Damping Control Techniques for A Microgrid with Dynamic Load

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Abstract - A microgrid consists of generation of electricity, storage of energy , and loads which usually operates connected to a centralized grid called as macrogrid. The microgrid can function autonomously as well if the Point of Common Coupling is disconnected. Microgrids can be subjected to a various level of dynamic loads such as induction motor loads. The high nonlinear Induction Motor dynamics coupling the active power, reactive power, voltage, and supply frequency dynamics affects the Microgrid stability. It has been found that the electromechanical rotor oscillations of Induction motor in Microgrid systems results in speed and torque oscillations. Analysis of oscillation of damping in microgrid with dynamic load is done. Instabilities are monitored via simulation. Voltage, Current and Power controllers are incorporated to suppress the instabilities.

Keywords – Distributed Generation, Microgrids, Dynamic loads, Induction Motor

I. INTRODUCTION

The microgrid is a small version of the electric grid. An electric grid consists of interconnected wires, poles and power plants delivering electricity to our homes and business. A microgrid normally operates connected to a traditional centralized grid (macrogrid). A microgrid is an electrical system that includes multiple loads and distributed energy resources that can be operated in parallel with the broader utility grid or as an electrical island. The single Point of Coupling(PCC) with the macrogrid can be disconnected. The microgrid can then function autonomously. Generation and loads in a microgrid are usually interconnected at low voltage. From the point of view of the grid operator, a connected microgrid can be controlled as if it were one entity.

1.1 Definition of Microgrid

The Microgrid concept assumes a cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area.[1] This concept provides a new paradigm for defining the operation of Distributed Generation(DG). The micro sources for Microgrid are units with power electronic interfaces. These sources are placed at customers sites. They are low cost, low voltage and have a high reliability with few emissions. Power electronics provide the control and flexibility required by the Microgrid concept. A properly designed power electronics and controllers ensure that the Microgrid can meet the needs of its customers as well as the utilities. Implementing a Microgrid can be as simple as installing a small electricity generator to provide backup power at an electricity consumers site, or it can be a more complex system that is highly integrated with the electricity grid that consists of electricity generation, energy storage, and power management systems. They comprise a portfolio of technologies, both on supply-side and demand-side, that can be located at or near the location where the energy is used. Microgrid devices provide opportunities for greater local control of electricity delivery and consumption. They also enable a more efficient use of waste heat in combined heat and power (CHP) applications, which boosts efficiency and lowers emissions. The CHP systems provide electricity, hot water, heat for industrial processes, space heating and cooling, refrigeration, and humidity control to improve indoor air quality and comfort.

1.2 Reasons for Microgrid

Microgrid technologies are playing an increasingly important role in the nations energy portfolio. They can be used to meet baseload power, peaking power, backup power, remote power, power quality, and cooling and heating needs. The Microgrid resources support and strengthen the central-station model of electricity generation, transmission, and distribution. Although the central generating plant continues to provide most of the power to the grid, the distributed resources meet the peak demands of local distribution feeder lines or major customers. Computerized control systems, typically operating over telephone lines, make it possible to operate the DG as dispatchable resources that generate electricity as needed.

The conventional arrangement of modern large power system offers a number of advantages. Large generating units can be made efficient and operated with only a relatively small number of personnel. The interconnected high voltage transmission network allows the generator reserve requirement to be minimized , the most efficient generating plant to be despatched at any time, and bulk power to be transported large distances with limited electrical losses. The distribution network can be designed for unidirectional flow of power and sized to accommodate customer loads only. However, over the last few years a number of influences have combined to lead to the increased interest in Microgrid schemes.

Microgrid concept is gaining widespread acceptance to overcome the environmental and economical difficulties facing the energy sector. Distinctive autonomous operational capability of microgrids has brought in higher reliability measures in supplying power demands when the utility grid is not available. DG generally refers to small-scale(typically 1 kW 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. DGs include, but are not limited to synchronous generators, induction generators, reciprocating engines, microturbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaics, and wind turbines. Microgrid can be defined as a cluster of DG units and loads at distribution level that can either be in operation connected to utility grid or can work in islanded mode. A majority of DG units are interfaced to the network by voltage source converters (VSCs). One well- established approach for autonomous microgrid operation is droop control. However, the stability of autonomous microgrids is a critical issue.

Owing to several advantages such as simple structure, ruggedness, high reliability, low cost and minimum maintenance, the Induction Motors (IMs) have been widely used in industry. In conventional power system analysis, several studies are reported to analyze the impact on large IM loads on power system dynamics. In addition to the well known impact of IMs on voltage stability, it has been shown that large IMs might interact with synchronous generator rotor dynamics and excitation systems leading to modal resonances, limit cycles and voltage oscillations. Considering today's power system load contains high percentage of Induction motors, ignoring these loads in stability analysis will result in unrealistic large stability operating region. Hence it is essential to include these loads in stability analysis.

1.3 Layout of the report

Section 2 mainly consists of discussion about inverter based microgrid, loads and previous studies relating to inverter connected Microgrids. Section 3 deals with the controllers incorporated to control the damping. Section 4 deals with simulation results and analysis of the systems under study. Section 5 is the conclusion section which contains final inferences and future scope.

II. LITERATURE REVIEW

2.1 Impacts of Microgrids on the distribution system

(a) Network voltage changes and system regulation

Every distribution utility has an obligation to supply its customers electricity at a voltage within a specified limit. This requirement often determines the design and expense of the distribution circuit so that over the years techniques have been developed to make the maximum use of distribution circuits to supply customers within the required voltage. Some distribution utilities use more sophisticated control of the on load tap changers of the distribution transformer by regulators on the feeder and including the use of the current signal compounded with the voltage measurement at the switched capacitor on feeders .Feeding power from a DG unit can cause negative impacts on the network voltage in case a DG unit is placed just downstream to a load tap-changer transformer . In this case, the regulators will not correctly measure the feeder demands. Rather, they will see lower values since the

DG unit reduces the observed load due to the onsite power generation. This will lead to setting the voltage at lower values than that required to maintain adequate levels at the tail ends of the feeder. However, the most favourable locations of DG units near the end user terminals can provide the required voltage support at the feeder nodes.[2]

(b) *Increase of network fault levels*

Most of the Microgrid plants use rotating machines and these will contribute to the network fault levels. Both induction and synchronous generators will increase the fault level of the distribution system although their behaviour under sustained fault conditions differs. The fault level contribution can be reduced by introducing impedance between the generator and the network by a transformer or reactor but at the expense of increased losses and wider voltage variations at the generator. In urban areas where the existing fault level approaches the rating of the switchgear, the increase in fault level can be a serious impediment to the development of DG.

