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Synchronization Control of A Microgrid Using Network Based Co-Ordination Control Technique

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Abstract: *A microgrid comprises of multiple distributed generators (DGs) and typically operates in parallel with this main grid. In certain cases this operation might fail and a microgrid may operate in an islanded mode. Synchronization occurs when such an islanded microgrid changes its operational mode back to grid connected operation by reconnection to the grid. Synchronizer used for synchronization of a single machine but a large microgrid which operates with multiple DGs and loads traditional synchronizer cannot be used to control it. This problem needs to be handled properly as it requires DGs to be controlled in a co-ordinated way to achieve synchronization. This paper presents work done on an active synchronizing control scheme which follows the network-based coordinated control of multiple DGs. Simulation results using Matlab/Simulink prove that the scheme is efficient enough to provide reliability in the reconnection of the microgrid.*

Keywords: *Active Synchronizing, Distributed Generators (DGs), Microgrid, Synchronization*

I. Introduction

A combination of on-site distributed generators (DGs) along with loads is typically classified as a microgrid [1-2]. Many of these DGs are nearer to the load demand and may consist of one or many renewable energy sources. This can prove energy efficient system and thus microgrids are considered as the future of power systems. A lot of research has been conducted in this area in the last few years [2-6]. As advantages of microgrid are numerous, its stability and reliability is a major area of research.

Traditionally for parallel operation of ac alternators the values of its difference of its voltage magnitudes, frequency and phase-angle are necessary to be kept as minimum as possible which is called its synchronizing criteria. A three phase breaker switch is given a make command when it is found that these conditions match. It is very important to satisfy this criterion as an out of sync generator can lead to a short-circuit condition and may cause mechanical vibrations of the generator shaft ultimately leading to trip condition. Furthermore it can lead to damage of equipment or ultimate blackout in the system which is economically not feasible for the growth of any country.

Earlier an operator would command a close signal relying on the synchroscope reading and a relay. Later an autosynchronizer was introduced to automatically control voltage magnitude and speed/frequency of the generator to be able to connect to the electric power system. Synchronization of a microgrid is more complex than a single machine as it consists of many elements which may be unpredictable in nature such as renewable sources or sudden varying loads. Therefore due to above reasons an autosynchronizer is not adequate for synchronization of the microgrid as it works only for controlling single machine [8]. Most commonly manual method is used even today for synchronizing of a microgrid as the operator waits until the synchronizing criteria are satisfied, but always reliable results cannot be guaranteed [15].

Researchers have shown keen interest and are continuously providing promising solutions for the microgrid synchronization problem [7-12]. This paper focuses on one such method of automatically synchronizing a microgrid with the electric power system based on network-co-ordinated strategy to actively control multiple DGs to adjust its voltage and frequency to satisfy the synchronization criterion. Simulation results show the effectiveness of the approach to solve the problem of synchronization.This paper is divided in five sections. Section I gives a brief introduction about the problem of synchronization. Basic control scheme is given in Section II. Section III contains the simulation study and its various components and gives an idea of system under observation. Sections IV discuss the results of the system under study and comments on the same providing proof of effectiveness of the proposed control strategy while in Section V paper is concluded.

II. Control Scheme

A network co-ordinated active synchronizing scheme for microgrid is discussed in this paper which makes use of multiple DGs and controls the voltage and frequency of the microgrid to make it possible to operate in parallel with the existing electric power system.

Basic scheme of a network co-ordinated signal flow of the active synchronizing control is shown in fig. 1. For the active synchronizing the microgrid central controller (MCC) acts as a central controller. As the components are distributed over a wide range communication network is used for operating controls. System's operational mode is decided by the MCC then MCC sends the operational mode command to every controllable DGs depending on the EPS connection status sensed by the IED/STS. Analog signals are received by the MCC from IED and then by using the active synchronizing control algorithm it calculates and distributes the control commands. Commands to controllable DGs are transmitted by it to control the frequency and voltage of the microgrid.

