2]. Most of the integration of renewable energy system to the grid takes place with aid of power electronic converter the main purpose of the power electronic converter is to integrate the DPGS to the grid in compliance with power quality standards [3] However, high frequency switching of inverter can inject additional harmonics to the systems, creating major power quality problems if not implemented properly [4]. As a result, requirements of grid connected converters become rigorous and quite difficult to meet high power quality standards like unity power factor, less harmonic distortion, active and reactive power control, fast response during transients and dynamics in the grid etc. Hence the control strategies applied to DGPS become of high interest and need to be further investigated and developed.

In this paper, a virtual grid flux oriented control(outer loop control)and different current controller (inner current controllers) techniques are proposed[5], with main focus on dc link voltage, reduction of harmonic distortion, constant switching frequency operation of inverter switches, unity power factor operation of inverter. Vector control of grid connected inverter is similar to vector control of ac electric machine [6]. Vector control uses decoupling control for active and reactive power control. The control structure for the vector control of grid side converter consists of two control loops. The inner control loop controls the active and reactive grid current components [7]. The outer control loop determines the active current reference for controlling the dc link voltage. A cascaded control system, such as vector control is a form of state feedback. The extensive feature of state feedback control structure is that the inner control loop can be made very fast. For vector control, current control is usually employed as an inner control loop [8].

The fast inner current control nearly eliminates the influence from parameter variations, cross coupling, disturbances and minor non-linearity in the control process. Vector control uses PI-controllers in order to improve dynamic response and to reduce the cross coupling between active and reactive powers [9]. The performance of converter system are mainly depends on type of current control technique. This paper presents the comparative study between hysteresis current controller and ramp type current controller. The proposed control system is simulated in MATLAB/simulink environment and acquired results are presented.

II. DPGS STRUCTURE AND CONTROL

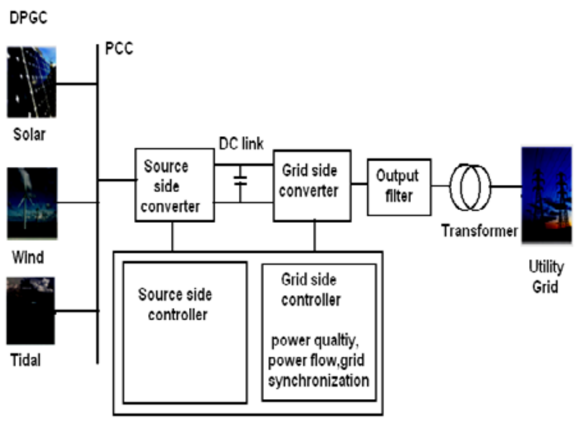


Figure 1 General Structure of DPGS

A general structure of a distributed generation system is shown in figure 1. Depending on the input power nature, i.e., wind, sun and hydrogen, numerous hardware configurations are possible. The system consists of renewable energy sources (wind, tidal, solar, etc), two PWM back to back converters with conventional pulse width modulation technique, grid filter, transformer and utility grid [10]. The input side controller controls the input side converter and grid side controller takes care of the DPGS interaction with utility grid. One of the main functions of input side controller is to extract the maximum power from the Input power source and to transmit this to the grid side controller [11].

In this case of grid failure, this controller should also protect the input power source. The grid side controller normally regulates the dc link voltage in order to maintain the power balance and take care about the quality of the generated power by controlling the output current. Synchronization with the grid voltage and grid (voltage and frequency) monitoring is also an important task of this controller.

III. CONCEPT OF VIRTUAL GRID FLUX ORIENTED CONTROL

Virtual grid flux oriented control of grid connected PWM converter has many similarities with vector control of ac electric machine. In fact grid is modeled as a synchronous machine with constant frequency and constant magnetizing flux. In space vector theory, the non measurable grid flux becomes a space vector that defines the rotating the grid flux oriented reference frame as shown in fig 2.

