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PERFORMANCE ANALYSIS OF STABILITY AND VOLTAGE CONTROL USING P-F AND Q-V DROOP CONTROLLER FOR AN AUTONOMOUS AC MICROGRID

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Abstract: *The present scenario structure of grid accommodates complex network which increases instability. At the same time, a small scale generating units using renewable energy sources is rapidly increasing. The increase in renewable energy source brings the concept of distributed generation and micro grid in the research area. These Distributed Energy Resources are interfaced to the conventional micro grid via power electronics converter. Hence these converters bring the problems of power quality and stability. Hence in this paper the performance analysis of DG are focused .To analyse the stability of the micro grid P-F and Q-V droop controller are used. The simulation was done in MATLAB/Simulink Sim power system software.*

***Keywords**-Distributed Generation; micro grid; MATLAB/Simu link..*

1. INTRODUCTION

Distributed generation (DGs) are normally linked through power electronic devices like Voltage Source Inverter (VSI) to the micro grid or main utility grid. Micro grid [1] is a group of interlinked distributed energy resources and loads in lucidly demarcated electrical boundaries. In accordance to the grid, the micro grid operates as a solitary controllable entity that disconnects and connects to the grid, in order to facilitate the micro grid to work in both grid-tied mode and autonomous mode. An enhanced power quality, reduced congestion in transmission lines, decreased energy losses and emission can be obtained by introducing the micro grids. Conventionally, when the microgrid operates autonomously, the inverters connected to it acts as voltage sources and as current sources when they are linked with the grid [2]. The stability problem arises at the moment of transferring the load from On-grid mode to Off-grid mode or during autonomous mode. The main utility grid has high reliability potential due to its adaptness of isolating the power generation and load from the grid [3].A micro grid paradigm is shown in figure.1.

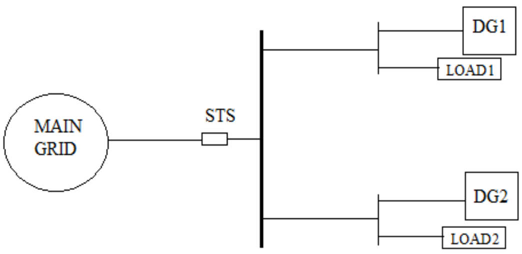


Figure 1: A micro grid with two DGs.

A meticulous fretfulness in micro grids is the issues of transient stability, at the time of interfacing the micro grid to the main utility grid, which is a foremost area of research that also helps in exploring the effect of problems of stability [4]. The circuit breaker linked between the main grid and the micro grid will open, when the unbalance in voltage is solemn, to isolate the micro grid. If voltage unbalance is not serious, the circuit breaker endures closed, which results in prolonged voltage imbalance at the PCC [5]. A robust control stratagem with the operation of hyperactive performance is adopted, so as to satisfy the requirement of stability.. Subsequently, an unique feature of the contemporary converters based on power electronics is the VSI accompanied by a PWM current control stratagem. It is more reliable in alleviating the problems of power quality and stability. The VSI is interlinked by using PWM, the nonlinearity in VSI's V-I characteristics and an elevated switching frequency are the major causes for disturbance in power quality [6]. An open loop PWM based linear control and a closed loop PWM based nonlinear control are the two types of current controllers [7]. In a network of three phase grid connection, a VSI designed with a nonlinear control based on hysteresis current control (HCC) is employed. The error signal is fed to the HCC and compensation of current error is made along with the generation of PWM signal with acceptable error. An enormous amount of total harmonic distortion (THD) is developed from a huge ripple current generation resulting from the self-regulation of delay current in order to control the signal of current error [8]. Although a sine pulse width modulation (SVPWM) is employed in linear current controller, an algorithm of predictive control or standard PI regulator is used in compensating the current error signals. This type of controller provides an excellent control of current signal along with proper compensation leading to the development of low ripple [9]. In order to enhance the micro grid voltage and frequency, a power control based on an inner loop of current control is investigated. To provide information involving analysis and design and to guarantee the system's dynamic stability is the controller's aspiration [10-11]. When changing or shifting the loads, a voltage unbalance and deviation in frequency occurs. So it is necessary to investigate power quality [12].

The organization of this paper is as follows. In section-2 micro grid structure is discussed. Section-3 presents about Distributed Generation. Section-4 describes the droop controller and its modelling. Section five is about simulation model and results. Conclusions are stated in chapter 6.