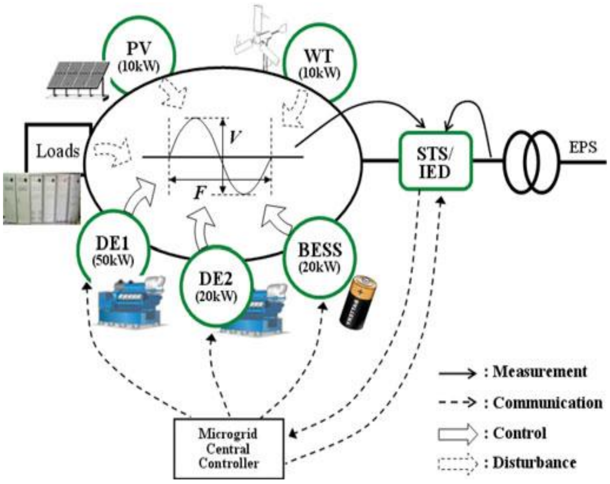

Fig. 1. Basic Scheme of an Network Based Active Synchronizing Control

Fig. 2 shows a detailed description of the IED/STS in Fig. 1 the main responsibility of the IED is to measure the signals which are being used for the synchronizing criteria to control the STS to switch the connection ON/OFF. As shown in figure IED senses the three-phase voltages of each side and IED calculates its magnitude, frequency, and phase of the voltage. This is required to determine the synchronizing criteria. The signals of microgrid side and EPS side are compared and the results are transmitted to the MCC through the network.

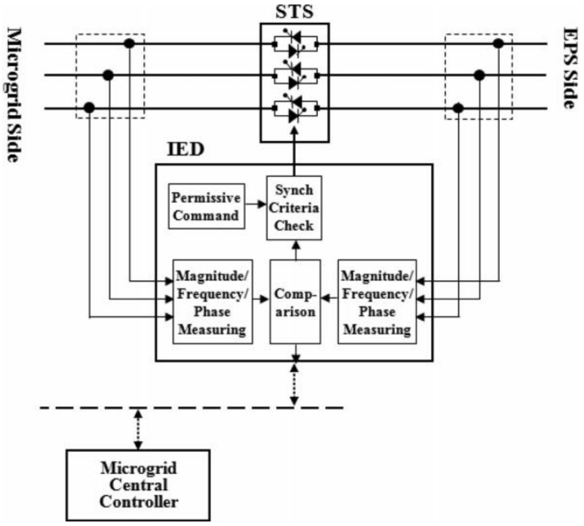

Fig. 2. IED/STS Functional Block Diagram

During the same time the MCC sends a permissive command to the IED for the reconnection of the power system. The permissive command initiates the IED to switch ON the STS only after the synchronizing criteria is being satisfied by the comparison results. Measurement of phase and frequency is the main part in measuring the synchronizing criteria. To measure consecutive phase-angle difference reference frame transformation measuring method is used. Microgrid is naturally subjected to the phase-to phase imbalance because of presence of single phase loads and DG units. Therefore to obtain proper operation and to compensate the voltage unbalance signal conditioner is used. In the measuring block of the IED the measurement method was implemented.

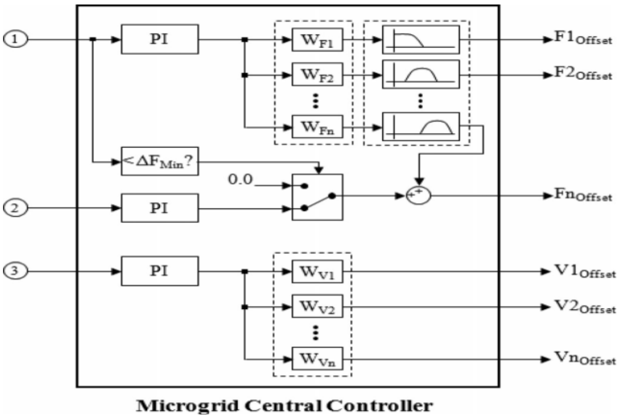

Fig. 3. MCC Functional Diagram and Proposed Algorithm

Fig. 3 shows the structure of the active synchronizing control algorithm implemented in the MCC. Frequency/voltage offset command signals are generated by the algorithm for the multiple DG controllers. Three input signals which are differences between the microgrid and the EPS sides are 1.frequency, 2.phase, and 3.voltage respectively. The prime most objective of the active synchronizing control is to satisfy the synchronizing criteria by minimizing these signals.

