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Distributed Generation in Power System Network to Alleviate Voltage Sag

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Abstract: *Now a days there is increase in consumption of energy than generation. So we have to maintain additional generation as well as power quality for continuity of supply. One of the problems that effects power quality is Voltage Sag or dip. Distributed generation has gained a lot of momentum due to market deregulation, and development of new technologies. Distributed Generation (DG) is defined as generation located at or near the load centre which is being recognized as an environment friendly, reliable, and secure source of power. Now a day there is increase in integration of distributed generation into the distribution network to meet ever increasing demand. Inverter based DG will increase system voltage profile. This paper mainly investigates on impact of Inverter based Distributed Generation in a power system network during voltage sag. The proposed method is tested and the results of simulation are observed using Matlab/Simulink.*
***Keywords*:** *Distributed Generation (DG), voltage sag, mat lab /simulink.*

I. Introduction

The continuously increasing energy consumption day by day, overloads the distribution grids by creating problems such as deterioration of power quality, outages and grid instability. Due to exhaustion of traditional energy sources and increasing price in the generation of electric power had raised interest in the production of electric energy from renewable power sources to balance the energy demand and generation. Distributed Generation (DG) is a small scale power plant connected at the load centre but not directly connected to the bulk power transmission system. DG includes small generators of ranges 1 KW to several MW [1].Typical distributed generation systems are wind power generation, photovoltaic power generation, fuel cell power generation, and micro turbine power generation.

One of the serious power quality problems is Voltage Sag [9]. Voltage Sag is a short duration reduction (between10%-90%) in voltage magnitude, lasting from few seconds to several seconds [5]. They may occur due to motor starting in distribution network etc. During sag, a power quality compensator is required for voltage support. It is very effective but need additional series compensation devices which may increase the overall cost of the system. In order to overcome this limitation, a powerful voltage support control for the grid connected inverter is used. The presence of a DG unit on the distribution feeders will mitigate the voltage sags experienced by the load connected to the equipment terminals [3] [10]. Depending on the duration of the voltage sag [6]-[7], the grid code forces disconnection of the system.

II. Inverter Based Dg

During voltage sag, continuous power should be generated from distributed generation systems to the grid for the purpose of grid support. For this purpose, a flexible voltage support control scheme is proposed for inverter based distributed generation, aiming at regulating voltage limits. Inverter based DGs operate as controlled voltage sources connected to the grid system through a step up transformer. The step up transformer with delta-delta connection eliminates the zero sequence components from inverter to the grid. Consider the active power of an inverter based DG, denominated as $P_{DG.}$

$$P_{DG} = \frac{|V_1||V_2|}{X}\sin(\delta) \qquad (1)$$

Where $|V_1|$, $|V_2|$ are the voltage magnitudes at the primary and secondary sides of the step up transformer and δ is the difference of phase angle between V_1 and V_2.

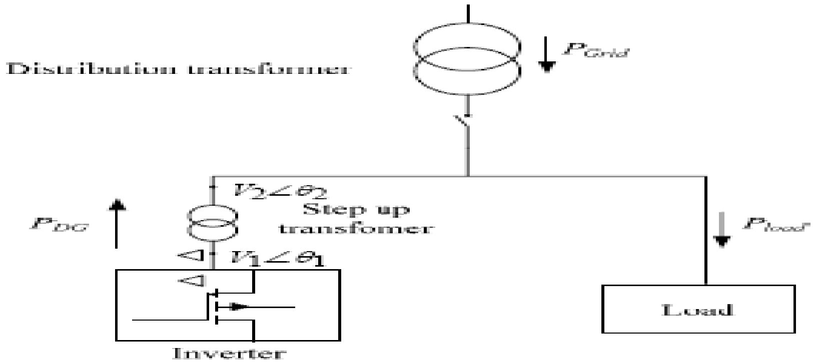

Fig 1: Block diagram of grid connected inverter based DG

A. Voltage sag

Electronic devices function properly as long as the voltage of the electricity feeding the device stays within a permissible range. There are several types of voltage fluctuations that can cause problems, including surges, sags, and harmonic distortions. Voltage Sag is a fundamental frequency decrease in the supply voltage for a short duration. Voltage sag is not a complete interruption of power; it is a temporary drop below 90% of the nominal voltage level. Nowadays, Voltage sag is the most significant power quality (PQ) problem faced by industrial customers as well as large commercial customers [8]. Depending on the magnitude and duration of the voltage sag, the effect of sag varies on the sensitivity of the equipment. Many types of electronic equipment are sensitive to voltage sags, including variable speed drive controls, motor starter contactors, robotics, programmable logic controllers, controller power supplies, and control relays [4].

