Voltage and Frequency Stability Analysis of AC Microgrid

Ilhami Colak
Istanbul Gelisim University, Istanbul, Turkey
icolak@gelisim.edu.tr

Ramazan Bayindir
Gazi University, Ankara-Turkey
bayindir@gazi.edu.tr

Mohammed Al-Nussari
Misan University, Misan-Iraq
muhammed.kh@uomisan.edu.iq

Eklas Hossain
University of Wisconsin Milwaukee, USA
shossain@uwm.edu

Abstract— **Microgrid is a single controllable unit constituting distributed generation (DG) and load in the power system. The micro source includes photovoltaic (PV) cells, wind turbine, micro turbine, fuel cell, electric accumulator and flywheel etc. Usually, the micro source operates in parallel with the normal distributed network that uses the power electronic devices. There are two typical operation modes of micro grid as the grid-connected mode and islanding mode. Thus, the running control problem is one key issue of the microgrid, which needs to be resolved in the actual operation. For exact synchronism, to protect the system and to reduce the load in case of imbalance condition, a control system is necessary to bring the system instability while providing efficient and robust electricity to the micro grid. This paper mainly analyses the micro sources with different types of loads and dispersion characteristics in different operating mode using droop control method.**

Keywords—Microgrid; Distributed Generation; Droop Control; Voltage & Frequency Stability

I. INTRODUCTION

Distribution generation (DG) is an approach that consists of small scale technologies to produce electricity. In recent years DG technologies have developed drastically and are very much focused due to its lower cost of electricity and high power reliability [1].Distribution generation (DG) technologies have not only positive impact but also negative impact on power system stability [2]. As electrical losses are very significant for power systems, the massive installation of DG systems help to reduce the electrical losses and to minimize the effect of CO_2emissions in the atmosphere.

An important consequence would be a significant reduction in the investment on electrical facilities. Moreover, the efficiency of the system can be increased by using the waste heat properly. Nevertheless, with the drastic increase of using DG systems in diverse electrical networks, problem may arise frequently. While using distribution generation systems, voltage regulation and frequency are likely to be affected because of the rapid changes in the levels of the generation and intermitting natural of source. If correct addressing coordination is not maintained properly it can have negative impact on the system's safety and reliability [3, 4].Organizing and coordinating these resources in the electrical networks can avoid these problems. Furthermore, a DG system can be utilized as supplementary service provider for voltage control, load regulation as well as spinning reserve [5].

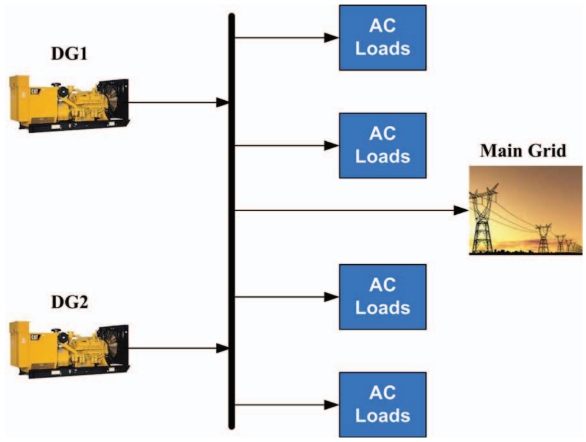

Fig. 1: Schematic diagram of stability analysis

To introduce the application of DG systems into the electrical network, a microgrid system is the most appropriate way, which is defined as a group of interconnected loads and distributed micro energy resources. A DG acts as a single controllable system capable of operating in parallel with, or independently from, the main power grid[6].In the following microgrid schematic diagram two DGs are connected with 60kW load with the Bus bar and AC loads are connected with real load of 40kW and reactive load of 20kW with bus bar. Apart from this the bus bar is also connected with the main grid. There exist various microgrid management patterns that can nearly be classified into three groups [7]. The first one mainly deals with the physical prime mover management, which comprises of a set of microgrids in where a huge unit absorbs the entire real and reactive power imbalances to adjust the stability of the voltage and the frequency. This concept is very analogous to typical centralized generation systems of microgrid. The main drawback of this particular approach while fault occurs is the loss and the cost of the system. The control system in the second group is basically rest on a virtual prime mover. In this regard a control unit mainly determines the state variables of microgrid, as well as conveys orders to microsources using a swift telecommunication system. Hence, the control scheme mitigates the excessive expense of the central physical prime mover, but the bandwidth of the communication system confines the extension of the microgrid and moreover to prevent the communication failure a back-up system is necessary. The third one is mainly the rest on a distributed control system. In this occasion, every unit tends to respond to variations in the local state variables. As this type of control does not need any communication system as well as large central unit, several researchers consider this type of control as the most suitable ones [8, 12]. Recently, some significant projects about microgrids have been introduced around the world [9,10] using the diverse microgrid management theories mentioned above.

