Soft Synchronizing Control of a Wind Microgrid

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***Abstract*— Microgrid is a combination of multiple DGs like conventional energy, renewable energy sources and load. Microgrid is always operated in parallel with main grid. Microgrid operated in two mode grid connected and islanded. In islanded mode it changes its operational mode to grid connected operation by reconnection to the grid. Traditional method is not suitable for operation therefore; soft synchronization technique is used to control the multiple DGs. The wind is by nature is intermittent. From the simulation study using matlab simulink result shows the dynamic model of diesel generator and wind turbine gives deterministic and reliable reconnection of microgrid. Wind provides maximum generation efficiency and stable operation.**

***Index Terms*—Microgrid, Soft Synchronizer, Static Transfer Switch (STS),BatteryEnergy Storage System(BESS), Microgrid Central Controller (MCC).**

I. Introduction

The CERT microgrid concept shows advance feature of power system which will made up the large number of onsite distributed energy resources like conventional sources, wind turbine and PV array through proper control of energy storage system and dispatch load.[1]-[2]

A. Introduction of Microgrid.

Microgrid plays important role in effective utilization of renewable energy sources and stable operation of public power grid. It can be operated under grid connected mode and islanded mode. An islanding is the disconnection of microgrid from main grid without interruption of the energy generation for load connected to the islanded part. It is only possible to have an islanding of only one part of microgrid more ever islanding can be planned or unplanned. The grid is continuously run in the islanded mode due to failure in main grid or high disturbances created in micro grid. Microgrid increases the penetration ratio of green energy and minimizes the CO_2 emission. It can also improve efficiency; reliability and power quality are the other benefits. Due to nature of onsite generation transmission losses are very less so customizing the quality of the power supply to meet the customer request to be flexible and reliable. The number of microgrid studied conducted for controlling the mode of operation and major research project underway all over the world.[3]-[4].

B. Synchronizing criteria.

When paralleling of an ac generators it is necessary to match the phase angle, slip frequency and voltage difference as small as possible these three conditions are called as synchronizing criteria. When the synchronizing criteria are match the breaker closes and the two individual systems may begin parallel operation.

C. Synchronizing control of a Microgrid.

In earlier days the traditional method is used for parallel operation. It can be of two types one is manual method in which the operator throw a switch close command according to synchroamps or synchroscope with assist the synchrocheck relay. The second one is the automatic method in which auto synchronizer is automatically control voltage and speed of generator to make the connection to the EPS. Synchronization of microgrid and single generator is quite different because microgrid contains many DGs, intermittent nature of renewable energy sources and changing electrical loads so, auto synchronizer may not be suitable for microgrid synchronization.

The manual synchronizing method waits until the synchronizing criteria is satisfied for maintaining the frequency and voltage at fixed value. For synchronizing control of an automatic synchronizing technique that used the network based control of multiple DGs to adjust frequency and voltage of a microgrid [5]. This technique deploys the reliable and deterministic synchronization under the condition of erratic renewable output and rapidly changes in load.

The purpose of this paper is soft synchronizing technique implemented through network coordinated control without and with wind system. Battery energy storage system is used to store the energy and also for reconnection [6]. The modeling of wind generator and information of wind is given in [7]-[9].

This paper contains five sections. In section I Introduction to study the purpose of work is given. In section II soft synchronizing control contains Microgrid system, control algorithm used for operation of synchronization in details. In section III Basic principle and modeling of wind energy in details. In section IV Simulation result shows the reliable operation using diesel generator and wind energy. In section V conclusion of the paper given.

II.SOFT SYNCHRONIZATION CONTROL

Microgrid configuration in fig.1 connected to EPS by step up transformer through the intelligence electronic device (IED) and static transfer switch. When the IED gives the signal microgrid central controller (MCC) decided to the operational mode similar to the EPS connection status and then send the operational command to each controllable DGs which is connected in microgrid also calculate and distribute the control command by using control algorithm and transmit to DGs to control the frequency and voltage of microgrid.

