

Synchronization of Microgrid by Actively Controlling Parameter

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Abstract— A microgrid consist of number of distributed generators (DGs) and renewable energy sources, Which operates in parallel with the main grid or in islanded mode. When it come for the parallel operation with main grid, microgrid cannot be Synchronized with main grid by using traditional synchronizer. As microgrid operates with multiple DG's and load, which is continuously varying. So I is necessary o use co-ordinate way to control multiple generators. This paper proposes an active synchronization technique with network based co-ordination to conrol the multiple DG's. From the simulation results using Simulink dynamic models, it is shown that the scheme provides the microgrid with a deterministic and reliable reconnection to the grid.[38]

Keywords- microgrid, microgrid central controller (MCC), Energy storage system, synchronization, static transfer switch (STS).

I. INTRODUCTION

Significant amount of research has been performed to explore the advanced features of future power systems and on the concept of Microgrid. This paper describes a novel approach for synchronization between an electric power system (EPS) and a microgrid by actively controlling the components of the microgrid. [2]

A. Introducing the Microgrid

A microgrid consists of large numbers of on-site distributed generators (DGs), as well as electrical and thermal loads. The microgrid can reduce CO₂ emissions so it is expected that it will improve the penetration ratio of green energy. Due to on-site generation, which does not incur transmission losses it can also improve energy efficiency. By customizing the quality of the power-supply system and meet the customer requests, a microgrid can provide flexible and reliable power. The benefits of microgrids can be classified into two groups: economical/environmental factors and power quality/reliability factors.

B. Synchronization of Generators

When paralleling ac generators, it is necessary to make the values of the phase-angle difference, frequency, voltage difference, and slip as small as possible. These three conditions are referred to as the synchronizing criteria. When the criteria are satisfied, by closing the breaker two individual systems may begin parallel operation. Synchronizing the generator to the other ac power system is very important, while considering that an out-of-step breaker closure generates a short-circuit current and high vibrations from the torsional oscillation of the shaft and, may finally goes to the trip condition [6], [7].

C. Synchronization of a Microgrid

The traditional methods used to start the parallel operation with an EPS can be grouped into two types. One is the manual method in which the operator gives a switch close command according to the synchronramps or synchroscope with the assist of the synchcheck relay. The other is an automatic method in which the auto synchronizer automatically controls the voltage and speed of the generator to make a connection with the EPS [6], [9], [10].But, the synchronization of a microgrid is quite different as compared with the synchronization of a single machine because the microgrid consists of numerous DGs, including unpredictable renewable energy resources and continuously changing electrical loads. We cannot predict that the synchronizing criteria are satisfied only by controlling a single generation unit, as the frequency and voltage of a microgrid are determined by multiple generators and loads. Therefore, using an autosynchronizer may not work for microgrid synchronization. Hence, manual synchronizing method is suitable that waits until the synchronizing criteria are satisfied, while maintaining the microgrid's frequency and voltage at fixed values. However, this manual method does not always yield consistent results. Specifically, when the difference in frequency between two systems is very small, we have to wait a very long time until the phase difference is matched to the criteria.

Much of the research has shown some promising solutions for the microgrid synchronization problem. However, we have to consider multiple facts to provide solutions for practical applications. The purpose of this paper is to propose an automatic synchronizing method for a microgrid, which can be applicable to practical microgrid implementations. This paper proposes an active synchronizing method that uses the network-based control of multiple DGs to adjust the frequency and voltage of the microgrid. With this method, we can get a reliable and deterministic synchronization under the condition of the fluctuating renewable outputs and rapid load change.

II. ACTIVE SYNCHRONIZING CONTROL

This paper describes an active synchronizing control system for a microgrid. The active synchronizing control makes the multiple generators to adjust the frequency and voltage of a microgrid actively to operate in parallel with the EPS.