2. STRUCTURE OF MICRO-GRID

Micro grid is an autonomous small scale power supply network that is designed to provide a power for a small community [16]. It contains various micro sources, controllable loads and storage devices. Two basic classes of micro sources are DC source (fuel cell, PV cells and battery storage) and AC sources (micro turbine). The DC voltage is converted to an acceptable AC voltage using Voltage source inverter. The main significant components of micro grid are static transfer switch (STS) and micro sources. During disturbances such as IEEE 1547 events or power quality events, the micro grid is disconnected from the main grid with the help of the static switch. Subsequently after islanding, the resynchronization of the micro grid is attained immediately after the tripping event is no longer present [10]. This synchronization is achieved by using the frequency difference between the islanded micro grid and the utility grid assuring a transient free operation without having to match frequency and phase angles at the connection point [4]. The structure of the micro grid is shown in the fig2.

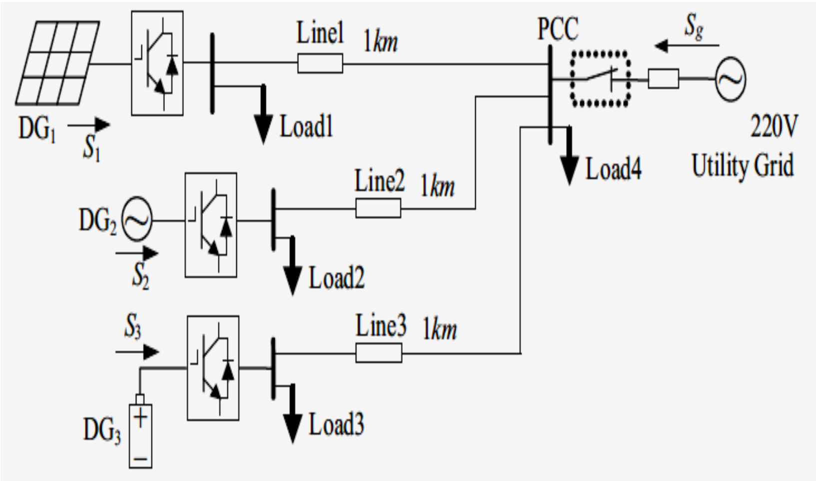


Fig.2 Schematic diagram of micro-grid structure

3. DISTRIBUTED GENERATION (DG)

Distributed generations are small electric power generators. Because of its size and clean energy technology, DGs can be installed close to the customers [13]. Installation & operation of electric power generation units connected to the local network or off-grid generation is characterized by:

- Generation capacity ranging from kW to MW level.
- Generation at Distribution Voltages (11kV or below).
- Grid inter-connection at distribution line side
- Inter-connected to a local grid, or
- Totally off-grid, including captive

Distributed generation generates electricity from many small energy sources [5].

- Distributed generation occurs when power is generated (converted) locally and sometimes might be shared with or sold to neighbors through the electrical grid (or over the fence)
    - i. Large central generation is not directly used
    - ii. The Public Service Commission may define only one supplier as a utility.
- Distributed generation avoids the losses that occur in transmission over long distances; energy is used nearby.
- Varying wind and sunshine averages across several houses, blocks, cities, or states, stabilizing the system.
    - i. Variability of one source is reduced by dividing the square root of the number of sources.
- Supply is robust, but automatic precautions are required to protect electricity workers when main base-load power is out, and a local system might feed back into power lines