(c) *Power Quality*

Two aspects of power quality are usually considered to be important: (i) transient voltage variations and (ii) harmonic distortion of the network voltage.[2] The Microgrid can cause transient voltage variations on the network if relatively large current changes during connection and disconnection of the generator are allowed. Therefore, it is necessary to limit voltage variations to restrict the light variation. Generally, load fluctuation can cause voltage variation as well as source fluctuation . Microgrid units have the potential to cause unwanted transient voltage variations at the local power grid. Step changes in the outputs of the MG units with frequent fluctuations and the interaction between the Microgrid and voltage controlling devices in the feeder can result in significant voltage variations . The standalone operation of Microgrid units gives more potential for voltage variations due to load disturbances, which cause sudden current changes to the DG inverter. If the output impedance of the inverter is high enough, the changes in the current will cause significant changes in the voltage drop, and thus, the AC output voltage will fluctuate. Conversely, weak ties in the grid integration mode give a chance for transient voltage variations to take place but lower degrees than in the standalone mode. Incorrectly designed or specified MG plants, with power electronic interfaces to the network, may inject harmonic currents, which can lead to an unacceptable network voltage distortion. The type and severity of these harmonics depend on the power converter technology, the interface configuration, and mode of operation. Fortunately, most new inverters are based on Insulated Gate Bipolar Transistor (IGBT), which uses Pulse Width Modulation (PWM) to generate quasi-sine wave. Recent advances in semiconductor technology enable the use of higher frequencies for carrier wave, which result in quite pure waveforms.[2]

2.2 Inverter based microgrids

Recent innovations in small-scale distributed power generation systems combined with technological advancements in power electronic systems led to concepts of future network technologies such as microgrids. These small autonomous regions of power systems can offer increased reliability and efficiency and can help integrate renewable energy and other forms of DG. Many forms of distributed generation such as fuel- cells, photo-voltaic and micro-turbines are interfaced to the network through power electronic converters .These interface devices make the sources more flexible in their operation and control compared to the conventional electrical machines. However, due to their negligible physical inertia they also make the system potentially susceptible to oscillation resulting from network disturbances[1].A typical structure of an inverter based microgrid is shown in Fig. 1.

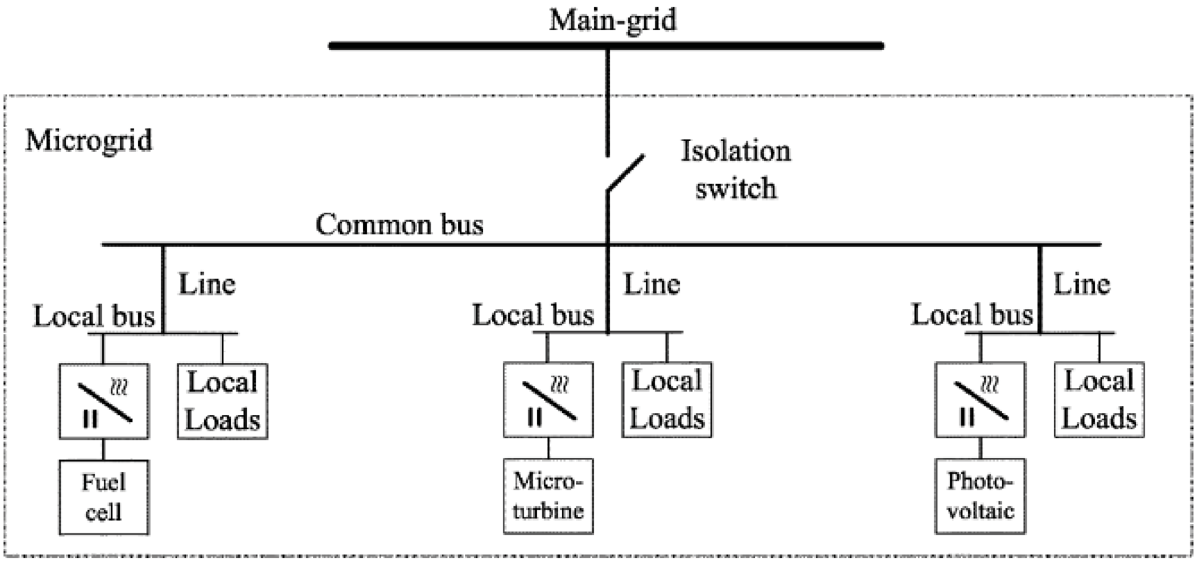

Figure 1. Watermark embedding algorithm Block Diagram

A microgrid can be operated either in grid connected mode or in stand-alone mode. In grid connected mode, most of the system-level dynamics are dictated by the main grid due to the relatively small size of micro sources. In stand-alone mode, the system dynamics are dictated by micro sources themselves, their power regulation control and, to an unusual degree, by the network itself. One of the important concerns in the reliable operation of a microgrid is small-signal stability. In conventional power systems, stability analysis is well established and for the different frequency ranges (or time horizons) of possible concern there are models which include the appropriate features. The features have been established on the basis of decades of experience so that there are standard models of synchronous machines, governors and excitation systems of varying orders that are known to capture the important modes for particular classes of problem. This does not yet exist for microgrids and may be difficult to achieve because of the range of power technologies that might be deployed. However, we can begin by developing full-order models of inverters and the inverter equivalents of governors and excitors. Examination of these models applied to various systems will develop that body of experience that allows reduced order models to be selected for some problems.

Previous dynamic analysis of standalone systems has been carried out by assuming an ideal inverter[3]. This means that the closed-loop inner controllers that track voltage and current references are assumed to track perfectly, accurately and quickly. They therefore do not have any effect on the small signal stability. This assumption is based on the fact that the closed-loop bandwidth of the inverter is well above the bandwidth of power sharing controllers that set the voltage and current references. This is a relatively safe assumption for low power inverters with a high switching frequency but cause important dynamics to be omitted for large inverters where low switching frequency limits the control bandwidth of the innermost control loop.