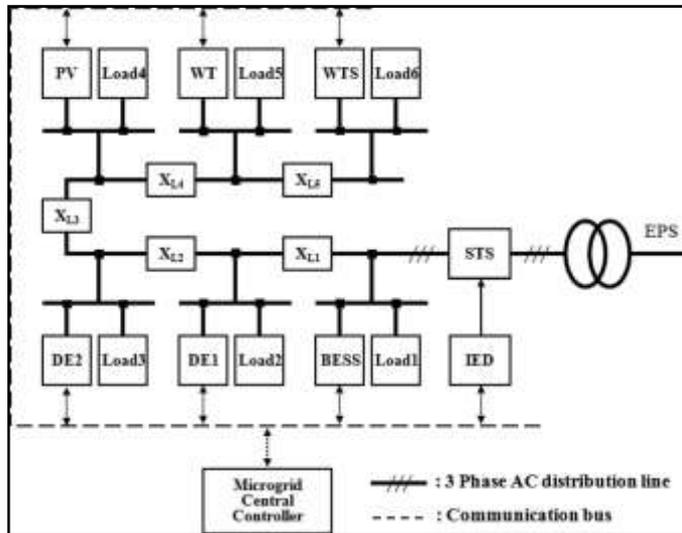


Fig. 1. Configuration of the microgrid pilot plant.

A. Microgrid Pilot Plant

To verify the behavior of a complex microgrid system, a microgrid pilot plant was developed. The size of the system is smaller than that of practical microgrids. Fig. 1 shows the configuration of the microgrid pilot plant. The microgrid pilot plant is connected to the EPS by a stepup transformer. Through a static transfer switch (STS) and intelligent electronic device (IED) that control the connection between two systems, the microgrid system is composed of a low-voltage single feeder. Depending on the line length the distribution line is simulated by the line impedances (X_{L1} – X_{L5}), which have different values.

At six different positions on this microgrid distribution line, there are electrical loads and DGs, including renewable sources. Controllable energy sources of the microgrid are the diesel engines (DE1, DE2) and battery energy storage system (BESS). DGs with renewable energy sources consist of the photovoltaic generator (PV), the wind turbine (WT) and the WT simulator (WTS). A WTS simulates the WT using a motor-generator (M-G) set to produce consistent and reproducible results even for no-wind condition.

B. Basic Scheme for an Active Synchronizing Control

Fig. 2 shows a basic scheme and the signal flow of the active synchronizing control. The microgrid central controller (MCC) is a central controller for the active synchronizing control. As the components are distributed over a wide range, communication network is used to operate in the proposed synchronizing control. At first, according to the EPS connection status sensed by the IED/STS the MCC decides the system's operational mode, and it sends the operational-mode command to every controllable DG. The MCC also receives analog signals from the IED and, then, calculates and

distributes the control commands by using the active synchronizing control algorithm. It transmits the commands to controllable DGs to control the frequency and voltage of the microgrid. Simultaneously, the renewable DGs operate normally in the maximum power point tracking mode that maximizes the generation efficiency so that it is not remote controllable.

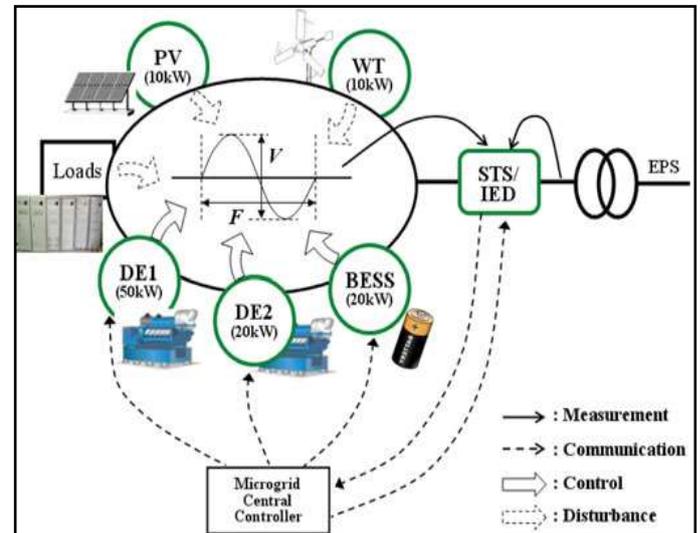


Fig. 2. Basic scheme for an active synchronizing control.