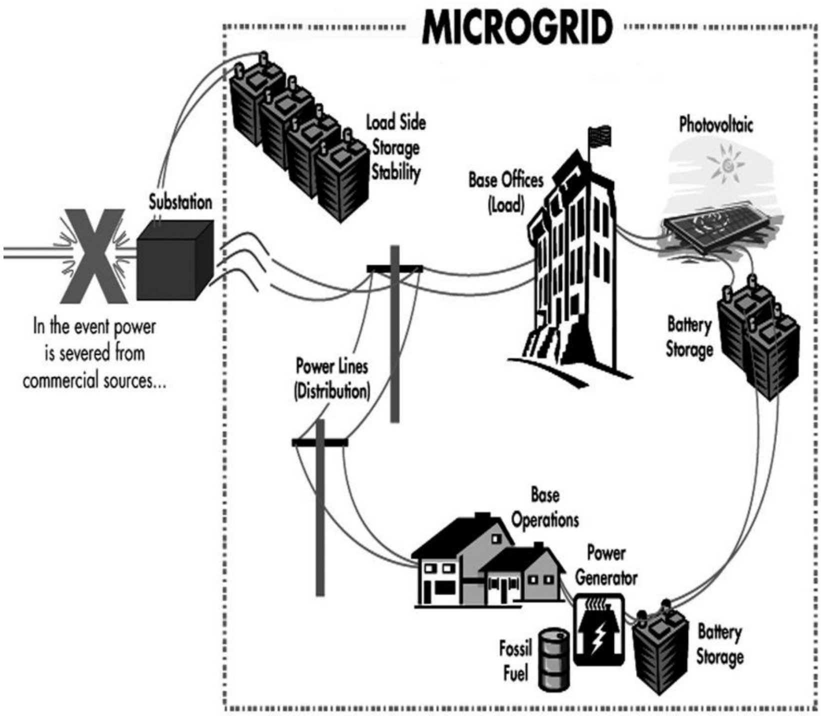


Fig.3. Distributed Generation

Distribution generation can be classified generally as renewable and nonrenewable DGs [15]. Micro turbines and fuel cells are considered as dispatchable DGs due to their capability of producing active power on demand whereas the solar and wind are considered as non-dispatchable DGs due to their operation according to their maximum power-tracking concept. This type of DG's output powers are dependent mainly on the weather rather than load. Hence non-dispatchable loads are considered to be negative loads. In this paper dispatchable DG is adopted i.e. DC source.

4. DROOP CONTROLLER

The inverter based DG utilize P-f and Q-V droop controller as shown in figure 5.2

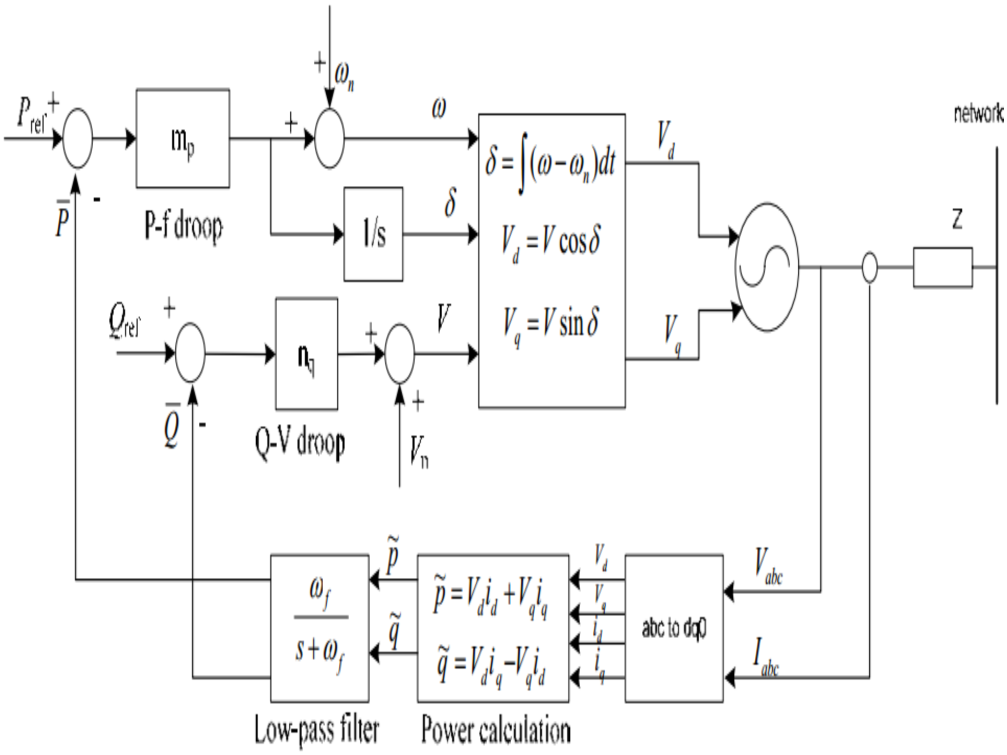


Fig 4 Structure of P-f and Q-V droop control

The system parameters of the micro grid model are listed in table 1

Table 1

S.no	Parameters	Range
1	Reference active of micro source 1(KW)	20
2	Reference active of micro source 2(KW)	50
3	Frequency droop gain rad/sec/watts	$1.256e^{-4}$
4	Frequency droop gain rad/sec/watts	$3.14e^{-4}$
5	Voltage droop gain Volts/var	$1.0e^{-4}$
6	Voltage droop gain Volts/var	$5.0e^{-4}$
7	Low Pass filter cut off frequency (rad/sec	40
8	Frequency	50 HZ