Droop Characteristic Control is used to control the local state variables usually applied in microgrid converters. This kind of control was first launched to the inverters, which is connected in parallel with separate system [1].In recent time, droop control method has been broadened to microgrid distributed control system [13]. A comprehensive study of the characteristics of droop control based on generators is presented below. Nonetheless, some researchers incorporated a distributed control that relates to the communication between the microsources. Primary control of microgrid is distributed for those cases, but secondary control loops are mainly focused with telecommunication system. These kinds of control loop are responsible for the improvement of the power-quality and economic efficiency. The primary controller works as a back-up system when any type of telecommunication fault occurs [13].

In this paper a control scheme for microgrids based on droop characteristic control has been proposed. According to the proposed control scheme, an inner current control loop in grid connected mode is used, which changes the inserted real and reactive powers depending on the voltage magnitude and frequency of the utility grid, hence provides a grid support capability. In this paper various control method, details of droop control method and the analysis of stability in terms of the voltage and the frequency have been presented for both the grid-connected and the islanded modes of operations. Moreover, the analysis of real and reactive powers will be illustrated.

II. DISTRIBUTED GENERATIONMODELING

There are two different types of generation technologies applicable for microgrid such as renewable distribution generation (solar thermal, photovoltaic (PV), wind, fuel cell, CHP, hydro, biomass, biogas, etc.), and non-renewable distribution generation (diesel engine, stream turbine, gas engine, induction and synchronous generators, etc.).Diesel gas generator may be defined as wind turbine with the Diesel as fuel. Electrical energy generated from ac synchronous generator. The schematic diagram of designed microgrid has been given in Fig.1.Prominent criteria for natural diesel generator is that they have fuel sustainability, which is necessary to produce electrical energy with the constant voltage and the constant frequency. The voltage and frequency experience a transient before settling at the steady state values whenever a load is added to or removed from the microgrid. A generator exciter and an engine governor can control the magnitude as well as the duration of this transient. Diesel generator must have the capability to maintain the voltage as well as frequency stability when there is a sudden and rapid change in the load. It is also applicable during rapid change in the renewable energy generations. In Fig.2, a diesel generator connected to a grid or microgrid is depicted.

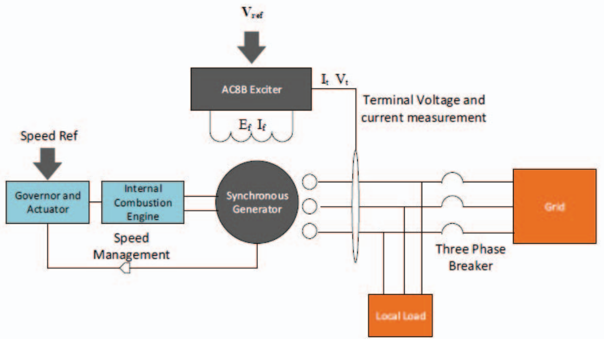

Fig.2: Block diagram of a diesel generator connected to microgrid [32].

The excitation system of the machine must be modeled with adequate details in order to know the proper characteristics of a synchronous machine for the power system stability analysis. This individual model can represent the definite excitation equipment performance for enormous, severe disturbances as well as for small perturbations.