C. Measuring Synchronizing Criteria and Switch Control

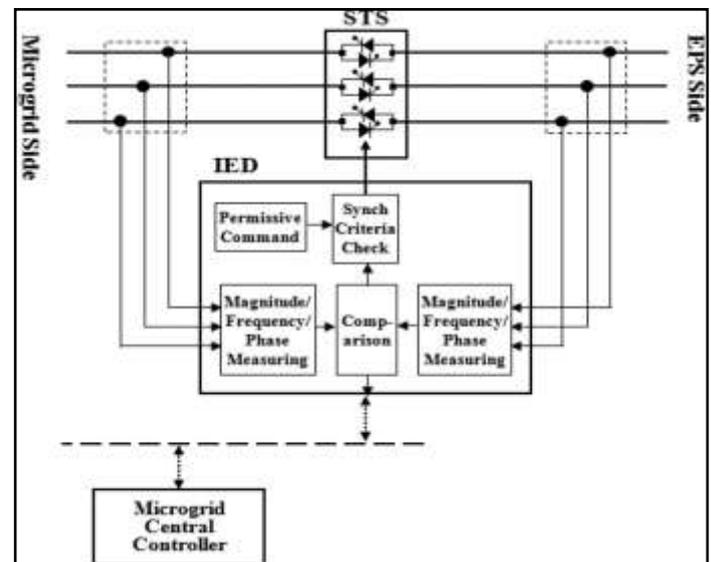


Fig. 3. Function of the IED/STS.

Fig. 3 shows more descriptions of the IED/STS. The IED is responsible for measuring the signals for the synchronizing criteria and controlling the ON/OFF STS for switching. As shown in the figure, the IED senses the three-phase voltages of each side and calculates the magnitude, frequency, and phase of the voltage that determine the synchronizing criteria. The signals of both sides are compared and through the network the results are transmitted to the MCC. When the reconnection to the EPS is required, the MCC sends a permissive command to the IED.

When the comparison results satisfy the synchronizing criteria the permissive command enables the IED to switch ON the STS. The most important factor in measuring the synchronizing criteria is to measure the phase and frequency. Various methods have been proposed to measure the frequency under harmonics and noises [16]–[18]. We adopted the reference frame transformation-based measuring method for the consecutive phase-angle difference measurement in this paper. The microgrid is subjected to the phase-to-phase imbalance due to the presence of single-phase loads and DG units [20]. Hence to ensure proper operation the imbalance among the measured signals should be solved. The signal conditioner for the voltage unbalance compensation is introduced [19]. The measurement method was implemented in the measuring block of the IED.

D. Control Scheme for Active Synchronization

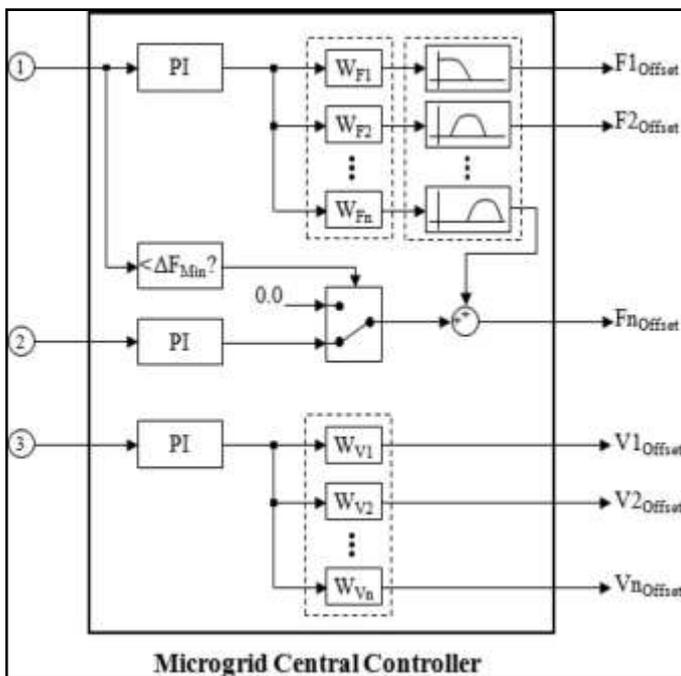


Fig. 4. Proposed algorithm for the active synchronizing control

Fig. 4 shows the structure of the active synchronizing control algorithm implemented in the MCC. The algorithm generates the frequency/voltage offset command signals for the multiple DG controllers. The left side of the figure shows that three input signals are transmitted from the IED through the communication network. These three signals are the differences between the microgrid and the EPS sides. The main objective of the active synchronizing control is to minimize these signals to satisfy the synchronizing criteria. Every controllable DG is able to adjust both the voltage and frequency set points. Therefore, with these difference signals, the MCC generates the frequency and voltage offset signals for each DG and delivers them via the network.

The frequency difference is caused by the difference in rotational speeds between the microgrid and the EPS. A control signal is generated through a proportionalintegral (PI) controller reduce the gap. This signal is weighted with the weight factors and is, then, distributed to the DGs through frequency filters that are suitable for the dynamics of each DG.