A systematic approach to modeling an inverter-based microgrid were also presented[8]. Each DG inverter will have an outer power loop based on droop control to share the fundamental real and reactive powers with other DGs. Inverter internal controls will include voltage and current controllers which are designed to reject high frequency disturbances and damp the output LC filter to avoid any resonance with the external network. The small-signal state-space model of an individual inverter is constructed by including the controllers, output filter and coupling inductor on a synchronous reference frame whose rotation frequency is set by the power controller of that inverter. Once the small-signal model has been formed, eigen values (or modes) are identified that indicate the frequency and damping of the oscillatory terms of the system transient response.

2.3. Micrigrid Model in Autonomous Operation

A typical characteristic of a microgrid is that it can be operated either in grid connected or in islanded (autonomous) mode. [4]Normally, when a microgrid is operated in grid connected mode the micro sources act as constant power sources which means that they are controlled to inject the demanded power in to the network. In autonomous mode the micro sources are controlled to supply all the power needed by the local loads while maintaining the voltage and frequency within the allowed limits. Autonomous operation of a microgrid might be initiated for either of the following two reasons.[5] First, because of preplanned (intentional) islanding due to maintenance or economical reasons. Depending on the market situation the owner of a microgrid can chose between autonomous and grid connected modes. Second,because of unplanned (unintentional) islanding due to the failure of the main grid caused by a network fault.

Autonomous operation is realized by opening the isolating switch (shown in Fig. 1) which disconnects the microgrid from the main grid.[6] Once the microgrid is isolated the micro sources feeding the system are responsible for maintaining the voltage and frequency while sharing the power. During autonomous operation it is important to avoid over-loading of inverters and to ensure that the changes in load are taken by inverters in a well controlled manner. Control techniques based on a communication link, such as the master-slave approach, can be adapted in systems where micro sources are connected to a common bus or located in close proximity. However, a communication link makes the system more expensive and less reliable. Also, in a typical microgrid micro sources can be located far away from each other making a communication link less attractive. Control techniques based on local measurements which do not require expensive communication facilities have been proposed in earlier studies. In this paper, the later method is adopted.

Network dynamics are generally neglected in small-signal modeling of conventional power systems. The reason behind this is that the time constants of rotating machines and their controls are much larger than those of the network. In the case of microgrids, the micro sources are connected through inverters whose response times are very small and network dynamics would influence the system stability. Previous work on small- signal modeling of parallel connected inverters was carried out without considering the network dynamics. In an earlier paper, the state equations of the network and the loads are represented on the reference frame of one of the individual inverters. This reference frame is considered as the common reference frame. All the other inverters are translated to this common reference frame using the transformation technique. It is to be noted that in the equations of the three phase voltages and currents are represented as vectors in d-q frame, where as the other variables such as real and reactive powers and angles are scalars. .Autonomous Microgrid feeding static load and induction motor is shown in Fig 2

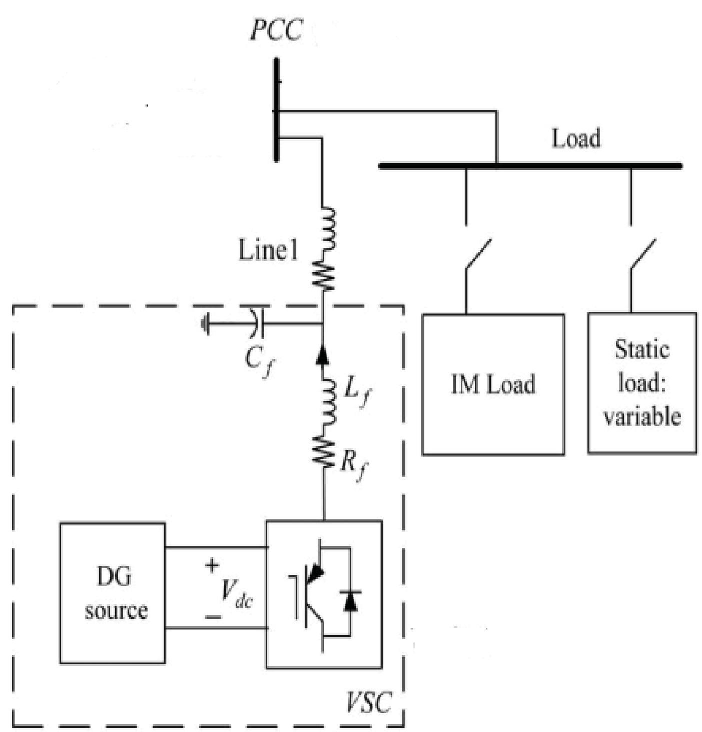

Figure 2. Typical structure of an Autonomous microgrid feeding loads

2.4. Study on Induction Motor

The Induction motor is a three phase AC motor and is the most widely used machine. Its characteristic features are

1. Simple and rugged construction
2. Low cost and minimum maintenance
3. High reliability and sufficiently high efficiency
4. Needs no extra starting motor and need not be synchronized

(a) Voltage oscillations in Induction Motor Loads

Voltage Oscillatory Instability caused by IM loads were discussed in earlier papers. Generators supplying predominantly motor loads can suffer from voltage regulator induced oscillatory instability. This phenomenon, which is more pronounced with high efficiency motor loads, is caused by the dynamic response of motor reactive current to changes in supply voltage, a characteristic that is revealed when using motor models which include rotor transients. Unlike oscillatory or dynamic stability with participation of generator rotor angle swings, this type of oscillatory stability is due entirely to voltage effects as can be shown by simulations where generator inertia is set to infinity. The oscillatory instability is worse with increased motor loading, increased impedance between generator and motor terminals and decreased voltage levels. A solution to this problem is to include a lead/lag stage in the AVR to compensate for the delayed response of generator terminal voltage due to motor load dynamics.