4.1 Modeling of Inverter Control Strategy

The control strategy needed for inverter based micro sources are discussed in this section. The micro source 1 adopts P-f droop control whereas micro source 2 works with Q-V droop control. The conventional droop control is described in 4.1.1.and section 4.1.2 explain about modeling of proposed droop control strategy.

4.1.1.Review of conventional droop Control

At the start to approach droop control strategy, consider the complex power transmitted along a transmission line of line impedance Z=R+jX as shown in figure 5.3.

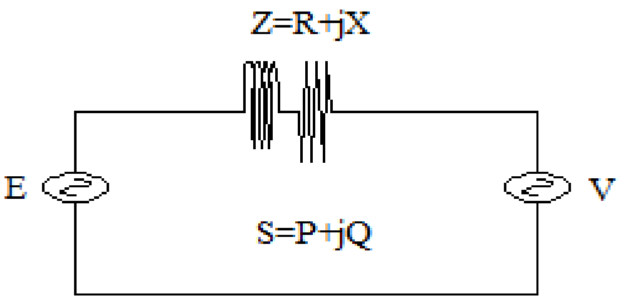


Figure 5 Complex Power Transmitted along a Transmission Line
E-magnitude of sending end voltage
V-magnitude of receiving end voltage
S-phase angle difference between E and V
In general, the complex power in transmission line is given by

$$\bar{S} = P + jQ = EI^{*} - - - -$$

$$= \bar{E}\frac{(\bar{E} - \bar{V})}{Z} - - - - - - - - - - - (2)$$

$$= E\frac{(E - Ve^{j\delta})}{Ze^{-j\theta}}$$

$$= \frac{E}{Z}e^{j\theta} - \frac{EVe^{j(\theta+\delta)}}{Z} - - - - - - (3)$$

Separate eqn(3) into real and imaginary parts by applying Euler's formula.
(i.e),

$$S = P + jQ = \frac{E^2}{Z}cos\theta - \frac{EV}{Z}\cos(\theta + \delta) - - - - - - - - - (4)$$

$$Q = \frac{E^2}{Z}sin\theta - \frac{EV}{Z}\sin(\theta + \delta) - - - - - - - - - (5)$$

We know

$$P = \frac{E}{R^2 + X^2}[RE - E\cos\delta + VX\sin\delta] - - - - - - - (6)$$

$$Q = \frac{E}{R^2 + X^2}[XE - V\cos\delta + RV\sin\delta] - - - - - - - (7)$$

Since inductance is dominating in a transmission line, neglect resistance.

Hence eqn(6)&(7) can be modified as

$$P = \frac{EV}{X}\sin\delta - - - - - - - - - - - - (8)$$

$$Q = \frac{E^2}{X} - \frac{EV}{X}\cos\delta - - - - - - - - - - - - (9)$$

Let power angle is small. Therefore sin

Again eqn(8)&(9) can be rewritten with the above assumption,

$$P = \frac{EV}{X}\delta - - - - - - - - - (10)$$

$$Q = \frac{E^2}{X} - \frac{EV}{X}$$

$$Q = \frac{E(E - V)}{X} - - - - - - - (11)$$

The equation (10) and (11) can also rewritten as

$$\delta \cong \frac{XP}{EV} - - - - - - - - - - - - (12)$$

--------------------------(13)

Equations (12) and (13) represents that real power depends δ whereas reactive power depends on v

Instead we can say that

1) In the droop control strategy, DG unit users the frequency as a signal to have the control over real power.

2) If we control reactive power, then voltage will be controlled.