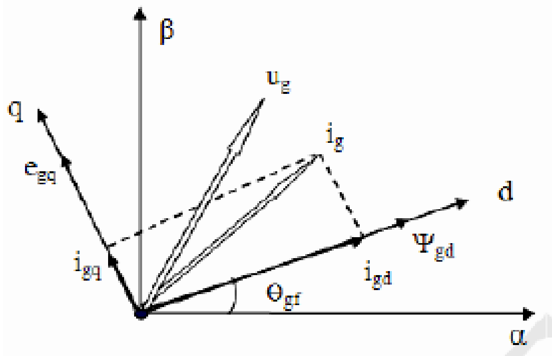


Figure 2 Virtual grid flux oriented reference frame

The grid flux vector is aligned along the d-axis in the reference frame, and grid voltage vector is aligned with q-axis. Finding the position of the position of grid flux vector is equivalent to finding the position of the grid voltage vector. And accurate field orientation can be expected since the grid flux can be measured.

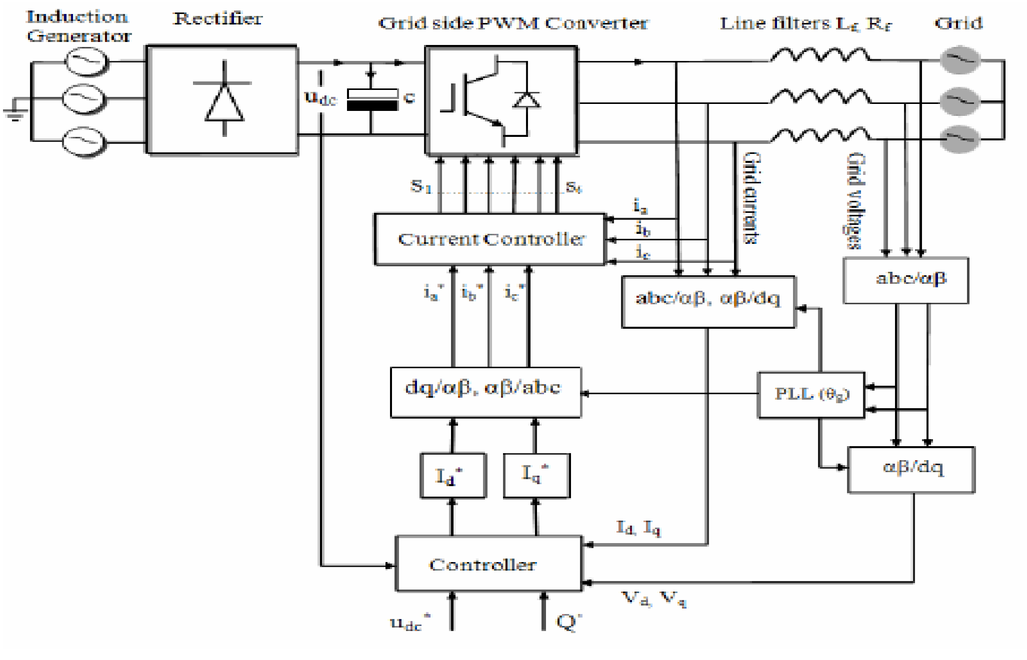


Figure 3 Block diagram of virtual grid flux control of grid connected VSI

The grid currents are controlled in a rotating two axis grid flux oriented reference frame. In this reference frame the real part of the current corresponds to active power and while imaginary part of the currents corresponds to reactive power .the reactive and active power can therefore be controlled separately since the current components are orthogonal. Accurate field orientation for a grid connected converter becomes simple since the grid flux position can be derived from the measurable grid voltages the grid flux position is given by

$$\cos(\theta_g) = \frac{e_{g\beta}}{|e_g|}, \sin(\theta_g) = -\frac{e_{g\alpha}}{|e_g|} \qquad (1)$$

Power. The reactive and active power can therefore be controlled independently since the current components are orthogonal.

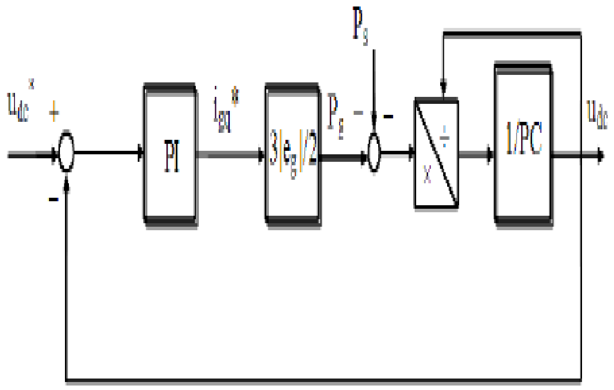


Figure: 4 Block diagram of closed loop control of DC Link voltage

IV. VECTOR CONTROL OF GRID CONNECTED PWM INVERTER

The block diagram of purposed system is shown in figure 3 the control system of vector controlled grid connected converter consisting two control loops. The inner control loop consists of current controller which controls the active and reactive grid current components. The active current component is produced by an outer direct voltage control loop and to maintain power factor unity, the reactive current can be set to zero. The grid currents are controlled in a rotating two axis grid flux oriented reference frame. In the reference frame the real part of the current corresponds to active