There are various diesel engine models which can be found in various literature and most of them have three main elements in common: a first order model represented by a fuel injection system, the internal combustion delay represented by a delay time, and the inertia of the internal rotating parts of the engine and flywheel. The coupling shaft model includes the effects of the inertia. The model equation is defined as:

$$\frac{d\tau_m}{dt} = \frac{1}{t_e}\tau_m + \frac{k_e}{t_e}u_\omega(t - t_d)$$

in where, $u_\omega$the control signal of the speed governor and τ_m is the mechanical torque developed bythe engine.The parameters are $t_e$which represents the time constant of the fuel injection system, $k_e$represents the gain of the engine and t_d is the delay that symbolizes the elapsed time until torque is developed at the engine shaft. The generator set contains coupling shaft, which is modeled as rotational two masses coupled by a flexible shaft. The equations of the model are given as:

$$J_{en}\frac{d\omega_{en}}{dt} = -k_{fens}\omega_{en} + k_{fs}\omega_{ge} - \tau_s + \tau_m$$

$$J_{ge}\frac{d\omega_{ge}}{dt} = k_{fs}\omega_{en} - k_{fges}\omega_{ge} + \tau_s - \tau_e$$

$$\frac{d\tau_s}{dt} = k_{ss}\omega_{en} - k_{ss}\omega_{ge}$$

In where the state variables are ω_{en} is the rotational speed of the prime mover,$\omega_{ge}$is the rotational speed of the electrical generator and τ_s the torque developed through the shaft. There are two inputs; one is $\tau_m$the mechanical torque supplied by the engine, and another input is $\tau_m$the electromagnetic torque developed due to electrical load.

III. Power Sharing Method in a Microgrid

Rapid development of digital signal processors have made it easy to increase the use of this control techniques for the parallel operation of inverters. These controltechniques can be divided into two main sections with regard to the use of control wire interconnections. The first method is mainly based on active load sharing, e.g., centralized, master–slave (MS) and average power sharing. However,these control techniques attainexcellent output-voltage regulation as well as equal current sharing and it is necessary for them to use critical intercommunication lines among modules that could minimize the system expandability and reliability [14].

The second one is mainly based on the droop method [15–16]. This methodmainly comprises of tuning the frequency and voltage amplitude for stabilty whlile in terms of the real and reactive power inserted by the inverter. The droop method is very much consistent, flexible and reliable than the communication based methods, since it utilizes the local measurements.

The droop method is based on a renowned concept in the power systems that based on rotating generators, frequency and active power, which are closely related[17-19]. This concept is widely used in the power sharing control of parallel connection of UPS and DG systems. While using electrically coupled DG systems with parallel structure, the real and reactive power components supplied to the ac bus are determined, and the resultant signals are applied to adjust and tune the frequency and voltage amplitude of thesystem

Voltage and Frequency Droop Control Method

The common droop characteristics equations can be depicted as follows.

$$\mathrm{f} = \mathrm{f}^* - \mathrm{m}(\mathrm{P} - \mathrm{P}^*) \qquad (1)$$

$$\mathrm{U} = \mathrm{U}^* - \mathrm{n}(\mathrm{Q} - \mathrm{Q}^*) \qquad (2)$$

Where U*and f*are respectively the voltage magnitude and frequency at no load. The m and n parameters are the droop frequency and amplitude coefficients, and P* and Q* are the reference signal of the active power. The strategy of droop control is that each DG shares the power demand according to its own droop characteristic functions [20]. The droop characteristic is shown in Fig.3.

Fig. 3 shows that DGs allocate power according to the new stable working point at ω and V and the DG with steeper slope will share less power. Figs. 4 and 5 represent the schematic of droop control and details of 'Voltage Formation' block. The flow of real power is linearly dependent on the phase angle difference, and the reactive power flow is linearly dependent on the voltage magnitude difference. As illustrated in Fig. 4, the measured P and Q, reference P* and Q*, nominal f* and V* are considered as the input to calculate the reference f_{ref} and v_{ref} in 'droop control' block. u_d_ref and u_q_ref are reference voltage at d and q axis respectively after 'voltage formation' block.

In Fig.5, f* and V* are grid rated frequency and voltage magnitude, respectively. f_{ref}, and V_{ref} are reference frequency and voltage magnitude, and they are obtained by droop control characteristic. Three-phase u_{ref} is obtained by voltage formation device and then converted into u_{d_ref} and u_{q_ref} by Park's transformation [21].