When there is a large frequency difference then phase difference control should not operate. Otherwise it will cause interfere with the frequency difference control and affects the result. As shown in Fig. 3by using selective circuit phase difference signal is nullified as zero until the frequency difference value becomes small. To minimize the error phase difference signal is fed into the PI controller and it is added to the frequency control signal. If we consider DG is responsible for both the frequency and phase control, the DG takes charge of controlling the initial frequency difference. After a short break DGs decreases frequency difference for the middle and low frequency bands, it again takes charge of the control for reducing the phase difference. The difference in the voltage level between the microgrid and the EPS is indicated by voltage difference signal. Voltage difference 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.

III. Simulation Study

Matlab/Simulink is used for testing and simulating algorithm. For the simulation of an EPS MATLAB supports the users with a physical modeling product called Sim Power Systems. To build dynamic models fast and with ease to simulate power systems MATLAB is used

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.

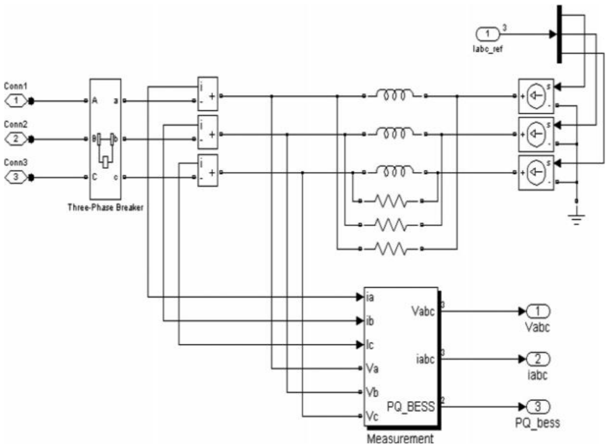

Fig. 4. Block Representation of Battery Energy Storage System

For the BESS simulation, an average model is used to make a three-phase balanced signal which can make the simulation time short. PCS block model and the control block model of the BESS shown in fig4 and fig 5 respectively. The control block consists of a PLL block, Parks Transformation, Power Control Block, Current Control Block and Inver Parks Transformation to convert the controlled parameters to Vabc reference which is used to control the gate pulses of IGBTs so as to maintain the output of the BESS at optimum operating point. The method of control uses a typical hysteresis control which is efficient as it avoid the need to tune any PI parameters as they are absent. It is the simplest form of control strategy.

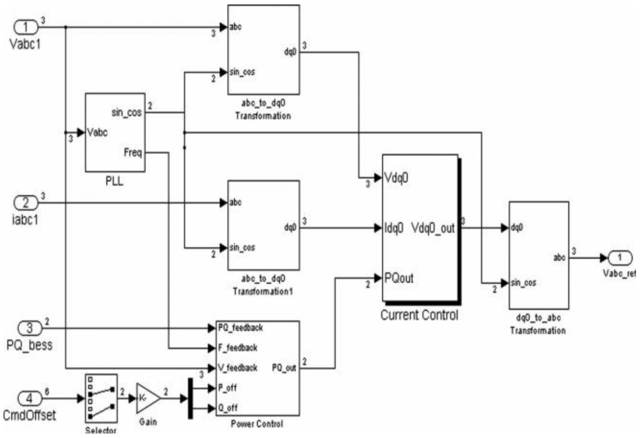

Fig. 5. Control Block of Battery Energy Storage System

Dynamic model of diesel generator and its control block diagram is shown in fig 7 and 8. It contains the exciter, engine, governor, voltage stabilizer and a synchronous generator. Same stands true for both 50kW and 20kW models used in the system under study.