A. DC voltage controller:

The following derivation of direct voltage controller assumes instantaneous impressed grid currents and perfect grid flux orientation. The instantaneous power

$$S_g = P_g + jQ_g = \frac{3}{2} e_g i_g{*} = \frac{3}{2}\left(|e_g| i_q + j|e_g| i_d\right) \qquad (2)$$

$$S_g = \frac{3}{2}\left(|e_g| i_q + j|e_g| i_d\right) \qquad (3)$$

flowing into grid can be written as
The active power is real part of above eqn

$$P_g = \frac{3}{2}|e_g| i_{gq} \qquad (4)$$

When neglecting capacitor leakage, the direct voltage link power is given by

$$P_{dc} = u_{dc} i_{dc} = u_{dc} C \frac{du}{dt} \qquad (5)$$

Assuming the converter losses are neglecting, the power balance in the direct voltage link is given by

$$U_{DC}\frac{du_{DC}}{dt} = -P_S - P_g = -P_S - \frac{3}{2}|e_g| i_{gq} \qquad (6)$$

Where Ps is the distributed energy system power is assumed to be independent of the DC voltage. A transfer function of between direct voltage and active grid current ig is obtained as

$$U_{DC} \approx -\frac{3|e_g|}{2pCu_{DC}} i_{gq} \qquad (7)$$

The transfer function is nonlinear, it is acceptable to substitute the direct voltage with the reference set value since the objective is to maintain a constant direct voltage the assumption gives linear zed transfer function.

$$U_{DC} \approx -\frac{3|e_g|}{2pCu*_{DC}} i_{gq} \qquad (8)$$

Applying internal model control gives the direct voltage link controller as

$$F = \frac{\alpha}{P} G^{-1} = -\alpha \frac{2Cu*dc}{3|eg|} \qquad (9)$$

From equation (8), a P-controller is obtained for regulating the direct voltage. The P-controller is optimal for an integrator process in the since that the P-controller eliminates the reaming error for steps in the reference value. However, there will be a remaining error for steps in the reference value. However there will be remaining error when the grid is loaded and active power flows between the direct voltage link and the grid. The remaining error can be eliminated by adding an integrator to the direct voltage link controller.

$$i^*_{gq} = K_P\left(1 + \frac{1}{T_P}\right)\left(u^*_{dc} - u_{dc}\right)$$

$$k_P = -\alpha \frac{2Cu*dc}{3|e_g|} \qquad (10)$$

The following is often adapted for selecting the controller integration time in tradition PI-controller design. The active reference current of the grid connected converter can be written as

$$i^*_{gd} = \frac{2}{3e_{gq}} Q^*_g \qquad (11)$$

Negative proportional gain is because the distributed energy source references are used for grid.

$$T_i = \frac{10}{\omega_c} \approx \frac{10}{\alpha} \qquad (12)$$

B. Open loop reactive power control (outer loop):

The reactive power flowing into grid is controlled by the reactive current component. Simplest form of controlling reactive power is through open loop control. Taking imaginary part of equation (3) Reactive reference current as the igq* and igd* current reference are converted into three phase current references ia*, ib*, ic* which are given to current controller.

V. ANALYSIS OF CURRENT CONTROLLERS

A. Hysteresis controller:

The operation of the hysteresis current control is explained by circuit shown in fig 5 (a). In this method, inverter output current is forced to follow the current reference in each phase. Deviation between these two quantities is limited by upper limit of hysteresis band; the inverter leg is switched off so that the current decreases till reach lower band of hysteresis loop where the inverter leg is switch on again and actual current increase to upper band. The sin-wave shape of reference signal causes inverter switching frequency vary and gives different current ripple in one fundamental inverter period.gap wide between upper and lower band of hysteresis loop determine the magnitude of current ripple.