For example, the fuel cell generator, which needs a long time to change its output, is responsible for the lowest frequency band using a low-pass filter. The diesel generator takes charge of the middle frequency band using a band-pass filter. The BESS, which has the fastest response, should control the higher frequency band. Since there is no fuel cell in the microgrid pilot plant, the diesel generator with the larger capacity (50 kW) is used for the lowest band, and the 20-kW diesel generator and the BESS take charge of the middle and high frequency bands, respectively. Although the frequencies are matched perfectly, the switch cannot be turned ON if there is a phase difference. The phase difference is very sensitive to the DG output variations, so it is preferable to be handled by a DG with a good dynamic response. The installation of a separate DG that is wholly responsible for the phase-difference control would give us the best solution. However, with the limited number of controllable sources, the DG that is responsible for the highest frequency can serve concurrently as a phase-difference controller. The phase-difference control should not be operational when the frequency difference is too big. If not, it will interfere with the frequency difference control and the results will be unpredictable. Therefore, as shown in Fig. 4, the phase-difference signal is nullified as zero by a selective circuit until the frequency-difference value becomes small enough. After that the phase-difference signal is fed into the PI controller and added to the frequency control signal to minimize the error. If we consider the matter from the standpoint of the DG that is responsible for both the frequency and phase control, the DG takes charge of controlling the initial frequency difference. After a little break while the frequency difference is decreased by the DGs for the middle and low frequency bands, it once again takes charge of the control for reducing the phase difference. The voltage-difference signal 2 is a signal that indicates the difference in the voltage level between the microgrid and the EPS. As in the case of the frequency-difference control, the signal goes through the PI controller to make the voltage difference control signal. The signal is distributed to the DGs after going through the blocks of the weight factors, which are adjusted according to the characteristics of the individual DGs.

E. Control Algorithm of DGs

Fig.5 shows the structure of the BESS inverter controller for the frequency/voltage control and the real/reactive power control. There are two modes of operation depending on the connection status of the EPS. The MCC determines the operational mode of the microgrid on the basis of the status data received from the IED/STS. According to the operational-mode command from the MCC, the BESS and the other DG controllers change their internal control structures to operate in either an islanded mode or a grid-connected mode. From the figure, we can see that the operational-mode command determines the direction of the selector switch, and then, the control structure is determined to control the active/reactive power in a grid connected mode or the frequency/voltage in an islanded mode. Because the inverter of the BESS should operate in the dual mode, a number of feedback signals, such as the voltages, currents frequency, and powers, must be measured or calculated. The other signals, such as the references (P , Q) and the offset signals (F , V), are received from the MCC. In the grid-connected mode, the real power

error ($P_{Ref}-P_{FB}$) and the reactive power error ($Q_{Ref}-Q_{FB}$) are regulated by the PI controllers. As a result, the q -axis and d -axis current reference signals are calculated. The signals are fed into the current controller of the inverter to build the IGBT gate drive signals. Consequently, the real and reactive powers straightforwardly follow the reference signals in the grid-connected mode.

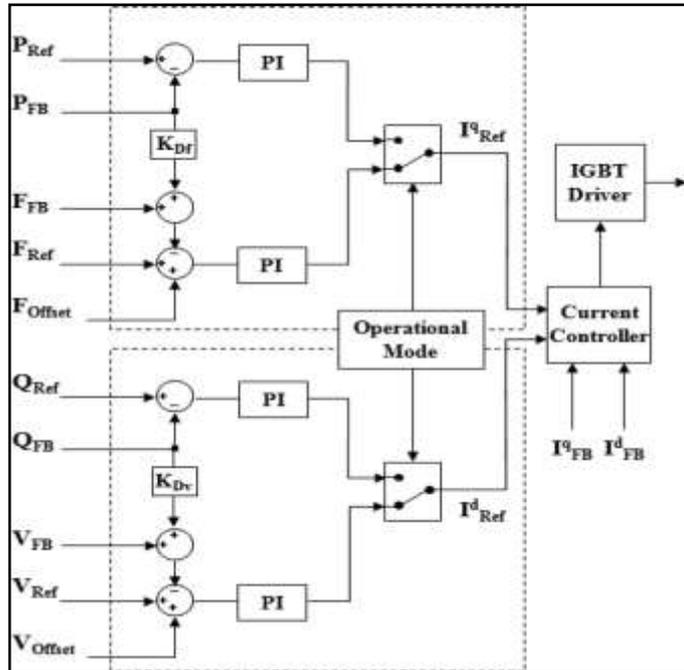


Fig. 5. Controller structure of the BESS including active synchronizing offset commands interface.