Voltage sags can be characterized by the module, frequency, and initial angle of each phase or by the positive, negative, and zero symmetric sequences:

$$v_a = v_a^+ + v_a^- + v_a^0 \qquad (2)$$

$$v_b = v_b^+ + v_b^- + v_b^0 \qquad (3)$$

$$v_c = v_c^+ + v_c^- + v_c^0 \qquad (4)$$

Where the indexes +, -, and 0 indicates the positive, negative, and zero symmetric sequences respectively. Instead of using a natural frame for characterizing the grid voltage, the Clarke transformation is applied to express measured voltages in the stationary reference frame (SRF)

$$\begin{bmatrix} v_\propto \\ v_\beta \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix} \quad (5)$$

A useful parameter to characterize the voltage sag is the voltage unbalance factor (n). This parameter describes the amount of imbalance in the system as the ratio between negative and positive voltage amplitudes. This can be represented as follows:

$$n = \frac{v-}{v+} = \frac{\sqrt{(v_\alpha^-)2 + \left(v_\beta^+\right)2}}{\sqrt{(v_\propto^+)2 + \left(v_\beta^-\right)2}} \quad (6)$$

B. Control Diagram for Inverter Based DG

Pulse Width Modulation (PWM) is used as the base technology for the inverter described here. In a PWM inverter [11], the key control elements are the amplitude controller and the phase controller. The amplitude controller provides the balanced three phase output voltage to the grid at the desired voltage amplitude.

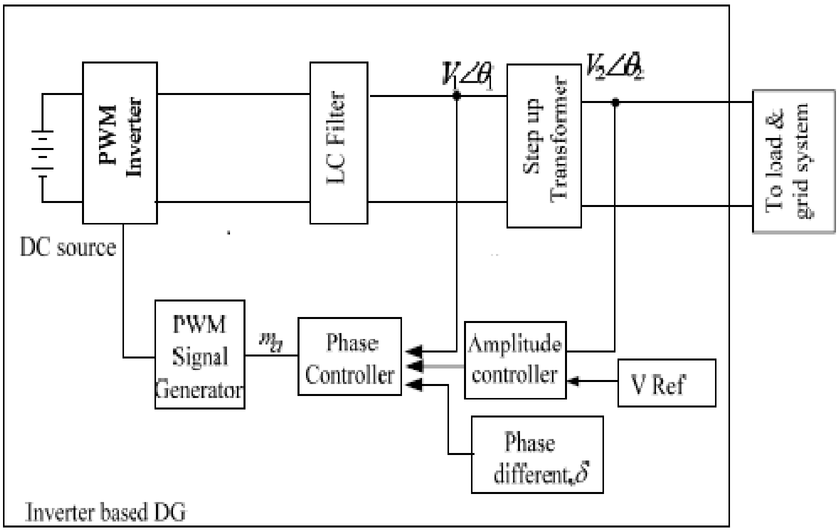

Fig2: Control diagram of Inverter Based DG

Input to the PWM inverter is DC voltage produced from a DC source. The harmonics in the voltage from the PWM inverter is filtered out by an LC low pass filter and the voltage is stepped up by using a step up transformer. The output LC filter is connected to remove high switching frequency components from the output current of the inverter [2].The output voltage of DG, V_2, is transformed via a time dependent transformation and is compared with the reference voltage VRef to obtain normal voltage profile. The amplitude controller consists of a phase locked loop (PLL) and a PI controller. In this process phase angle of voltage V2 is locked. PLL techniques causes one signal to track another one. It keeps an output signal synchronized with a reference input signal in frequency and phase. In three phase grid connected system PLL can be implemented using the d-q transformation and with a proper design of loop. The signals from amplitude controller are given to phase controller. The value of the phase difference, δdiff and approximate power flow can be calculated. In the phase controller, a PI controller is applied to minimize the error of specified power output value, Pref. The output of the PI controller is added to V1 and used to calculate the required amplitude and phase of the modulating signal. Thus the amplitude and phase controller provide the modulating signal to the pulse width modulation signal generator which generates the voltage waveform.