From the above said, voltage and frequency are regulated with the help of real and reactive power and hence the droop equations are framed as

$$f' = f_0 - k_m(P' - P_0) - - - - - -(14)$$

$$V' = V_0 - k_n(Q' - Q_0) - - - - - -(15)$$

$$K_m = -\frac{\Delta f}{P' - P_0} - - - - - - - - (16)$$

$$K_n = -\frac{\Delta V}{Q' - Q_0} - - - - - - - - (17)$$

Where

f=nominal operating frequency of DG

P1 =Output power at new operating point

P0= Nominal value of output power

V^0 = nominal voltage

V' = Shift in new voltage of DG

=set valve of reactive power

From the above equation, when the load increases under island mode of operation, the DG output power also increases and thereby frequency decreases.

4.1.2 Modeling of proposed Control strategy

The modeling of proposed control strategy is shown in fig 5.2.From the figure, output voltage is calculated by means of dq quantities,it reduces the complexity of the equation. The instantaneous real and reactive power components computed from the obtained output voltage and current as given in equations (18) and (19)

$$\tilde{p} = V_d i_d + V_q i_q \text{---------------} (18)$$

$$\tilde{q} = V_d i_q - V_q i_d \text{---------------} (19)$$

The fundamental real and reactive power components are obtained by allowing the instantaneous components via filter (Fig) as given in the following equations

$$\bar{P} = \frac{\omega_c}{s + \omega_c}\tilde{p} - - - - - (20)$$

$$\bar{Q} = \frac{\omega_c}{s + \omega_c}\tilde{q} - - - - - (21)$$

Where - low pass filter cut-off frequency

Offering an artificial droop will help to share the real power sharing among inverters as represented in equation.

$$\omega = \omega_n - K_m P - - - - - - - - (22)$$
$$\delta = \int (\omega - \omega_n) dt - - - - - - - - (23)$$

$$V_d = V \cos\delta - - (24)$$
$$V_q = V \sin\delta - - - - - (25)$$

By applying inverse Park's transformation, and are converted into abc quantities.

5. MODELLING AND SIMULATION RESULTS

To carry out the simulation, three distributed generator units are interconnected with different loads like linear load, R load, RL load and Induction Motor load. The performance analysis of voltage and frequency droop controller are investigated and the results are given below.

5.1 Simulation Study & Results

For the purpose simulation study, the micro grid structure shown in figure 6. The figure is modeled using MATLAB/SIMULINK software. The effectiveness of control strategy was tested as follows.

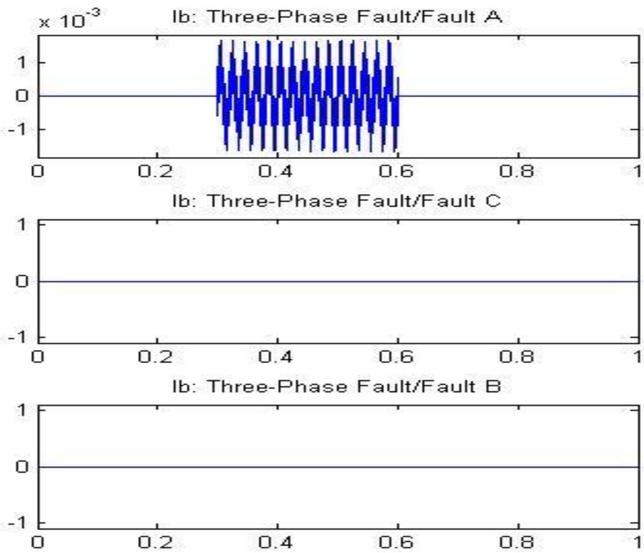
Case Study: Transient Stability Analysis at the time of starting Induction motor start.

The simulation conditions for case study and the corresponding results are discussed below.
Case 1: (i) The micro grid is in island mode
(ii)The Induction Motor load is removed at 2.00 sec