In the islanded mode, the BESS acts as one of the several controllers for the frequency and voltage control of the

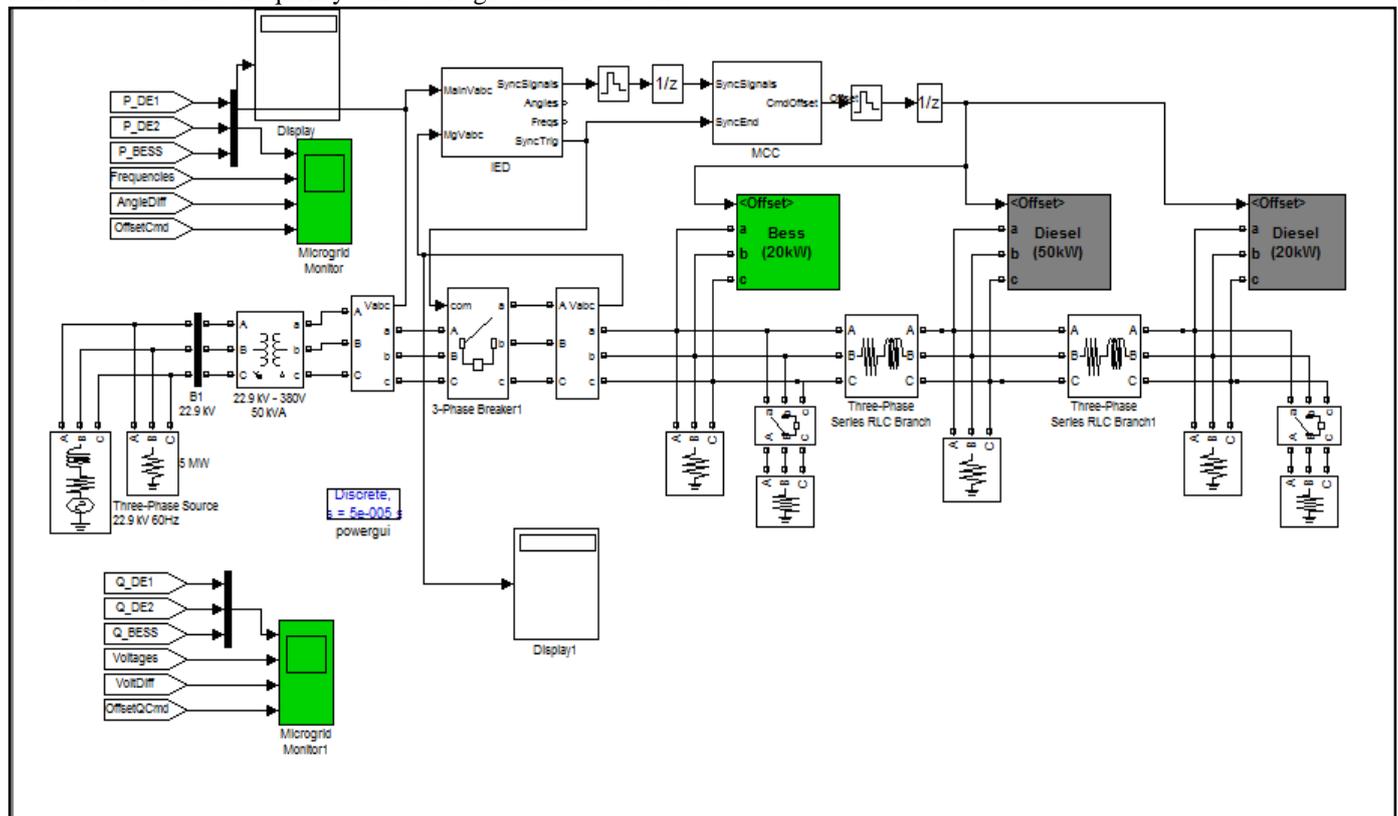


Fig.6. Dynamic model of the microgrid with an active synchronizing control.

II. DYNAMIC MODELING AND SIMULATION

A. Dynamic Models and Simulation

In this section, the feasibility of the active synchronizing control for the microgrid is evaluated by the dynamic modeling and simulation and performed a software simulation using MATLAB/Simulink. Fig. 6 shows the simulation setup of the active synchronizing control. The EPS is simulated as a 22.9 kV/60 Hz three-phase voltage source connected to a 380-V low-voltage microgrid through a step-up transformer. Three controllable DGs and local loads are arranged at three different sections that are divided by *RL* distribution line impedances. The detailed dynamic models for the IED, MCC, and BESS are shown in Fig.7, Fig.8, Fig.9 respectively and they can be easily built from the conceptual diagrams for the BESS simulation, we use an average model to make a three-phase balanced signal that can make the simulation time short. Figs.10 is the dynamic model and its control block diagram for the diesel generator.