Initial studies quickly concluded that the single most important sensitivity was the percentage of motors modeled at the load bus. A level of 20% to 30% of motor load best simulated the phenomena described. Varying the motor inertia and impedances had varying impacts but, relatively, not as great as the motor percentages. The system damping of oscillations decreases when motor inertia is increased in the model if all other design parameters remain the same. The static model load part is 80% of the total load and comprises existing static load data from the members. The dynamic part is a default induction motor model for approximately 20% of the total load. The studies indicated that much higher levels of motor load modeling at HV buses could likely produce too great a system undamping. Conversely, too small a level could likely yield unrealistically well-damped simulation responses for highly stressed systems.The recommended range for motor loads is between 20% and 30% when the motor load modelling is applied at the HV buses.

(b) *Investigation of Induction Machine contribution to Power System Oscillations.*

An important factor contributing to this growing interest in many countries is the increasing penetration of increasing penetration of wind farms, many of which are equipped with conventional induction machines. The interaction of induction machine dynamics and synchronous generator exciter or rotor angle dynamics may lead to nonlinear phenomena, such as voltage oscillations and the appearance of limit cycles as well as modal resonance. Previous studies investigated power system small-signal stability, considering induction machines as dynamic elements[3].These coefficients are expanded into matrices in the case of multi machine systems, where the off-diagonal elements represent the interaction between machines. Modal interaction between induction machines, as well as between induction and synchronous machines were investigated. It was shown that a large proportion of induction machines in a realistic power system significantly affects the inter area electromechanical mode and consequently, the power system stabilizer design.

III. CONTROLLERS OF VOLTAGE SOURCE INVERTER

VSI is commonly used to interface DGs to the network. The power processing section consists of a three-leg inverter, an output LC filter and coupling inductor. Assuming an ideal source from the DG side, the dc bus dynamics can be neglected. With the realization of high switching frequencies (410 kHz), the switching process of the inverter may also be neglected. The control system includes voltage and current controllers, which are designed to reject high frequency disturbances and provide sufficient damping for the output LC filter. A state space model is presented for the subsystems. The model is constructed in a rotational reference frame set by the external power controller of the particular individual inverter. The Power circuit and control structure of a microgrid-connected VSI for improving damping is as shown in Fig. 3

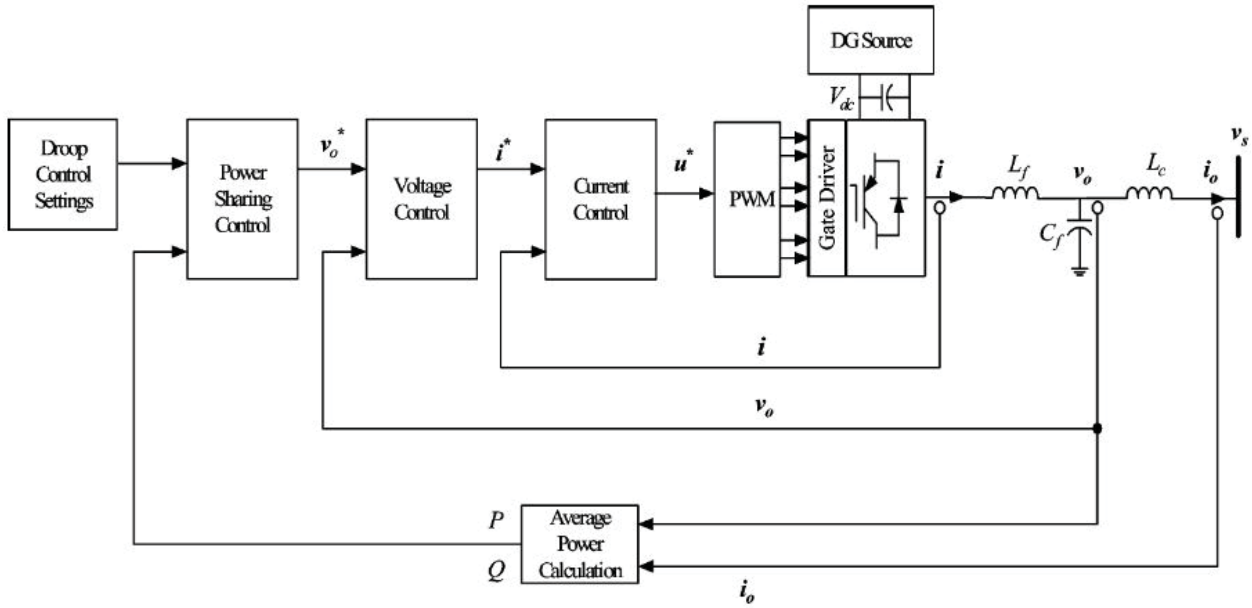

Fig 3. Control structure of microgrid connected VSI

1. Power Controller:-The basic idea of Power controller is to mimic the governor of a synchronous generator.[7] In a conventional power system, synchronous generators will share any increase in the load by decreasing the frequency according to their governor droop characteristic. This principle is implemented in inverters by decreasing the reference frequency when there is an increase in the load.[8] Similarly, reactive power is shared by introducing a droop characteristic in the voltage magnitude.Fig 4 represents power controller.

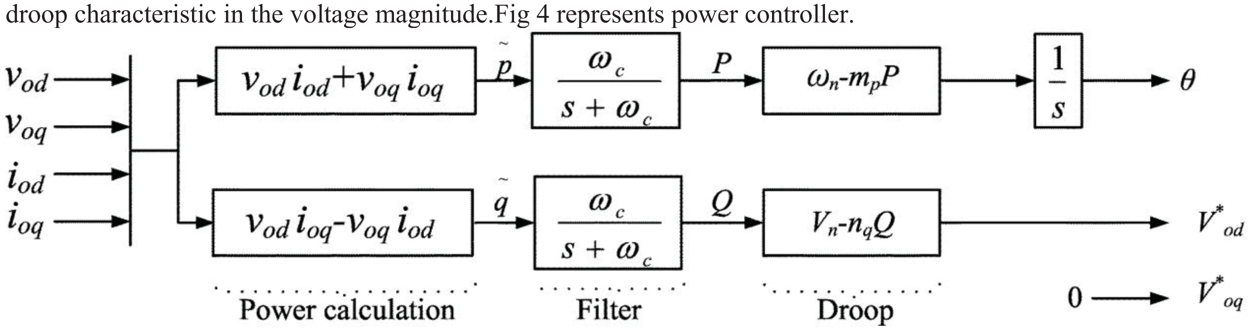

Fig 4. Power Circuit

As shown in Fig. 4, instantaneous active and reactive power components p and q are calculated from the measured output voltage and current as

$$p = v_{od}i_{od} + v_{oq}i_{oq} \qquad (1)$$

$$q = v_{od}i_{oq} - v_{oq}i_{od} \qquad (2)$$

The instantaneous power components are passed through low-pass filters,, to obtain the real and reactive powers P and Q corresponding to fundamental component. ω_c represents the cut-off frequency of low-pass filters.