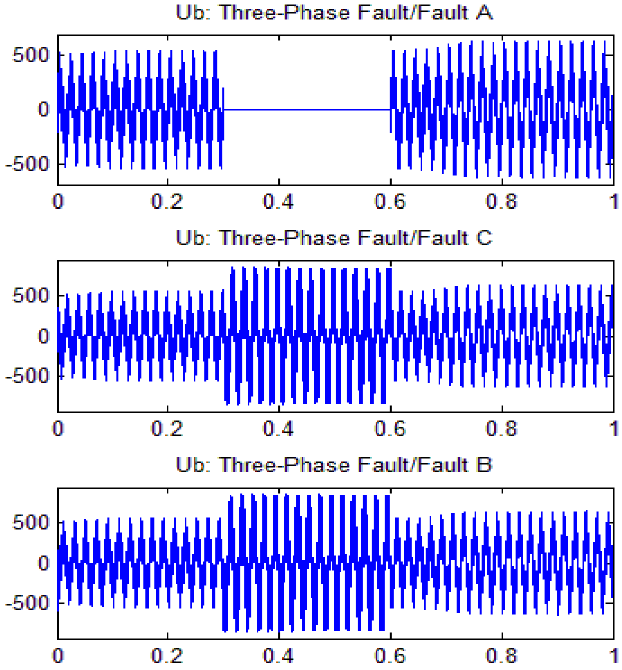
5.1.1 Fault Voltage and Current

The Micro grid is in autonomous mode.Intially it is connected to RL Load.By that time the voltage is 1 per unit.At 2 sec,the Induction Motor is started and so that there is a deviation for a period of 2 sec and then it settles down.The P-f and Q-V droop controller plays a vital role in reducing the oscillations due to the removal of the load.

Fault Current:



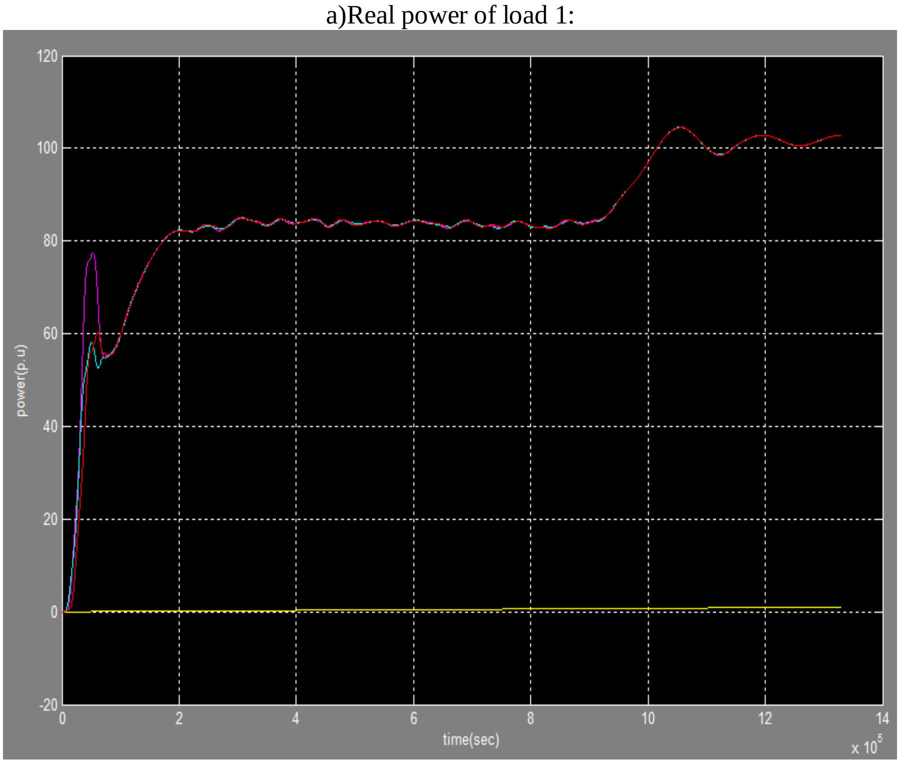
Fault Voltage:



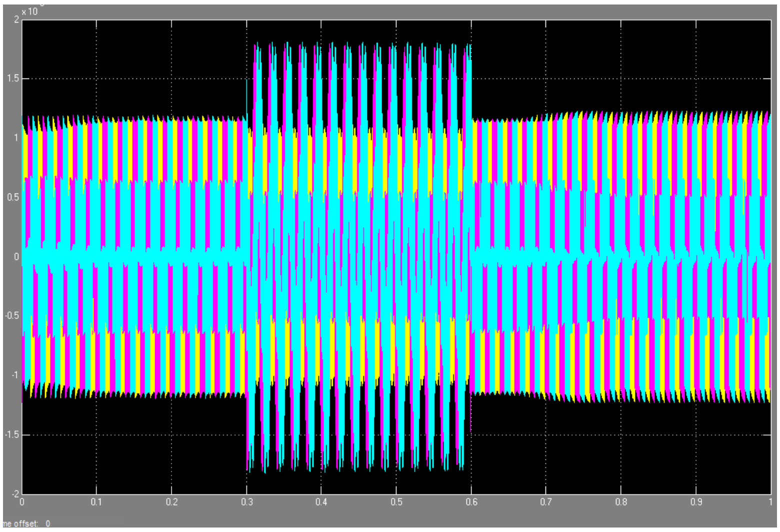
5.2 Real Power and voltage for load1 and 2:

The Real and Reactive power waveform during RL Load was 1per unit.At 2 sec Induction Motor load was removed and so there is a surge in power and comes around 1.6 per unit due to the effectiveness of controller.

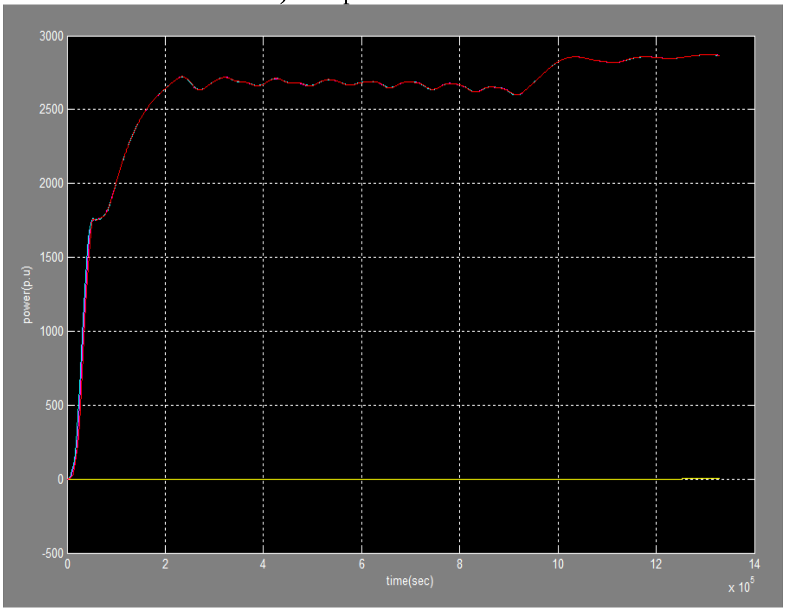
a)Real power of load 1:



b)Voltage for load 1 and 2:

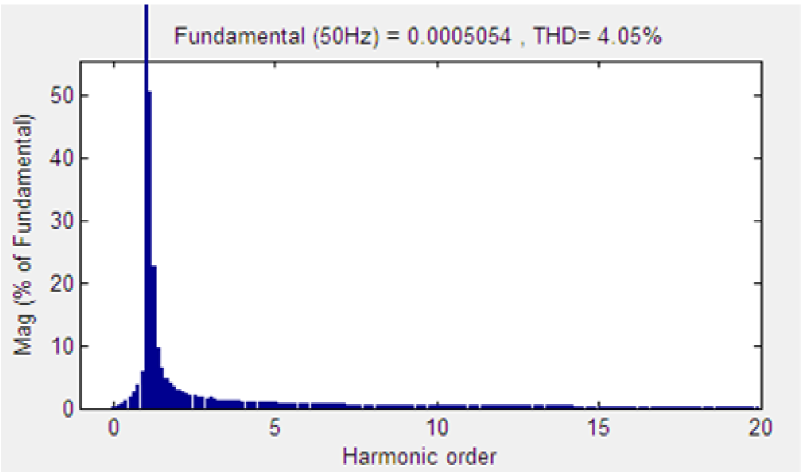


c)Real power for load2:



5.3Total Harmonic Distortion

The THD spectrum graph for the load current are shown below.It was found that THD comes around 4.05% after implementing P-f and Q-V Droop Controller.



6. CONCLUSIONS

The performance analysis of voltage –frequency droop controller in an autonomous micro grid was analysed in this paper. For the purpose of analysis two DGs are interconnected and supplying RL and Induction Motor load. In order to analyse the stability during the removal of load, P-f and q-V droop controller was introduced in this work. The simulations are carried out using MATLAB/Simulink software. It was found that the controller works effectively and the simulations results prove the same.

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