III. Proposed Voltage Support Control

Voltage control can be obtained by the feedback loop provided in the control diagram. Here Parks transformation or dq0 transformation is applied. The Parks transformation refers the machines variables to a frame of reference that can be chosen to rotate at an arbitrary angular velocity.
A change of variables to an arbitrary reference frame can be expressed as

$$f_{dq0} = T_{dq0} f_{abc} \quad (7)$$

Where f represents variables, such as voltage, current, and flux linkages f_d. f_q and f_0 are the variables in direct-axis, quadrature-axis, and zero sequence respectively.

$$f_{dq0}^T = [f_d \quad f_q \quad f_0]$$

$$f_{abc}^T = [f_a \quad f_b \quad f_c]$$

$$Tdq0=\frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

$$\omega_e = \frac{d\theta}{dt} \quad (8)$$

The inverse transformation can be expressed as

$$T_{dq0}^{-1}=\begin{bmatrix} \cos\theta & -\sin(\theta) & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & -\sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \quad (9)$$

The total instantaneous power can be written in abc variables as

$$P_{abc}=v_{an}i_a+v_{bn}i_b+v_{cn}i_c \quad (10)$$

The total instantaneous power written in the dq0 domain is

$$P_{dq0}=P_{abc}=\frac{3}{2}\left(v_d i_d + v_q i_q + 2v_0 i_0\right) \quad (11)$$

The transform equations from vabc to vdq0 (t) is

$$\begin{bmatrix} v_d(t) \\ v_q(t) \\ v_{0(t)} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(\omega_e t) & \cos\left(\omega_e t-\frac{2\pi}{3}\right) & \cos\left(\omega_e t+\frac{2\pi}{3}\right) \\ -\sin(\omega_e t) & -\sin\left(\omega_e t-\frac{2\pi}{3}\right) & -\sin\left(\omega_e t+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} * \begin{bmatrix} v_{an}(t) \\ v_{bn}(t) \\ v_{cn}(t) \end{bmatrix} \quad (12)$$

and the inverse transform from Vdq0 to Vabc is

$$\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_{c(t)} \end{bmatrix} = \begin{bmatrix} \cos(\omega_e t) & -\sin(\omega_e t) & 1 \\ \cos\left(\omega_e t-\frac{2\pi}{3}\right) & -\sin\left(\omega_e t-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\omega_e t+\frac{2\pi}{3}\right) & -\sin\left(\omega_e t+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} v_d(t) \\ v_q(t) \\ v_0(t) \end{bmatrix} \quad (13)$$

For the purpose of designing and modeling a controller, rms voltage of $v_{an}(t), v_{bn}(t), v_{cn}(t), v_d(t), v_q(t)$and $v_0(t)$are used. These rms values are denoted as $V_{an}, V_{bn}, V_{cn}, V_d, V_q$, and V_0. The same notation is used for current.

A proportional plus integral (PI) controller minimizes the error signal, that is, the difference between the reference signal and the instantaneous voltages$v_d(t)$and $v_q(t)$. The transformation of an unbalanced three phase signal which can be expressed as

$$v_a(t) = 100\cos\omega t + 10\cos 5\omega t + 5\cos 9\omega t$$

$$v_b(t) = 90\cos\left(\omega t - \frac{2\pi}{3}\right) + 8\cos 5\left(\omega t - \frac{2\pi}{3}\right) + 4\cos 9\left(\omega t - \frac{2\pi}{3}\right)$$

$$v_c(t) = 80\cos\left(\omega t + \frac{2\pi}{3}\right) + 6\cos 5\left(\omega t + \frac{2\pi}{3}\right) + 3\cos 9\left(\omega t + \frac{2\pi}{3}\right) \quad (14)$$

Transformation of the signal in (14) associated with the velocity of reference frame is done by applying eqns (7), (8), (9).