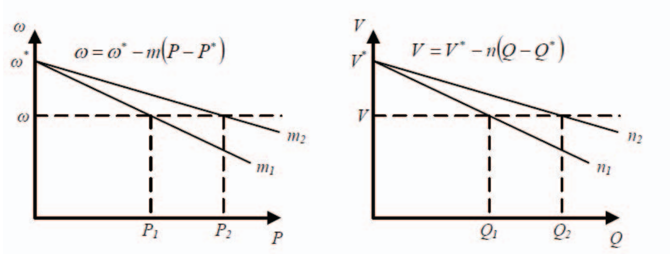

Fig.3: The droop characteristic

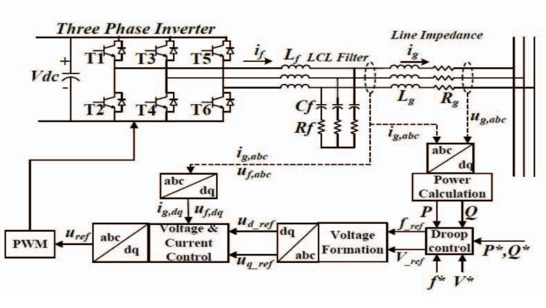

Fig.4: Schematic of the droop control [33].

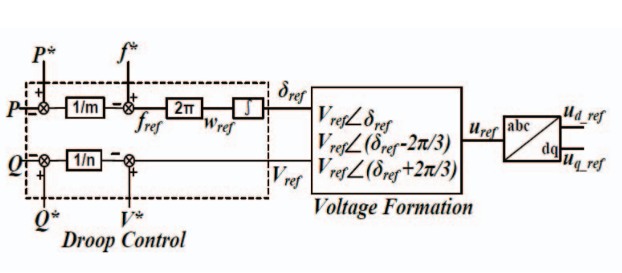

Fig.5: Details of droop control and voltage formation [33].

In this paper, the involved schematic of the low voltage microgrid is shown in Fig.3. The microgrid is consisted by two micro sources and load components, and then through the line and the switch is connected to the low voltage distribution network. It is assumed that the two micro sources are the DC source or rectifier DC source, which are inverted the three-phase AC by the inverter of the space vector pulse width modulation (SVPWM). LC low-pass filter is used to filter out high-order harmonic. The four micro sources are used PQ control in grid-connected operation, which keep the output power at constant value. DG1 and DG2 use V/f control in the grid-connected operation and islanding operation in order to control constant voltage of the system

TABLE 1. MICROGRID DETAIL

COMPONENT	PARAMETER
Main Grid	Voltage AC = 400 V , P-P Source Resistance= 0.8929 Ohms Source Inductance= 16.58e-3 H
Distributed Generation(DG)1	DC VOLTAGE=400 V
Distributed Generation(DG)2	DC VOLTAGE=400 V
LOAD1	Active load= 40kW Reactive load=20kW
LOAD2	Active load=20kW Reactive load=10kW
LOAD3	Active load=60kW Reactive load=30kW
LOAD4	Active load and Reactive load very high
DROOP CONTROL	1/m1 = 5×10-5, 1/n1 = 3×10-4, 1/m2 = 0.15×10-5, 1/n2 = 1×10-4

In the following table, two Distributed Generators (DGs) are used and the generation voltage is 400 V. The AC grid p-p voltage is 400 V including some source resistance and inductance. In the microgrid system, four loads is used where two is resistive loads having resistance of 5 and 15 ohms respectively and two inductive loads having resistance and inductance of 5 Ohms,1×10-6 H and 15 Ohms 1×10-6 H respectively.

IV. SIMULATION RESULTSAND DISCUSSION

To verify the effectiveness of droop control, grid connected and island mode was simulated for controller testing. As shown in Fig.8, both controllers for DGs have quick responses and track the references effectively. Note that real and reactive power can be controlled independently because of the decoupling of the reference current. At t=3 sec microgrid is disconnected from the grid which is shown in Fig.9. To maintain frequency stability, the real power generation of microgrid increases in order to match load demand which is defined in droop characteristics in Fig.3. Similarly, to keep the acceptable level of the voltage in system, the reactive power of microgrid (Fig. 5) decrease, meaning that the grid is absorbing reactive power from microgrid. The frequency analysis mainly depends on real and reactive load simulation results which are given below when real load is 40 kW and reactive load is 20 kVAR and later we have studied few case study such the load decreases 50% and the load increases 50%. The frequency goes unstable region when the load increases drastically, but using a PI controller it again comes into stable region [19-36].