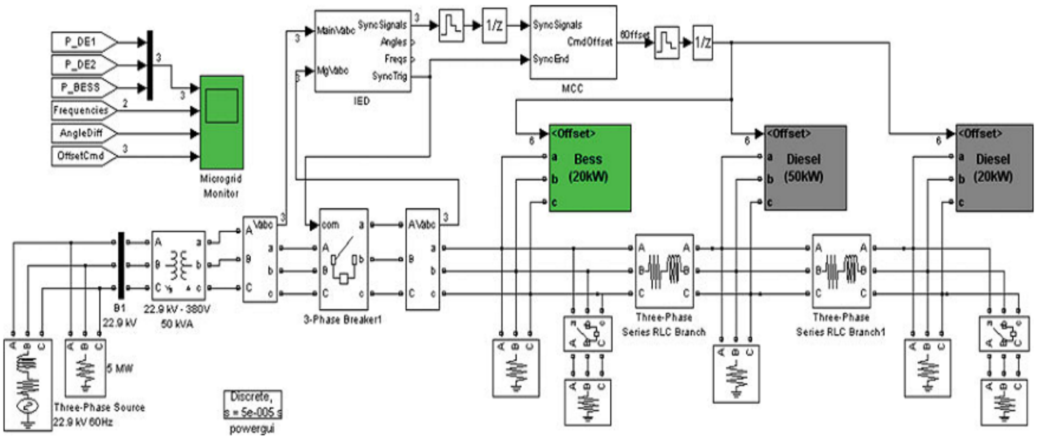

Fig. 6. Model of the Proposed System

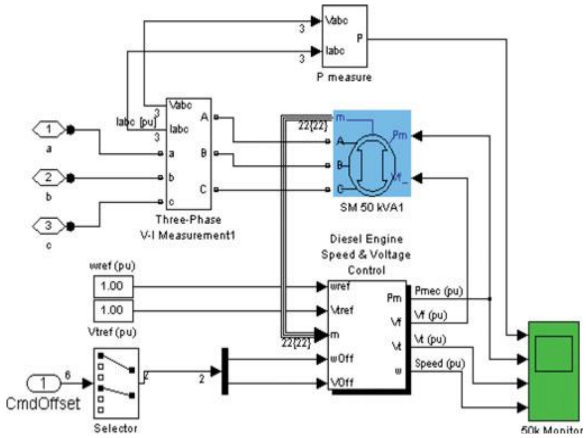

Fig. 7. Model of a Diesel Generator

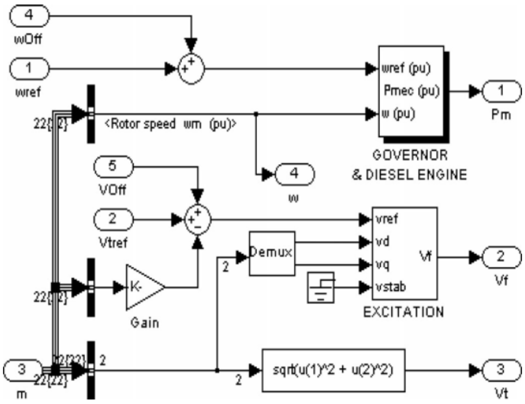

Fig. 8. Control Block arrangement for a Diesel Generator

IV. Results

Matlab simulation is performed By Using the dynamic model of the microgrid with the active synchronizing control scheme. For three different network delays results are obtained are as follows.

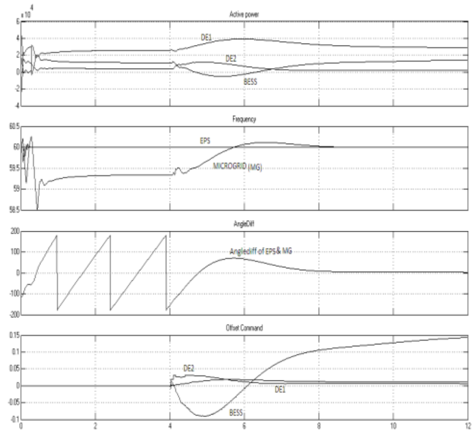

Fig. 9. Simulation Result For 64ms Network Delay

Three simulation cases are selected having different network delays (64, 200, and 500 ms) to observe the network delay effect to the synchronizing control. The network delay is modeled as a zero-order hold with a time-delay element. Digital filters of the MCC are recalculated at each case to get exact comparison with the same conditions. Smooth synchronization is achieved for 64-ms delay. Results for 200 ms are marginally acceptable in synchronization. But for 500-ms delay the synchronization cannot be achieved and results into the failure in microgrid operation.