IV. Simulation Results

Nowadays, Simulation has become a very powerful tool in the industrial applications as well as in academics. Simulation is one of the best ways to study the system or circuit behavior. It is now essential for an electrical engineer to understand the concept of simulation and learn its use in various applications. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. Sim Power Systems extends simulink with tools for modeling and simulating basic electrical circuits and detailed electrical power systems. Mitigation of voltage dip by using Inverter Based DG is evaluated by using Mat lab/Simulink environment. The proposed method can achieve more effective voltage support in a grid. Fig.3 and Fig.4 shows the simulated circuit diagram of power system network and powers system network with change in load respectively. Fig.5 shows the output waveform of voltage at normal load. Fig.6 shows that voltage sag occurs at the load side of a power system network. Fig.7 and Fig.10 shows the simulation circuit diagram of the grid connected inverter based distribution generation (active load) and grid connected inverter based with change in load (active load + lagging load) respectively. Fig.8 and Fig.9 shows the input and output voltage waveforms of the grid connected Inverter based DG which shows rated values of voltage in the presence of active load. In Fig.10, load is changed with change in active load and addition of inductive load which may cause voltage sag. But due to the presence of Inverter based DG, voltage at load side remains constant which is shown in Fig.12. Fig.11 shows normal input voltage waveform at rated value in the presence of both active and lagging load. Here, the controller is a main component which can be used to reduce voltage sag.

The simulated output voltage waveform in Fig.14 shows that voltage dip is reduced by the controller during grid connection. It can be observed that the unbalanced bus voltage is reduced at the expense of the larger power oscillations.