2. Voltage controller:-:- Output voltage control is achieved with a standard PI controller as in Fig 5

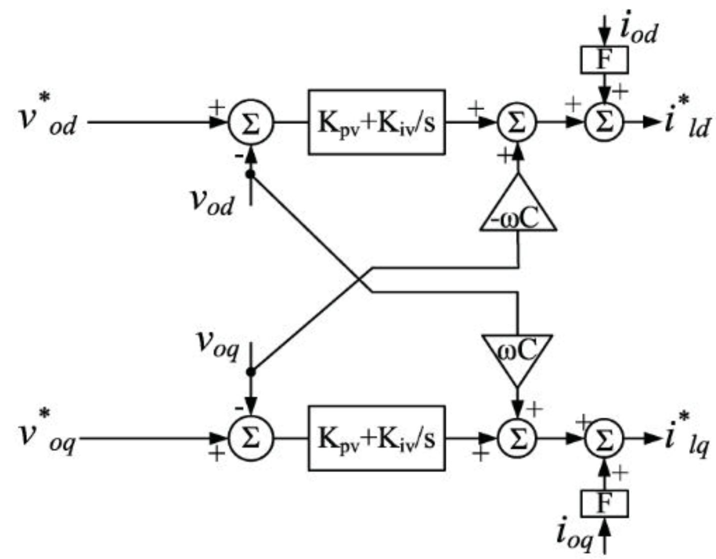

Fig 5 Voltage Controller

3 Current Controller:- voltage control is achieved with a standard PI controller as in Fig 6

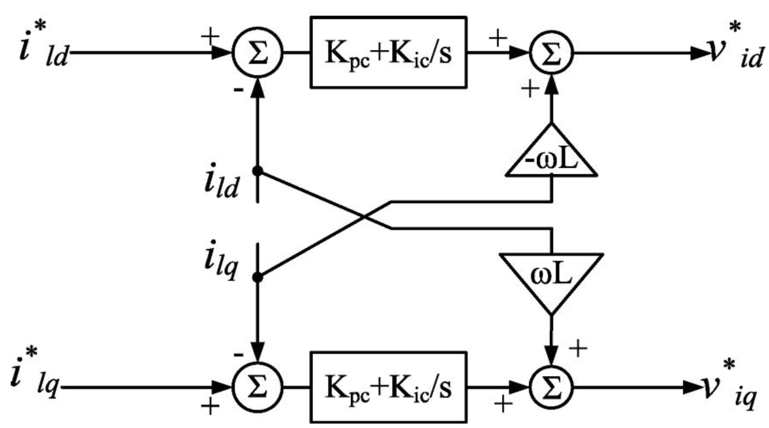

Fig 6 Current Controller

IV. Experiment and Result

In order to evaluate the performance of a IM load in a DG connected microgrid system, Fig. 7 is implemented by time-domain simulation under the MATLAB/Simulink environment .The parameters of IM are shown in table 1.

Table 1: Parameters of Squirrel Cage IM

Parameter	**Value(Unit)**
Nominal Power	**3 (HP)**
Voltage(L-L)	**220 V**
Frequency	**60 Hz**
Stator Resistance	**1.15 Ω**
Stator Inductance	**0.005974 H**
Rotor Resistance	**1.083 Ω**
Rotor Inductance	**0.005974 H**
Mutual Inductance	**0.7037**
Inertia	**0.02**
Friction Factor	**0.005**
Pole Pairs	**2**

Fig. 7 is simulated with initially the motor at noload and then load torque is applied at 1s.

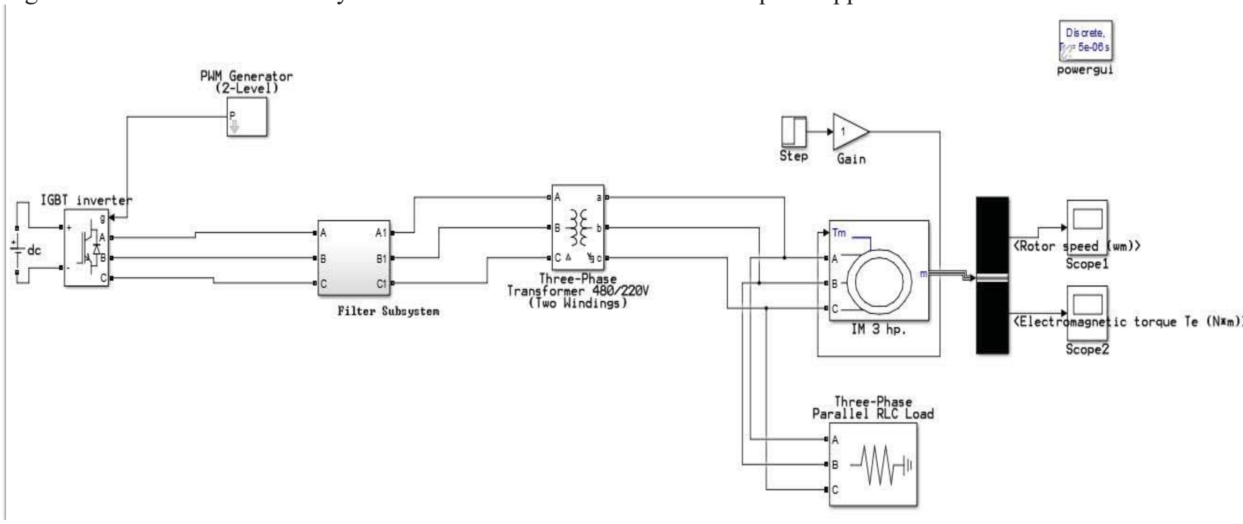

Fig 7 Open loop system

Fig. 8 shows the speed response (in rad/s) of DG connected microgrid in the case of IM load.