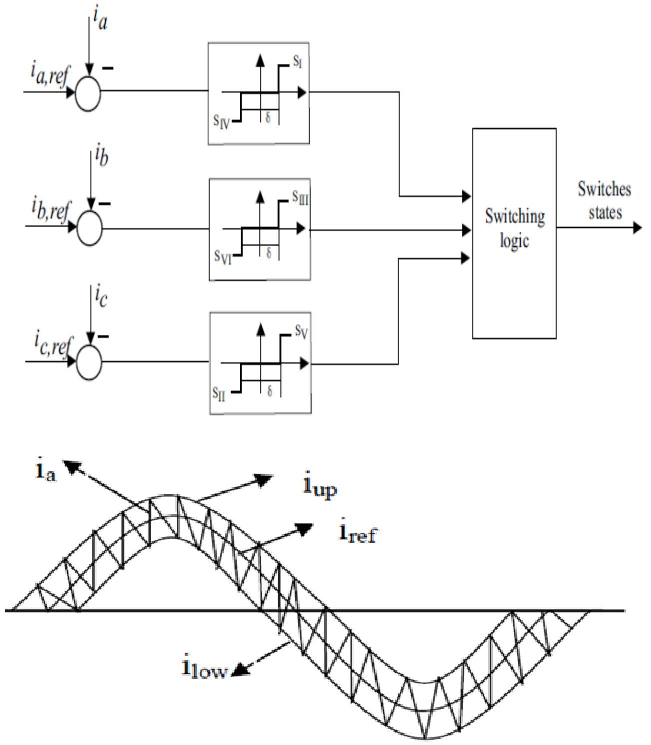


Figure 5 (a) Basic circuit diagram of hysteresis controller (b) hysteresis controller control structure

The waveform of fixed band hysteresis current controller is shown in fig.5. (B). in the fixed band scheme, the hysteresis band is fixed over the fundamental period. The mathematical equations for fixed band control is given as

$$i_{ref} = I_{max} \sin \omega t$$

$$i_{up} = i_{ref} + H$$

$$i_{lo} = i_{ref} - H$$

The advantage of this controller lies in its simplicity and its providing of excellent dynamic performance. So it used mostly. On the other hand, the disadvantage is that the switching frequency varies during fundamental period, resulting in irregular operation of the inverter. As a result the switching losses are increased. Varies strategies have been proposed in the literature to control or minimize the switching frequency variation. The load current waveforms are, thus, obtained and simulation results have been carried out.

B. Ramp type current controller:

A ramp comparator controller is shown in fig 6.The actual load currents are measured and compared with reference current waveforms. The generated error signals are compared with triangular waveforms of fixed frequency (to maintain constant switching frequency of voltage source inverter at frequency of triangular waveform). If the current error is positive and larger than the triangular wave, the inverter switches are activated to apply +VB to load. However if the current error is smaller than the triangular wave, inverter switches are activated to apply –VB to load.

In order to avoid multiple crossings of error signal with triangular wave Hysteresis band is added. The feature of ramp comparator current control is to maintain constant switching frequency with lower harmonic content. However this controller has some disadvantages, as the output current has amplitude and phase errors. This result in transmission delay in the system, a zero voltage is applied to load. This means that load is disconnected several times over the fundamental period. To avoid phase and amplitude errors phase shifters are included. The current error signals are compared with 120 phase-shifted triangular waveforms having fixed frequency and amplitude. It is to be noted that there is no interaction between the phases. As a result, the zero voltage vectors will be eliminated for balanced operation. This does not lead to the possibility of creating the positive and negative sequence currents due to controller alone. The zero voltage vectors eliminate the necessity of neutral connections for some applications, in such cases no harmonic neutral current flow in the load.