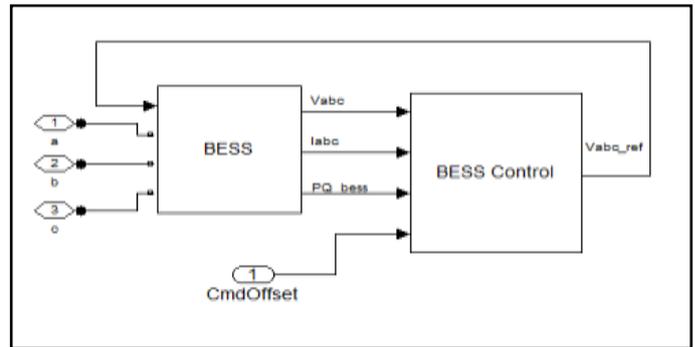


Fig. 9. PCS block diagram of the BESS.

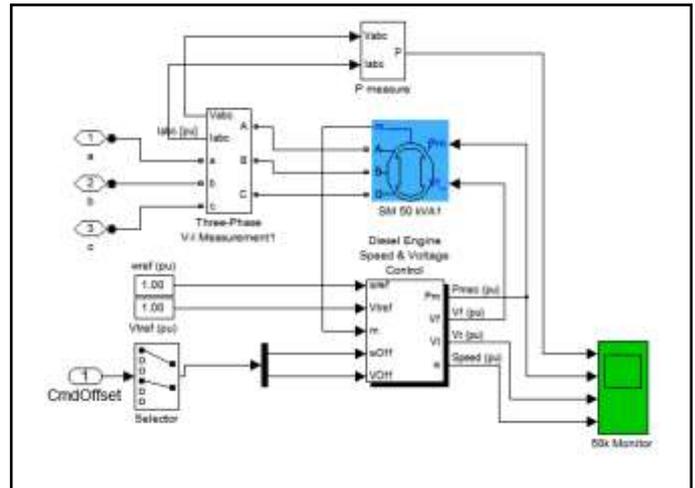


Fig. 10. Diesel generator model.

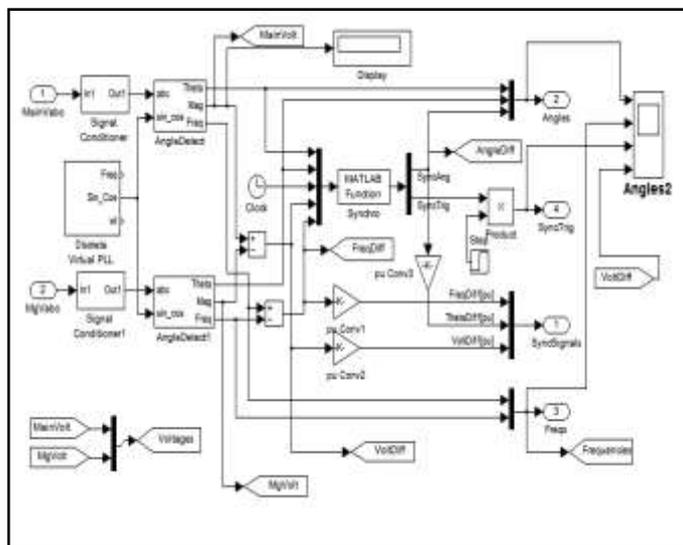


Fig. 7. Block diagram of the IED.