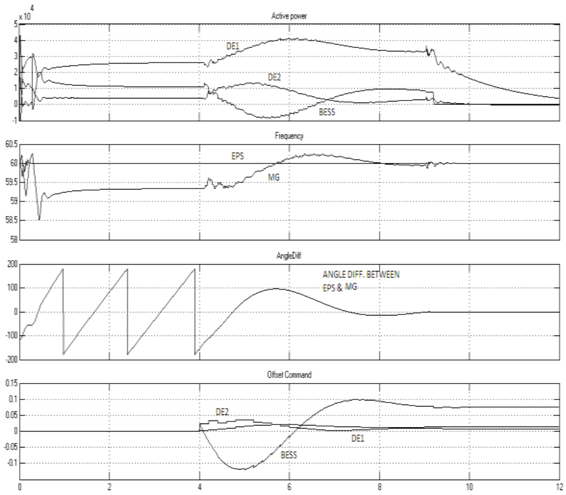

Fig. 10. Simulation Result For 200ms Network Delay

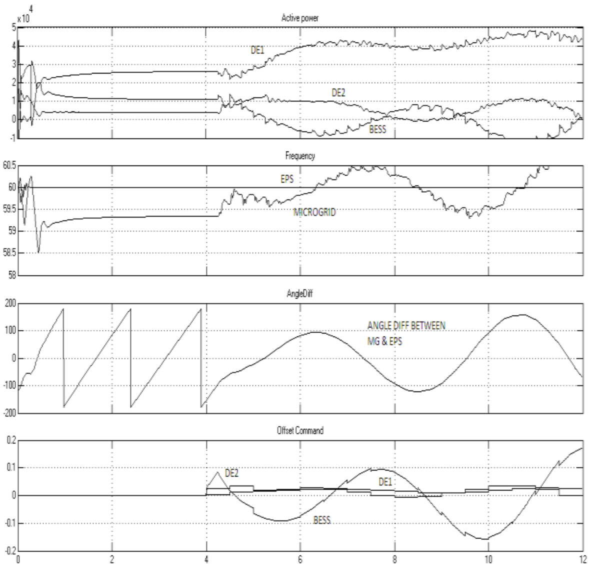

Fig. 11. Simulation Result For 500 ms Network Delay

V. Conclusion

A network co-ordinated control scheme is presented in this paper and an active synchronizing control of multiple DGs is adopted to adjust the voltage and frequency of the microgrid under study. Simulation is done using MATLAB/Simulink and modeling of the system was done. The results show the effect of network delay on the performance of the system at the instant of synchronizing. It is observed that a large network delay may cause instability in the system and thus reliability is compromised.

Appendix

The specifications of parameters used for experimental study are as follows.

DG 1
Specification-50kW, 380/220V, 3Φ 4 wire, 1800 RPM, 60 Hz.
DG 2
Rating- 20kW, 380/220 V, 3Φ 4 wire, 1800RPM, 60 Hz.
Active synchronizing controller
1) Digital filter: sampling time 62 ms.
2) Low-pass filter: Fcutoff = 0.1 Hz.
3) Band-pass filter 1: Fcenter = 0.3162 Hz, Fbandwidth =9.99 Hz.
4) Band-pass filter 2: Fcenter = 3.1623 Hz, Fbandwidth =99.9 Hz.
5) Weight factors: w1 = 0.2, w2 = 1.0, w3 = 1.0.
6) Frequency PI controller gains: Kp = 2.0, Ki = 0.9.
7) Phase difference PI controller gains: Kp = 5.0, Ki = 0.9.
8) Voltage difference PI controller gains: Kp = 3.0, Ki = 0.9.
9) ΔFMin: 0.055 Hz.
10) Synchronizing criteria.

1. Estimated phase-difference angle <±2º.
2. Slip frequency <±0.1 Hz.
3. Voltage difference <±3%.

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