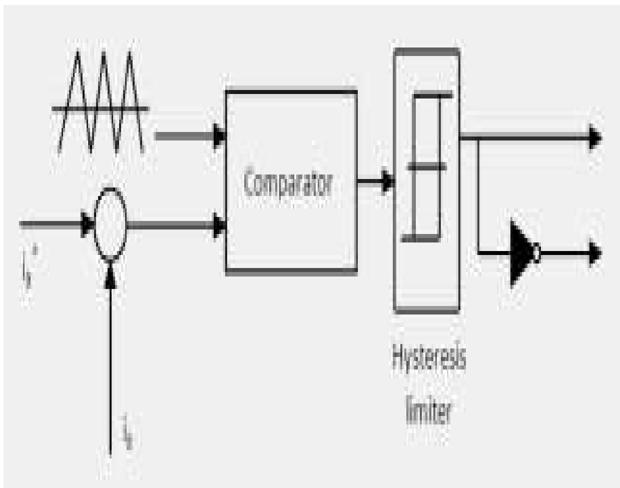
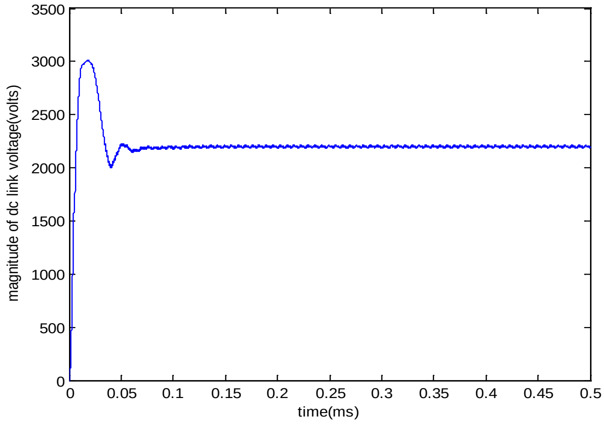


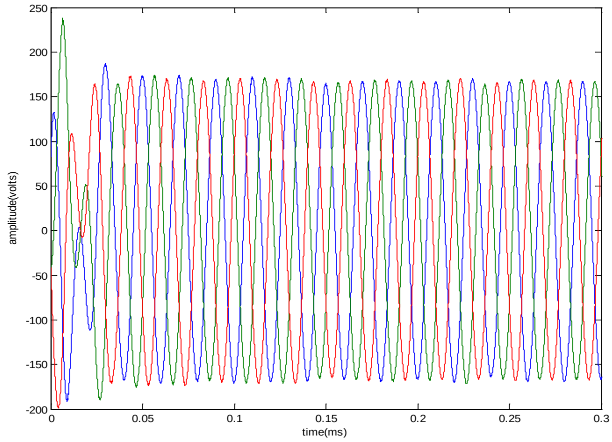
Figure 6 ramp type current control

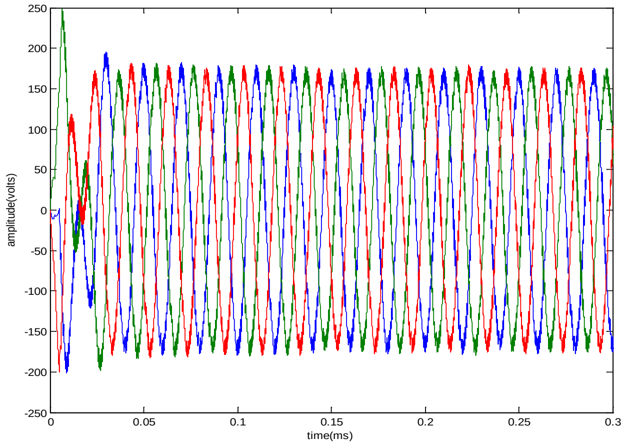
VI. SIMULATION RESULTS & DISCUSSION

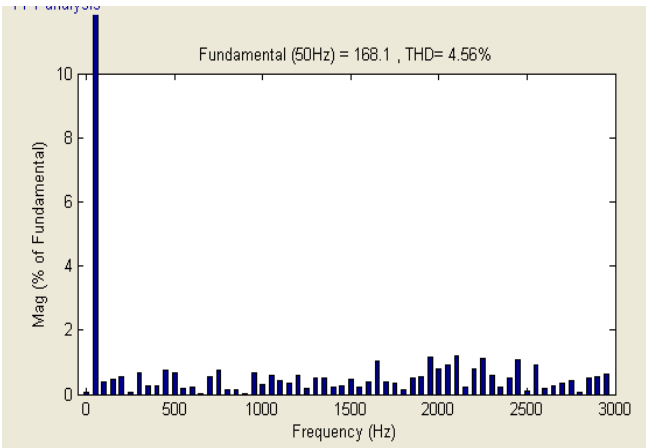
The proposed virtual grid flux vector control of grid connected inverter with hysteresis and ramp type current controllers is simulated in MATLAB/Simulink environment, Results of direct link voltage, grid currents, harmonic spectrum of grid currents, active and reactive power, displacement power factor are shown. Control parameter values