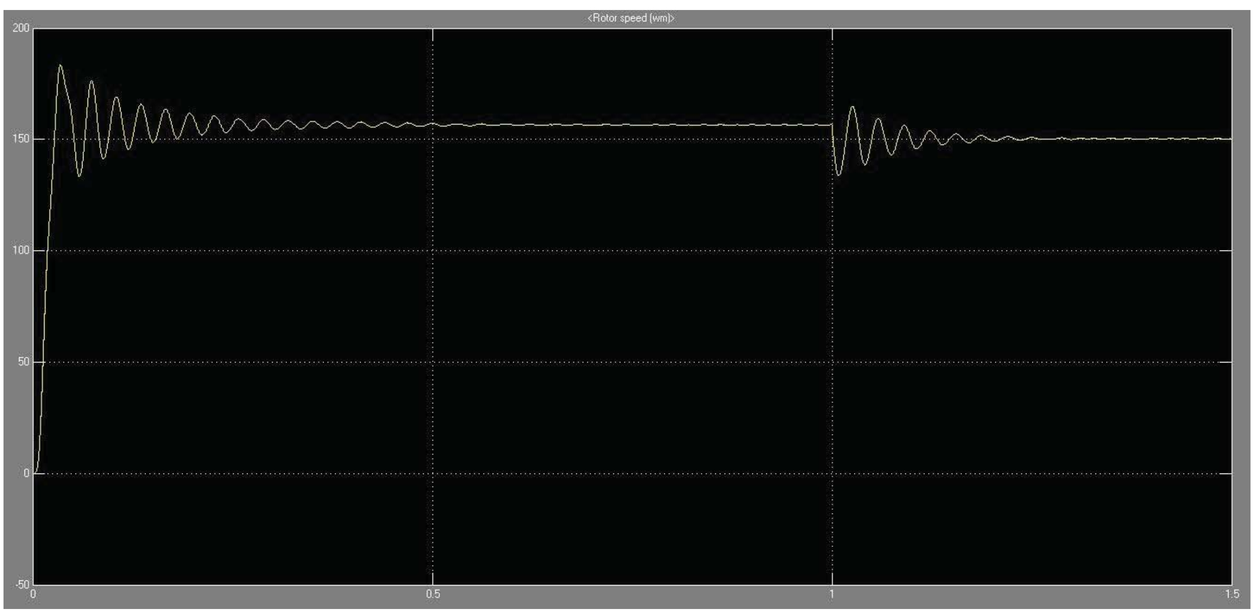

Fig 8 Speed Response(rad/s)

Fig. 9 shows the torque response (in Nm) of DG connected microgrid in the case of IM load.

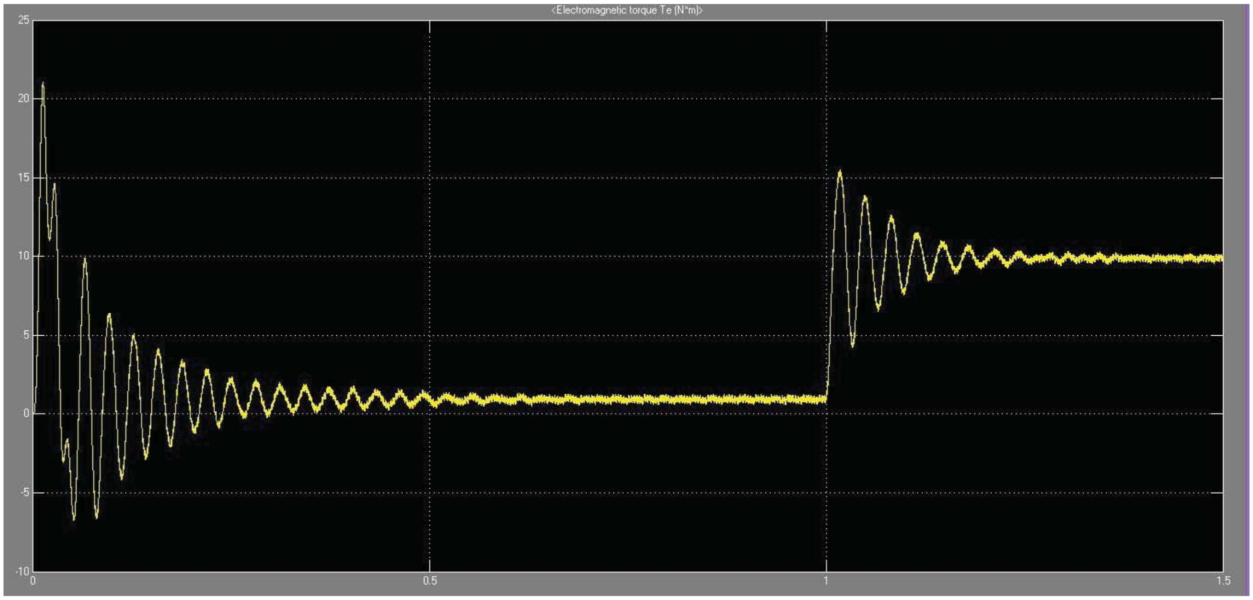

Fig 9 Torque Response(Nm)

Fig. 10 is simulated with initially the motor at noload and then load torque is applied at 1s. The subsystems used in Fig. 10 are as shown in Fig. 11, Fig. 12, Fig. 13 and Fig. 14