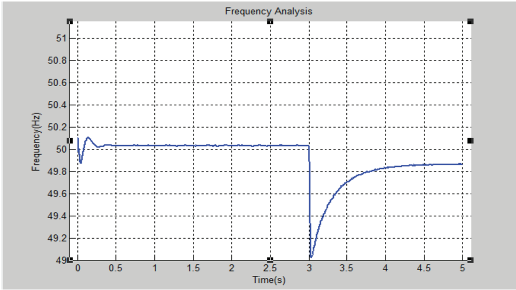

Fig.6: Frequency analysis when load is very high at grid connected mode

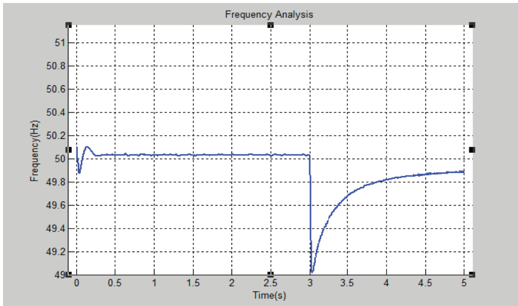

Fig.7: Frequency analysis when load is very high at islanded mode

In Fig.6 and Fig.7, shows the frequency analysis for grid connect microgrid and islanded microgrid respectively when load is really high, the distributed system is became unstable. By implementing droop control method, those instability issues have overpowered as shown in Fig.8 and Fig.9.

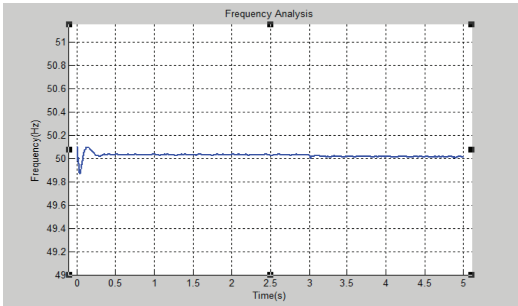

Fig. 8: Frequency analysis when both active and reactive load increased by 50% at grid connected mode

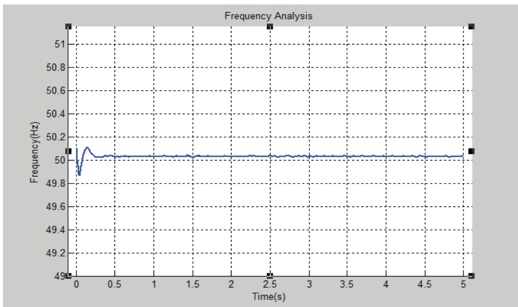

Fig. 9: Frequency analysis when both active and reactive load increased by 50% at islanded mode

In Fig.10 and Fig.11 the first distributed generator voltage analysis have been given for grid connected mode and island mode respectively. Similar graphs have generated for second DG system that are presented in Fig.12 and Fig.13.