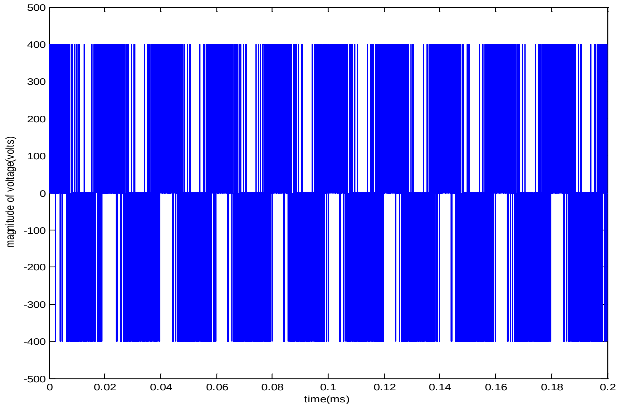
The reference value of direct link voltage Udc*=2200v, Reference value of reactive power Q*=0 to maintain unity power factor.Kp = 0.01, Ki=60, Hysteresis band H=20, Switching frequency=2 kHz.

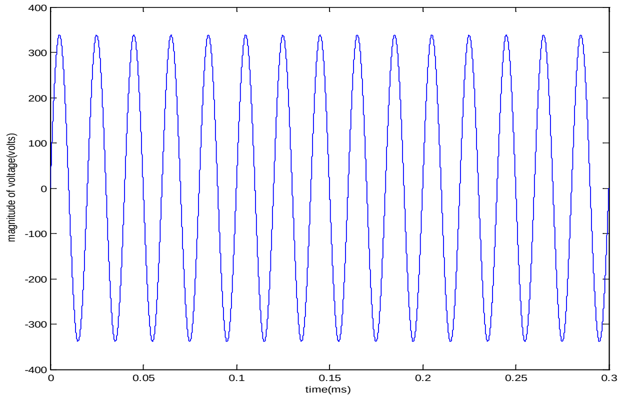












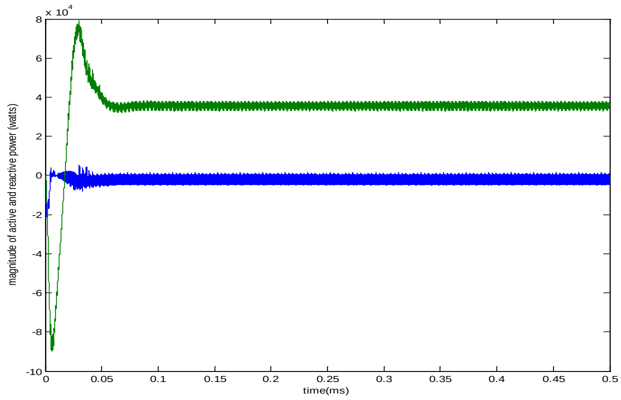
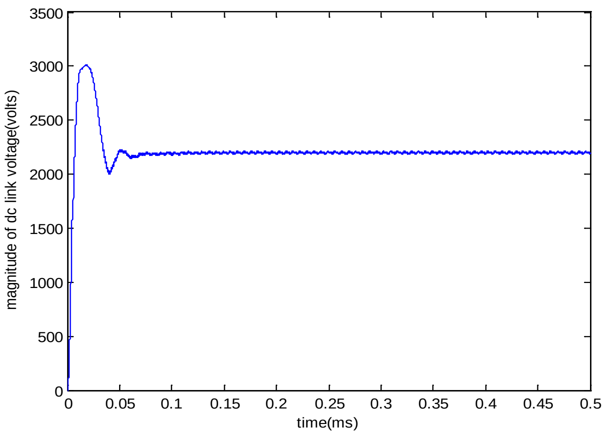