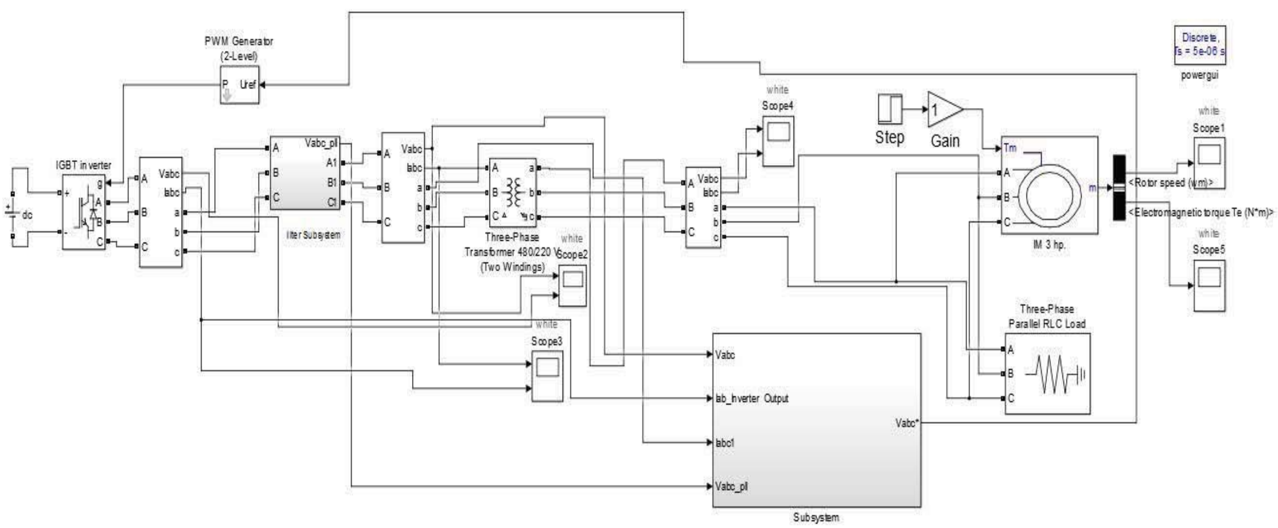

Fig 10 Closed loop system

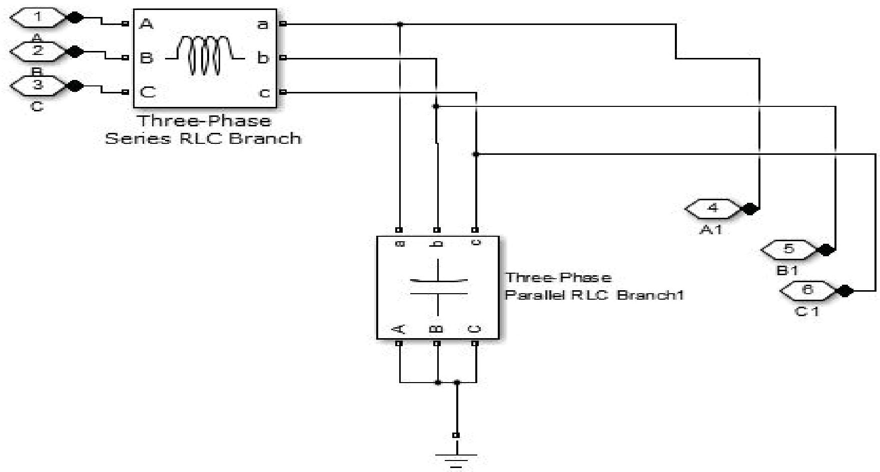

Fig 11 LC filter

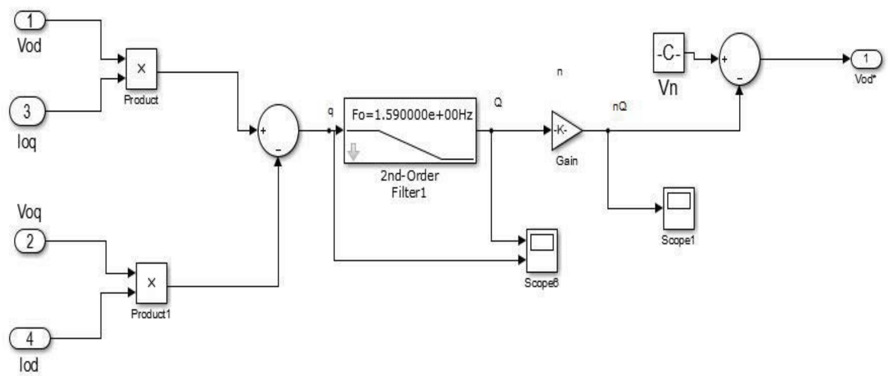

Fig 12 Power Circuit

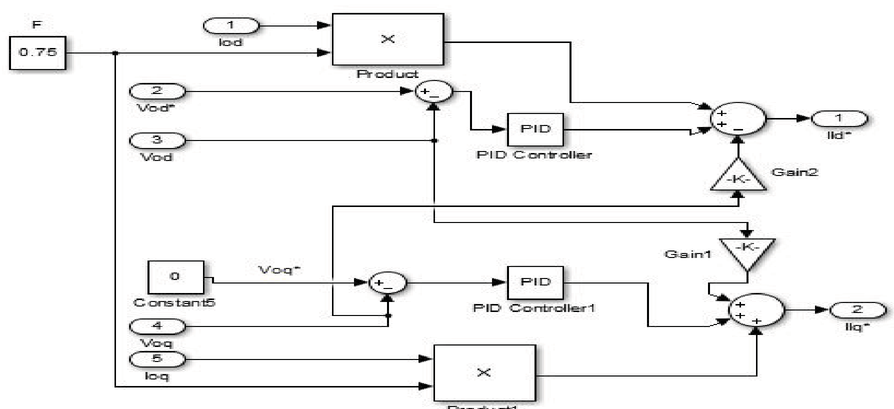

Fig 13 Voltage Controller

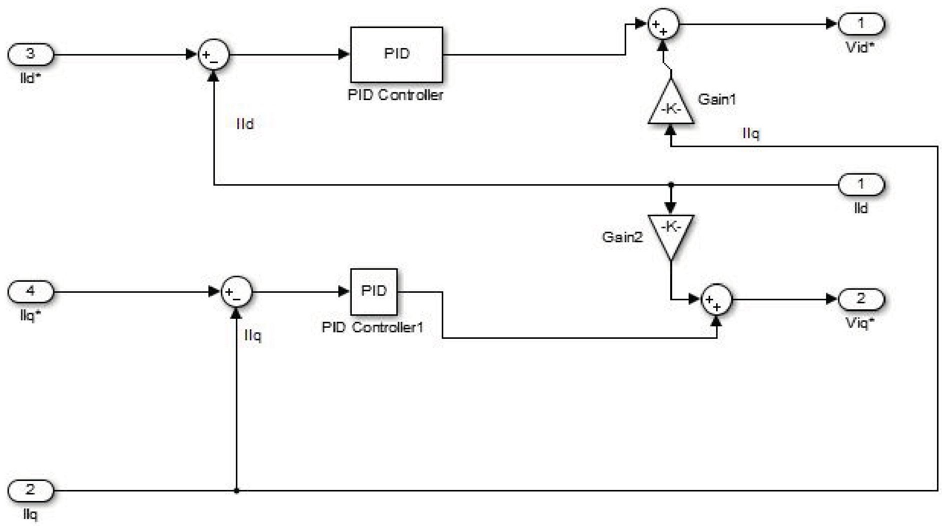

Fig 14 Current Controller

The other system parameters used are as shown in table 2.