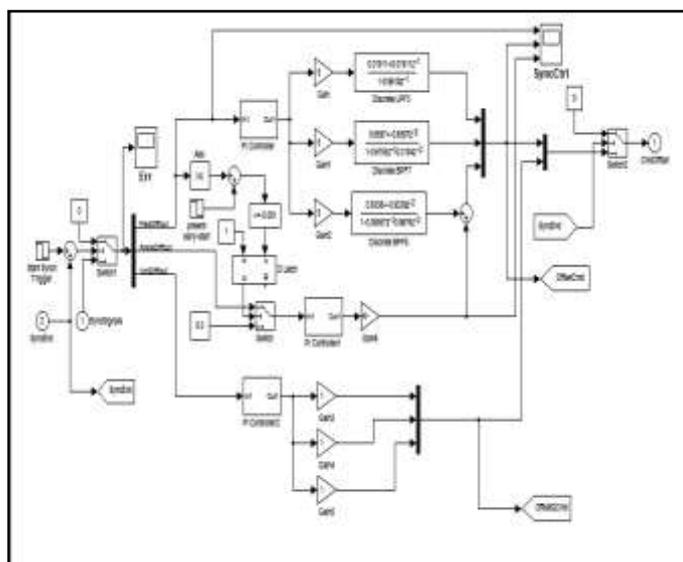


Fig. 8. Block diagram of the MCC.

B. Simulation Conditions and Results

Using the dynamic model of the microgrid with the active synchronizing control scheme in C the MATLAB simulation is performed. And result is shown in Fig.11, Fig.12. Due to the limitation of the simulation time, the rate limiters of the DG's offset command input are intentionally discarded.

III. CONCLUSION

The purpose of this paper is to propose an automatic synchronizing method for a microgrid, which can be applicable to practical microgrid implementations. An active synchronizing control scheme adopts the network-based control of multiple DGs to adjust the frequency and voltage of the microgrid. Dynamic modeling and simulation are conducted under the proposed method to show the system behavior. And simulation results shows how much the network delay has an effect on the synchronizing control performance.