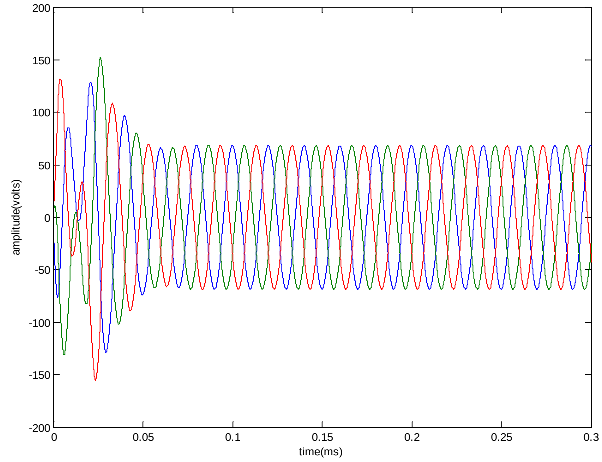
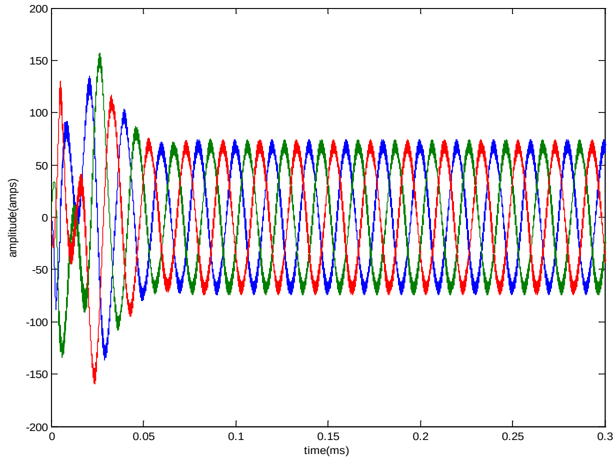
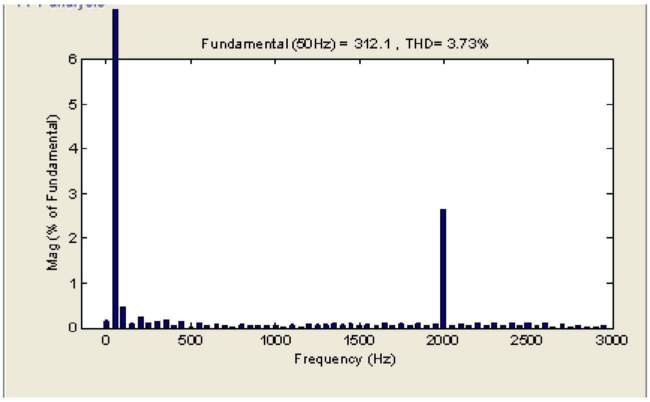


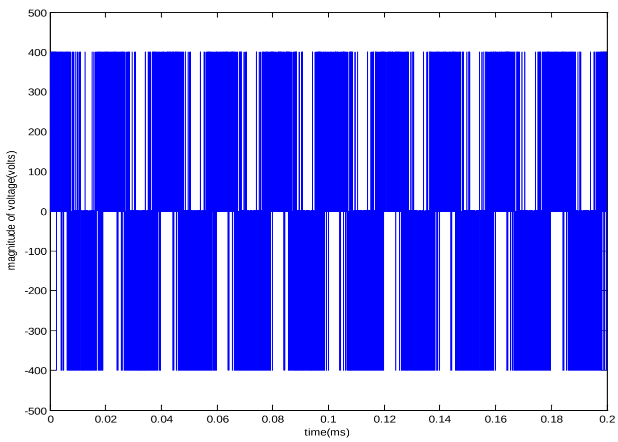
Figure.6. (a) dc link voltage (b) reference currents(c) grid currents (d) harmonic spectrum of grid current for hysteresis current controller (e) inverter output voltage (f) inverter output voltage after filter (g) active and reactive power