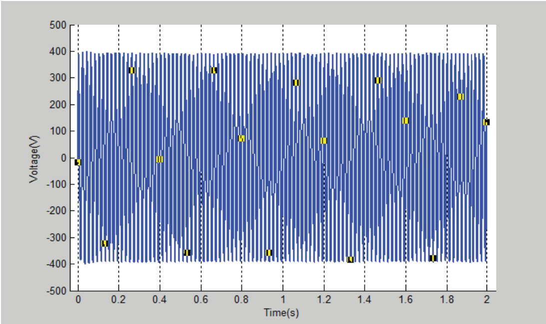

Fig. 10: Voltage of DG1 at grid connected mode

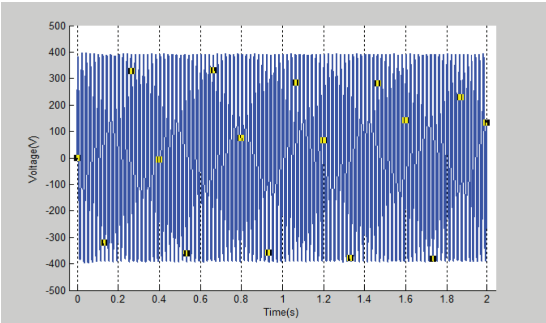

Fig.11: Voltage of DG1 at islanded mode

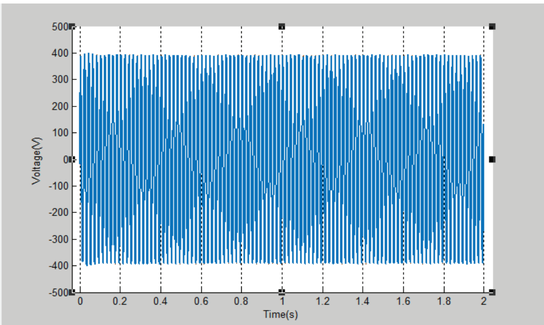

Fig. 12:Voltage analysis of DG2 at grid connected mode

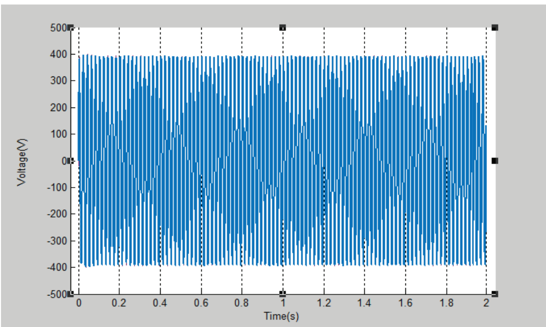

Fig. 13:Voltage analysis of DG2 at islanded mode

Finally the demand side voltage analysis has been presented in Fig.14, which shows the stability of system in those cases of study.

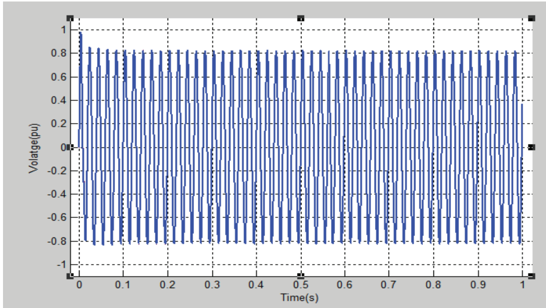

Fig. 14:Voltage Analysis in load side in per unit

Furthermore, the power analysis of grid connected mode and islanded mode are given in Fig. 15 and Fig.16. Those analyses also represent both active and reactive power separately.

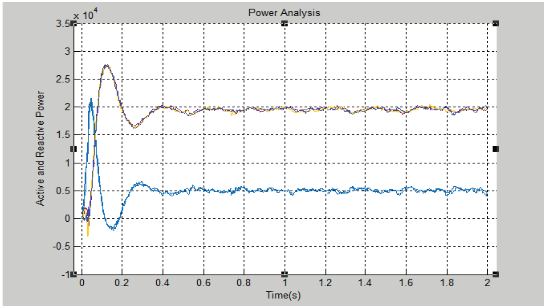

Fig. 15: Active and Reactive Power at grid connected mode

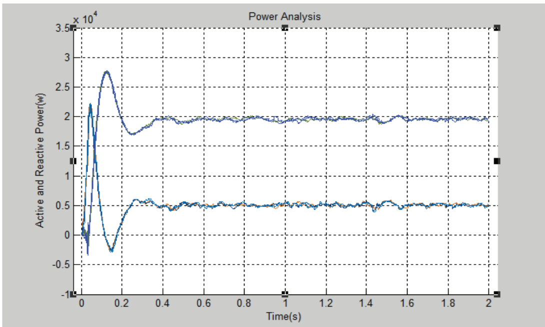

Fig. 16: Active and Reactive Power at islanded mode

V. CONCLUSION

Researchers nowadays focus on onsite generation system as it has no transmission loss and easy stability analysis compared to utility grid. However, absence of proper control techniques and design, it might be tricky to manage renewable based microgrid system. In this study, both cases (islanded and grid connected microgrid) have shown that the droop controller works effectively in terms of reallocating power sharing between two DGs and fast responding to load changes while maintaining the frequency and voltage at acceptable level. Droop controller is developed to ensure the quick dynamic frequency response and proper power sharing between DGs when a forced isolation occurs. Here, we have also studied on both real and reactive power analysis of the system. Researchers believe that the distributed generation system will play an important role with utility grid with the help of sound power sharing techniques.

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