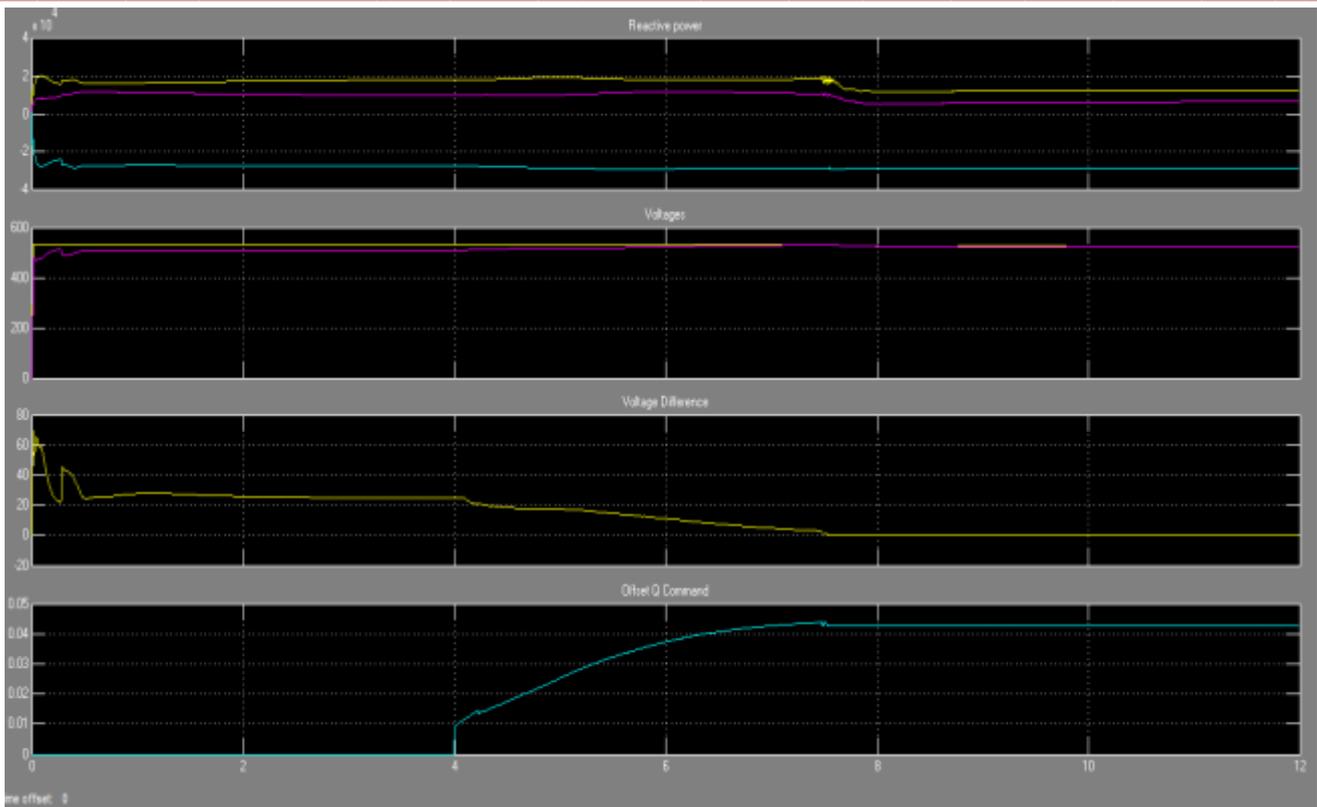


Fig. 11. Voltage and Voltage difference

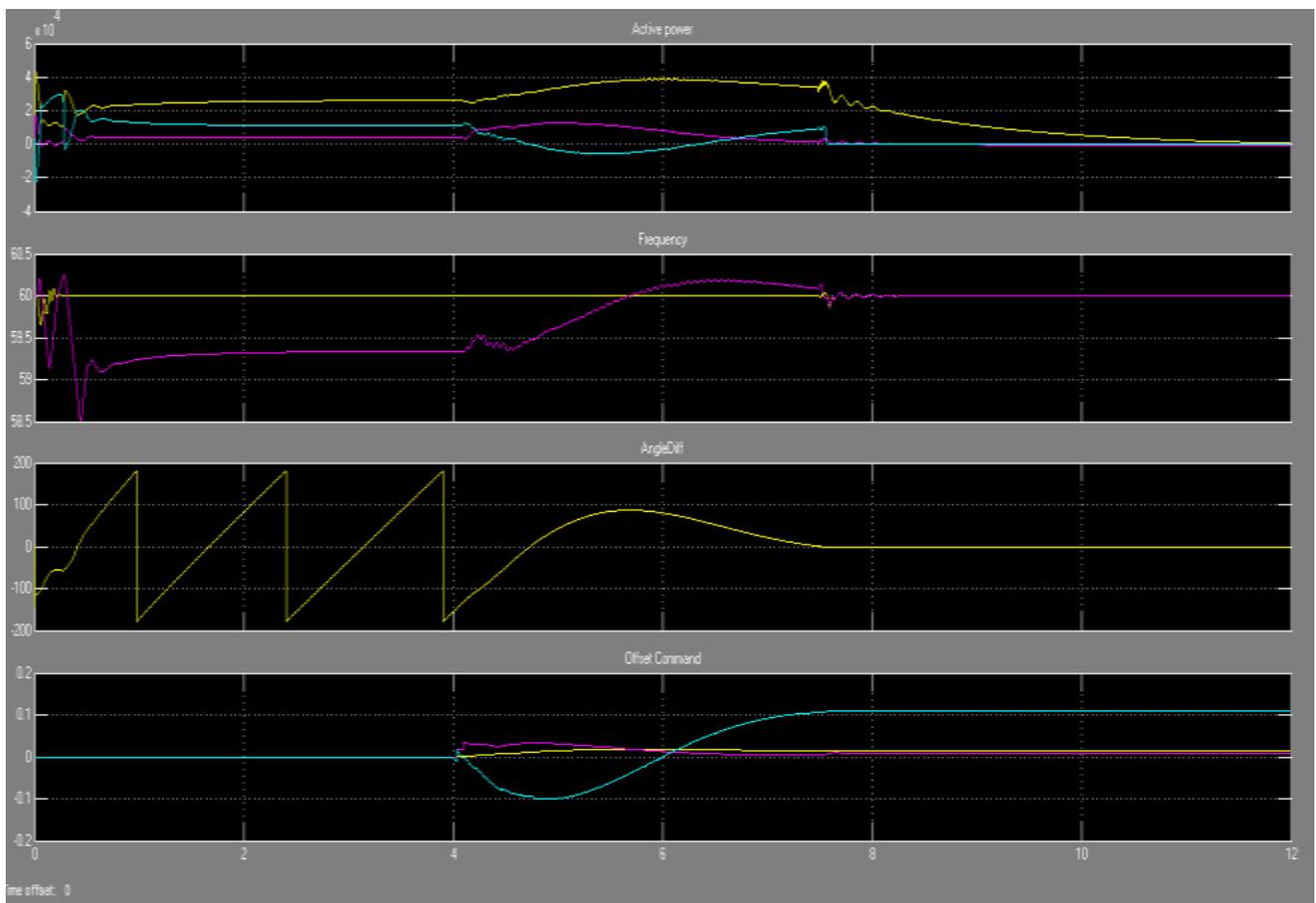


Fig.12. Active power, Frequency and Angle difference.

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