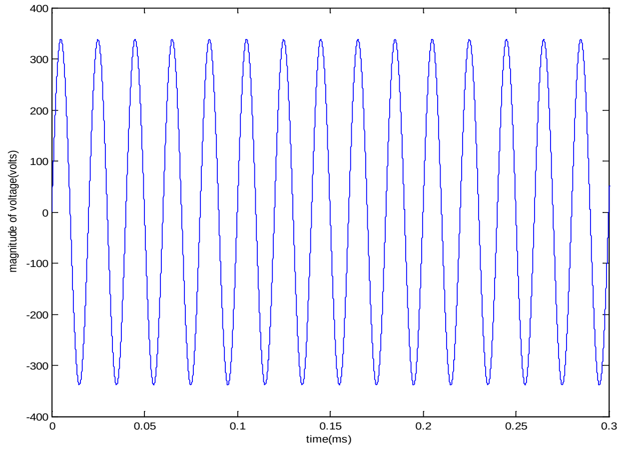












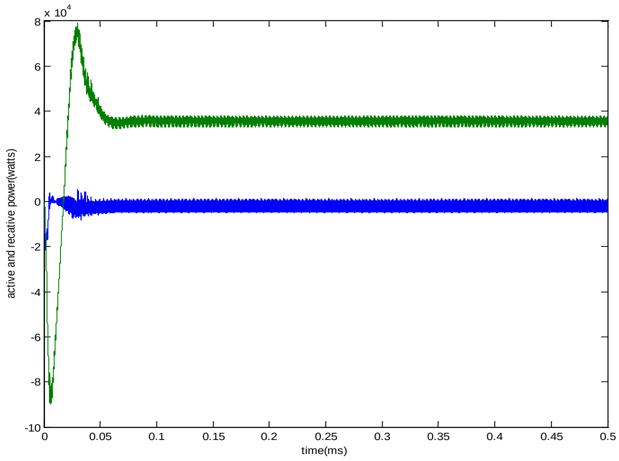


Figure7(a)dclinkvoltage,(b)actualcurrents,(c)referencecurrents,(d)harmonic spectrum of grid currents (e) inverter output voltage,(f)inverter output voltage with filter,(g)active and reactive power

The performance of two current controllers is studied at same load conditions. Fig 6 (a), 7 (a) shows the waveform of DC link voltage which is maintained at 2200v as that of reference set value. There is a ripple present in the dc link voltage, which is due to diode bridge rectifier. This ripple current can be decreased by increase in capacitance value or by using dc link inductor. dc link capacitor is selected in such a way that voltage ripple in capacitor voltage should be minimum.fig 6(b), 6(c) and 7(b), 7(c) grid current wave forms which are follows the reference current waveforms7 (d) shows the harmonic spectrum of load current 40^{th} harmonic having higher magnitude compared to other harmonics this is because of inverter is operating at 2khz frequency and THD of 3.10 for hysteresis current controller and 2.89 for ramp type current controller.

The harmonic spectrum of load current waveform is analyzed using the Fast Fourier transform (FFT) and measure the THD of load current for different values of R, L. Fig 6. shows the reference current waveform, load current waveform, error signal and corresponding harmonic spectrum along with THD in percentage of load current for a hysteresis current controller (for load values R=3ohm, L= 5mH). Fig 7. shows the load current waveform, error signal and corresponding harmonic spectrum along with THD in percentage of load current for a Ramp type current controller (for load values R=3ohm, L=5mH). THD of ramp type current controller is less compared to that of hysteresis current controller Hysteresis band which taken here (HB is 10% of load current magnitude) compromise between switching frequency and THD of load current. While decreases hysteresis band switching frequency will increases which leads to more switching losses and increase in hysteresis band load current waveform is distorted which leads to more THD. In modified ramp type current controller. Since the inverter switching frequency is limited to that of carrier frequency, it produces less current error when compared to hysteresis type controller. This current error signal is shown In the Fig 7.

The corresponding harmonic spectrum of three-phase load current waveform shown in the fig7. And it almost reduces the lower order harmonics. So the load current profile and its harmonic spectra are defined exactly fig 7(a) shows displacement power factor between grid voltages and currents which is unity.fig shows the instantaneous and average active power flowing into grid.fig shows the instantaneous and average reactive powers flowing into grid is zero, and then we can say that active power is delivering to grid almost at unity power factor.

VII. CONCLUSION

This paper discussed the virtual grid flux oriented control of grid side inverter for distributed power generating system. From that we observed that ramp type current controller on the inner current control loop provides good dynamic response as compared to hysteresis current controller. Also it proves the decoupling control on active and reactive power in the grid region. further the response of constant dc link voltage, grid current, active power flow in the grid and reactive power exchanged between DPGS and utility grid are discussed hear. Harmonics spectrum of grid current satisfies the existing IEEE 519-1992 standard. The reactive power flowing thorough the grid is zero and it shows the grid is operating at almost unity power factor. The power quality issues like power factor, harmonic reduction are improved by the proposed control technique.

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