A. Simulation results

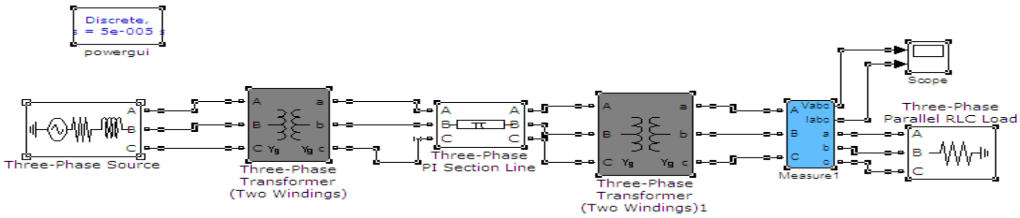

Fig3: Simulated circuit diagram of power system

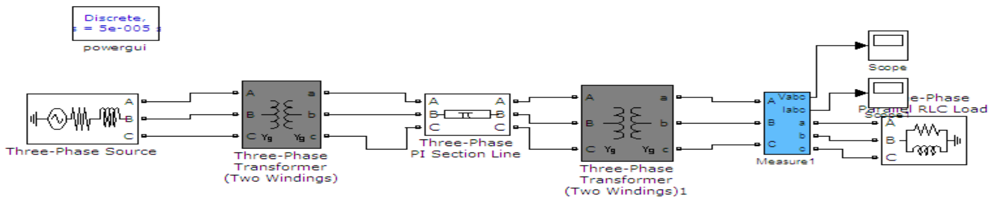

Fig4: Simulated circuit diagram of power system with change in load

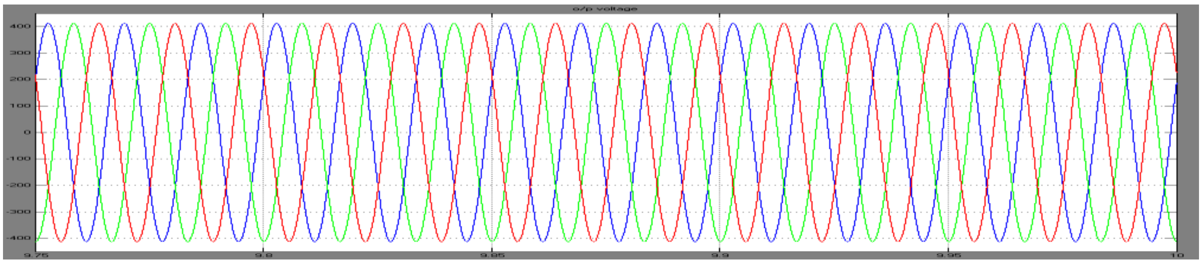

Fig.5: Output Voltage Waveform during normal load

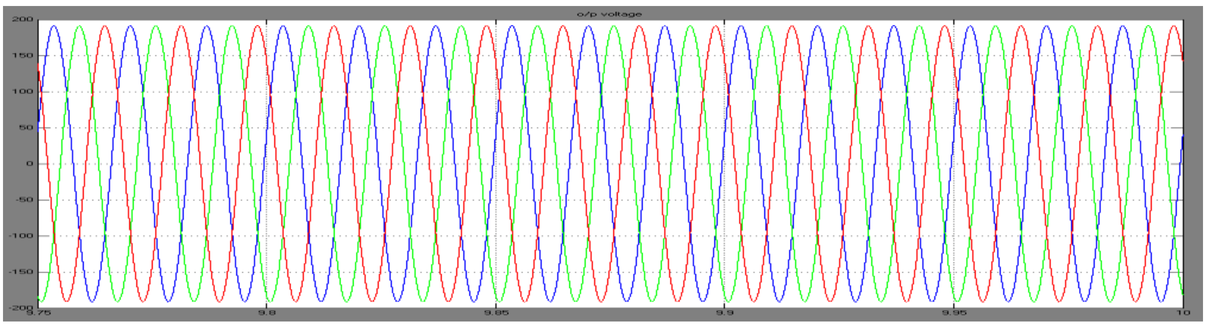

Fig.6: Output Voltage Waveform during change in load

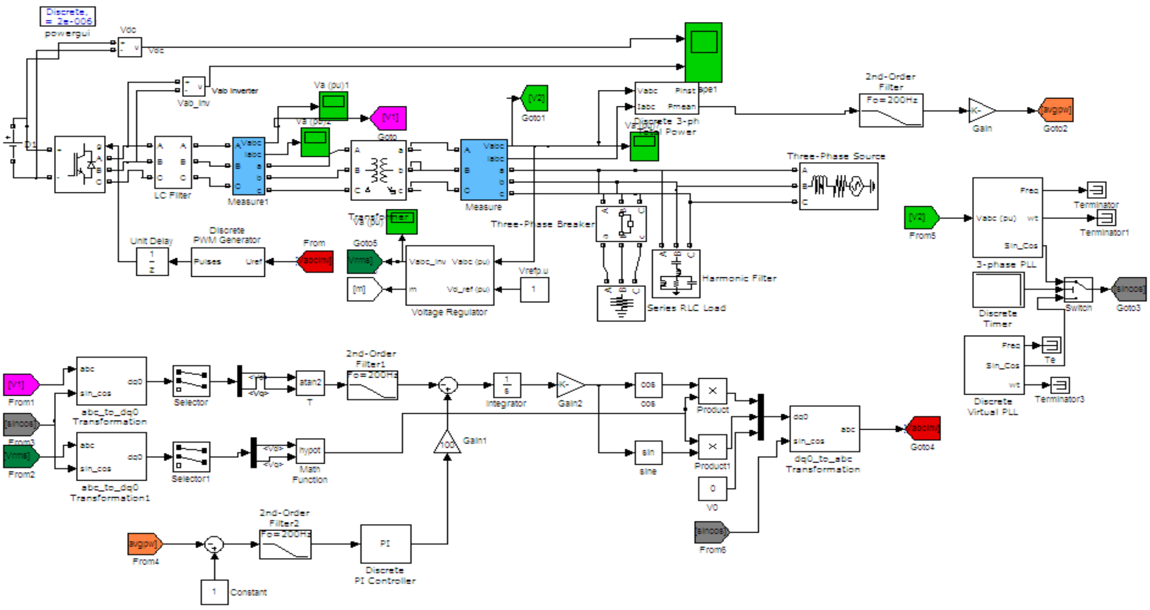

Fig7: Simulated circuit diagram for grid connected Inverter based DG

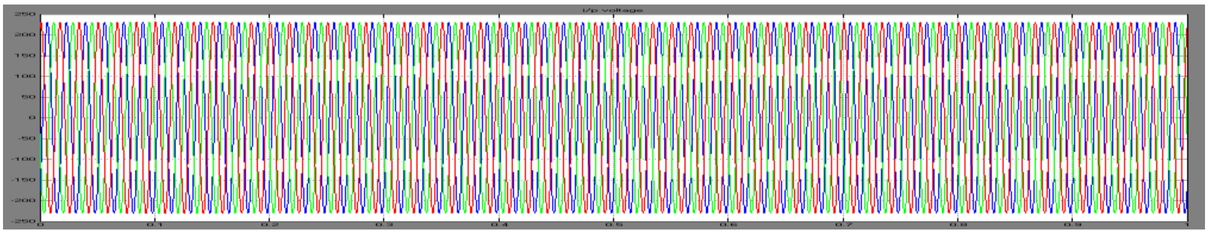

Fig.8: Input Voltage Waveform of grid connected Inverter based DG

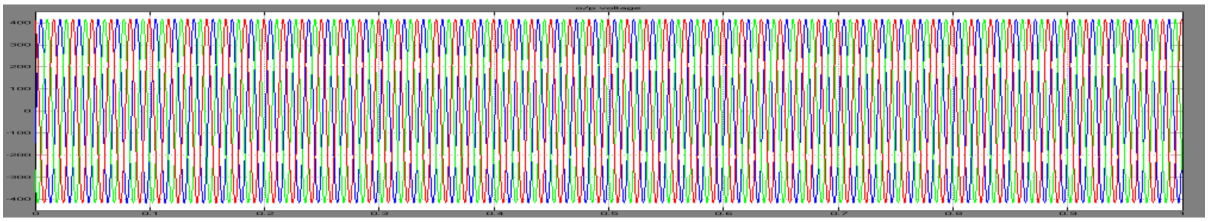

Fig.9: Output Voltage Waveform of grid connected Inverter based DG