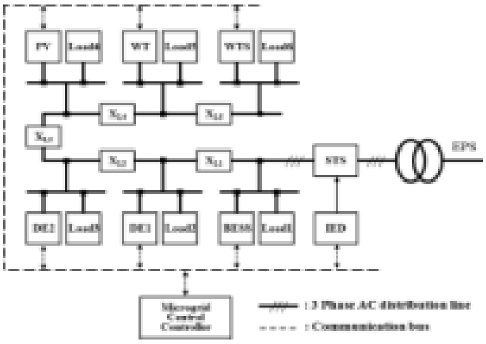


Fig.1 The Microgrid Configuration

A. Synchronizing Technique for achieving Criteria

The manual and auto synchronization has four devices are normally used synchrocheck relay, voltage relay synchronizing relay and automatic synchronizer. Zero crossing method is used for synchronizing criteria due to simple structure and accurate but it has some disadvantages it produce more noise ,harmonics and also wait for long measurement. A new synchronizing technique contains detecting signal for synchronizing criteria, signal conditioner, and zero phase angle difference estimation. This method help to reduce harmonics and noises also gives instant and precise phase angle difference [5]. The intelligence electronic device made up of new synchronizing method is responsible for measuring synchronizing criteria also control static transfer switch. In Fig. 2 Intelligence Electronic Device (IED) sense the three phase voltages of both sides and calculate the frequency, phase and magnititude of voltage for synchronizing criteria boths sides are compare results send to MCC through network. When Synchronizing criteria satisfied MCC send a permissive command to IED to switch ON the STS for reconnection to EPS.

B. Control Algorithm

The control algorithm as shown in fig.3 is implemented in MCC it creates frequency/voltage offset command for DG controller. The main aim of control algorithm to minimized the frequency and voltage signals to fulfill the synchronizing criteria. Every DGs have ability to adjust voltage and frequency to set points. With this difference the MCC create offset signal and delivers for each DGs through network.

The frequency difference occurs due variations in the speed between the microgrid and EPS. To minimize the gap between the speed control signal send to the PI controller weighted with the weight factor and distribute to the DGs filter suitable for each DGs in the microgrid. The filters are decided depends upon DGs connected in microgrid. The diesel generator medium frequency band using band pass filter and BESS has fastest response so medium and high frequency band using band pass filter are used.

Even though frequency is match still the switch cannot turn ON position due to the phase angle difference. The phase angle is very important for controlling the DGs. The phase difference not operated if the frequency difference is very high. In fig.3 phase angle nullified circuit operated upto the frequency difference value small. After the signal send to the PI controller and frequency signal is added to minimize the error.

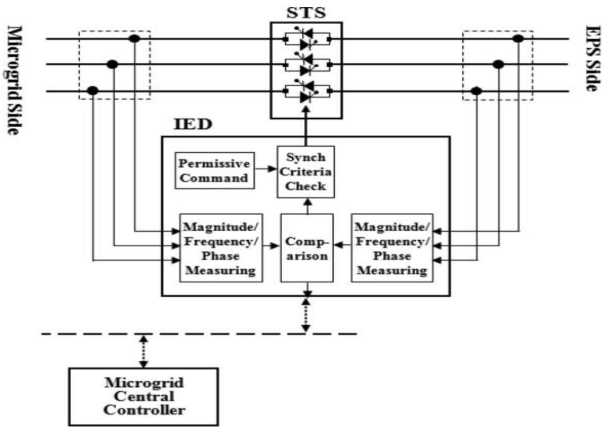


Fig. 2 Block diagram of IED

The voltage difference signal produces due to the difference between the microgrid and EPS. The frequency difference signal sends to the PI controller to produce the voltage difference control signal. This signal is send to the controllable DGs through the weight factor for adjusted the voltage according to the individual DGs characteristic.

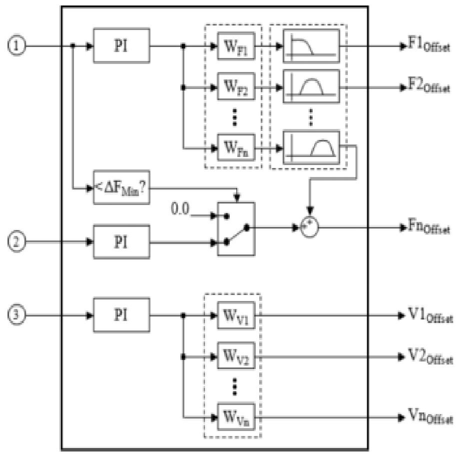


Fig. 3 Microgrid Central Controller

C. Control Algorithm for BESS and DGs.

The internal structure of BESS inverter as shown in fig.4 controller for frequency/voltage also active/ reactive power control. The BESS and other DGs changes their operational mode when the signal comes from the MCC. Their operational modes are two types one is grid connected and islanded mode. In the grid connected mode real power error and reactive power error are regulated by PI controller from their q-axis and d-axis current signal produces and send to current controller for making gate drive signal.