Table -2 System Parameters

PARAMETER	VALUE (UNIT)
DG RATING	**10 MVA**
SWITCHING FREQUENCY	**2 KHz**
Kpv	**0.05**
Kiv	**390**
Kpc	**10.5**
Kic	**16e3**
N	**1.3e-3**

Fig. 15 shows the speed response(Speed in rad/s) of DG connected microgrid in the case of IM load

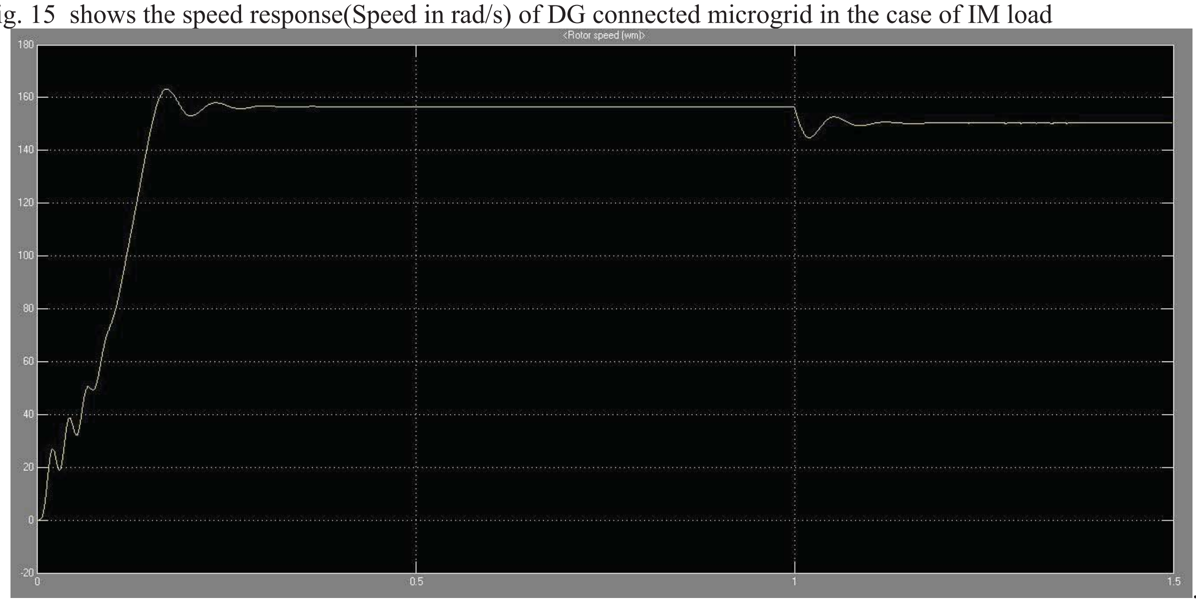

Fig 15 Speed response(rad/s)

Fig. 16 shows the Torque response(Torque in Nm) of DG connected microgrid in the case of IM load.

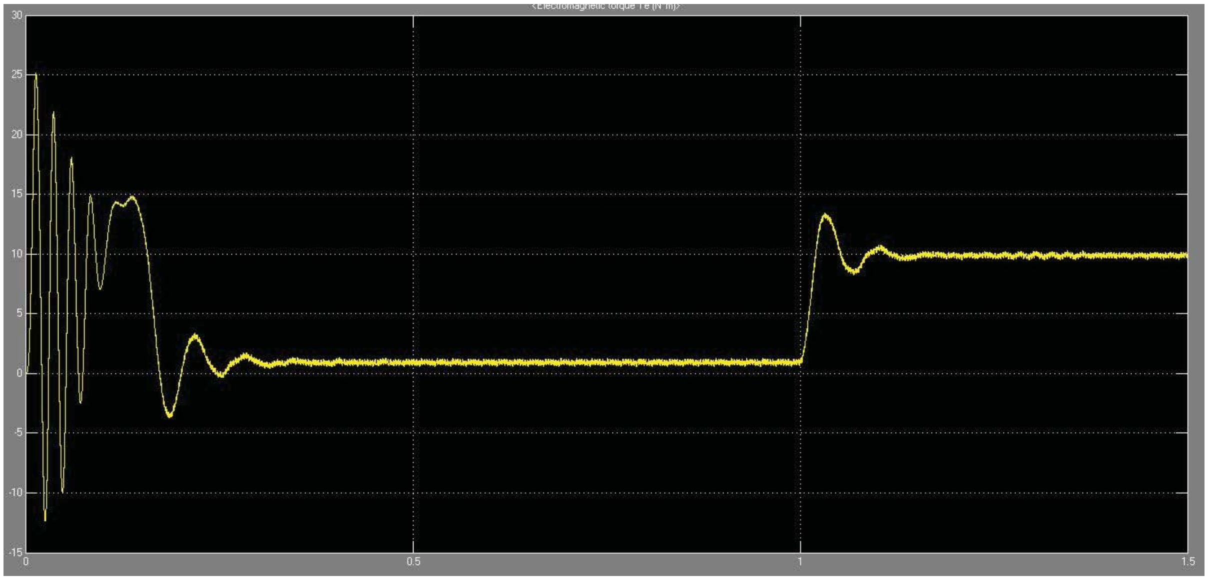

Fig 16 Torque Response(Nm)

V.CONCLUSION

The problems associated with IM connected microgrids were studied and a model for a microgrid system that includes both DG and IMs was presented.The speed and torque oscillations were observed. Power,voltage and Current controllers were incorporated to improve the damping of oscillations. Simulation results of circuit employing these controllers revealed that the damping was improved since it reached steady state early(less settling time).

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