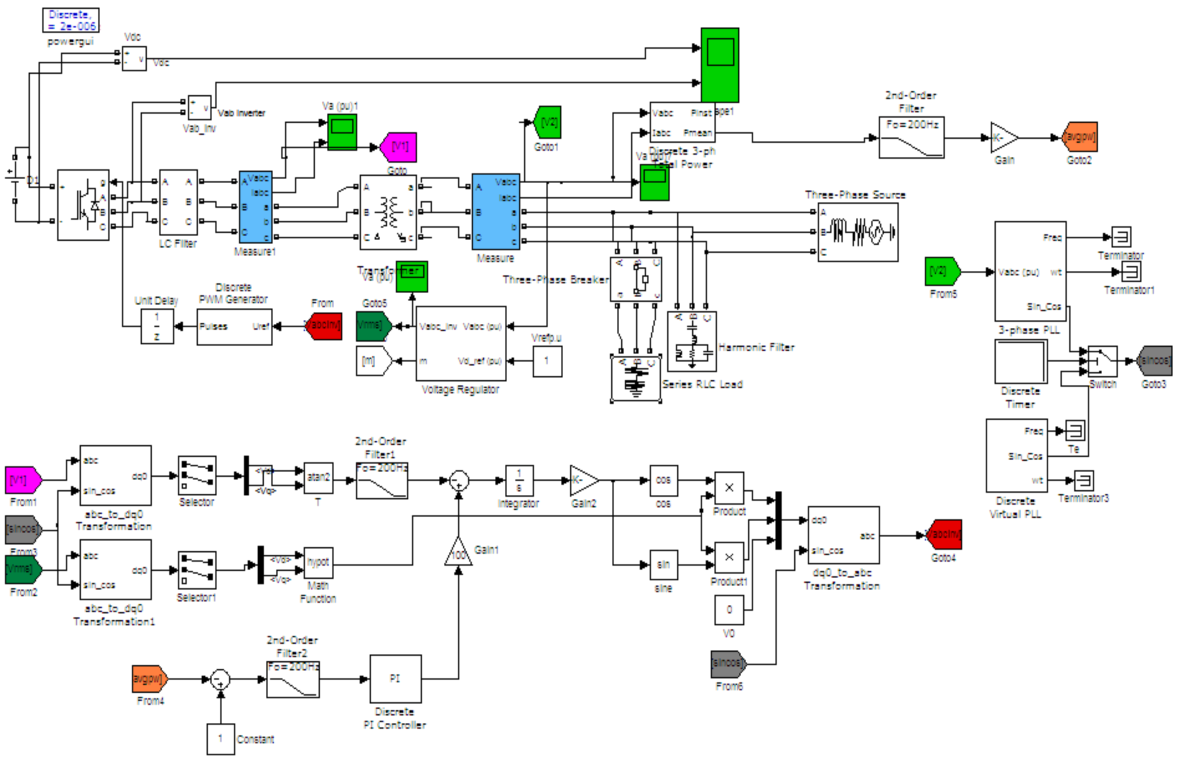

Fig10: Simulated circuit diagram for grid connected Inverter based DG with load change

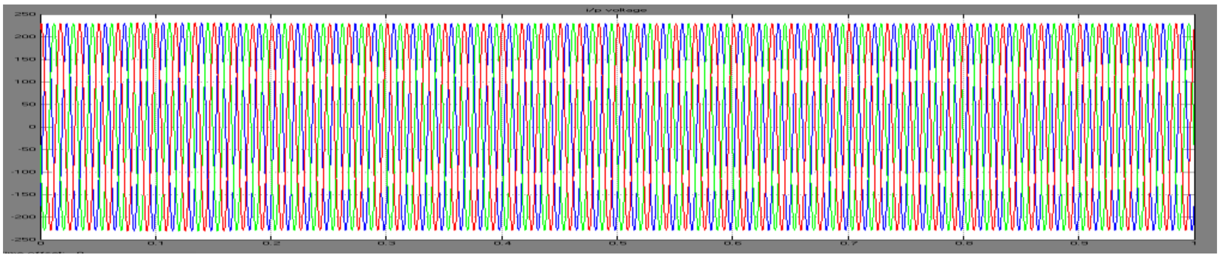

Fig.11: Input Voltage Waveform of grid connected Inverter based DG with load change

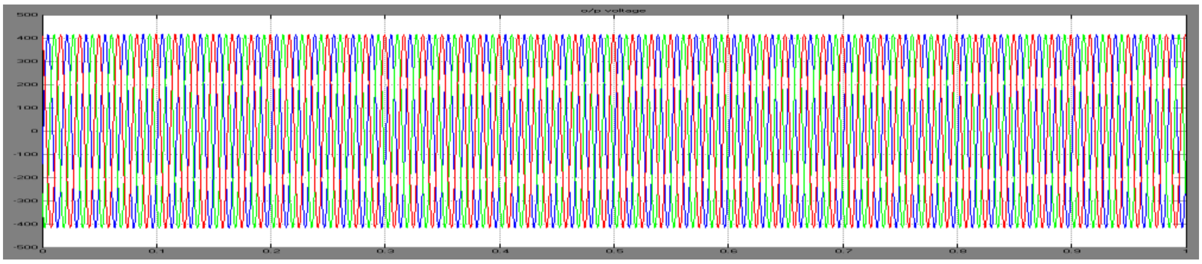

Fig.12: Output Voltage Waveform of grid connected Inverter based DG with load change

V. Conclusion

Due to increasing of demand more than generation, market deregulation, need of high reliability and power quality, demand was raised for distributed resources. These distributed resources consist of solar, fuel cells, micro turbines which mostly depend on the electronic inverters. These inverters will interface with the power system network to produce necessary changes when there appears a disturbance in the system. Here Inverter Based DG is analyzed by using abc-dq0 transformation. This paper has proposed the method for voltage support control of inverter based Distributed generator in the presence of voltage sag. The voltage at load side is seen in Fig.9 in the presence of Inverter based DG under active load which shows the rated value. The influence of inverter Based DG on the retained voltage during voltage dips in low voltage distribution networks is observed in the Fig.12 with change in load (active load + lagging load).

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