In the islanded condition frequency error signal is produce by difference between reference and feedback signal and it is subtracted from real power feedback signal with droop gain. The frequency offset signal generated, transmitted and distributed by MCC to minimize the frequency and phase difference between microgrid and EPS. These signals send to PI controller and created q-axis current reference signal. Same in case of voltage control voltage difference between reference and feedback and adding the reactive power for making the offset signal. In this signal voltage offset signal is added from the MCC to produce the d-axis current reference signal from PI controller. The q-axis and d-axis reference signal are fed to current controller and IGBT driver produces the gate signal for BESS inverter [6].

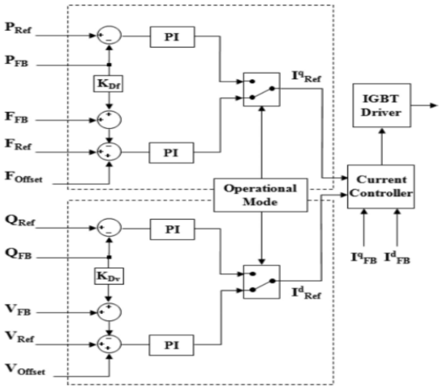


Fig.4 Control structure of BESS inverter.

III.WIND ENERGY CONVERSION SYSTEM

1. *Basic Principle*

Wind energy means kinetic energy of air in the motion.Air flown on the earth due to uneven heating of Earth surface by radiant energy from the sun. Wind or flow of air on earth is cause by massive convection current in the atmosphere. Wind energy, as a renewable energy source to generate electricity, has rapidly developed and assumed more importance [8], as awareness of global warming due to fossil-fuel energy consumption and environmental pollution has risen. Nevertheless, wind generator designs must be optimized to lower the cost of energy, which remains a primary factor for the inclusion of wind technology in the energy mix. Favorable incentives in many countries impact straightforwardly on the commercial acceptance of grid-connected wind turbines. Wind generator consists of wind turbine coupled to the generator. In the large turbine gearbox is coupled to low speed wind turbine rotor for high speed. The direct shaft coupled is normally used in small wind turbine for high speed. The large wind turbine used for grid connected whereas small wind turbine used for stand-alone system. The maximum conversion efficiency in the wind turbine is the ratio between angular speed of turbine and wind speed. Modification of turbine shape and blade pitch angle used to limit the power. The grid connected wind turbine has variable full span pitch control, rotational speed of turbine to be constant to control grid frequency. By nature wind is erratic therefore, asynchronous generator is used for maximum power point tracking mode for operation instead of synchronous generator [7] – [9].

2. *Wind Generator Model.*

2.1. *Wind turbine and power torque* [8].

The power available in the wind is given by.

$$P_W = \frac{1}{2}\rho_a A_T V^3 \qquad (1)$$

Where, P_W is the wind power, ρ_a is the air density, A_T is the Cross-sectional area of the rotor and V^3 the wind velocity. The power extracted from the wind is given by

$$P_T = \frac{1}{2}\rho_a A_T V^3 C_P \qquad (2)$$

where, P_T is the power produced by the wind turbine and C_P is the power coefficient.

The rotor torque is given by

$$T = \frac{1}{2}\rho_a A_T V^2 R C_T \qquad (3)$$

The relation between C_P and C_T is

$$\frac{C_P}{C_T} = \lambda \qquad (4)$$

λ is the tip speed ratio is how many times the speed tip of turbine blade is more than the wind speed .

2.2. *Self Excited Induction Generator*

The d-q model is used for electric behavior of SEIG. The electromagnetic torque is given by

$$T_e = 1.5\,P\left(\varphi_{ds} i_{ds} - \varphi_{qs} i_{qs}\right) \qquad (5)$$

$$\varphi_{qs} = L_s i_{qs} - L_m i_{qr}$$

$$\varphi_{ds} = L_s i_{ds} - L_m i_{dr}$$

Where T_e is the electromagnetic torque, P is the number of pole pairs, $i_{qs}, i_{qr}, i_{ds}, i_{dr}$ are the stator and rotor currents on the d-q axis, L_s the stator leakage inductance and L_m the magnetizing inductance.

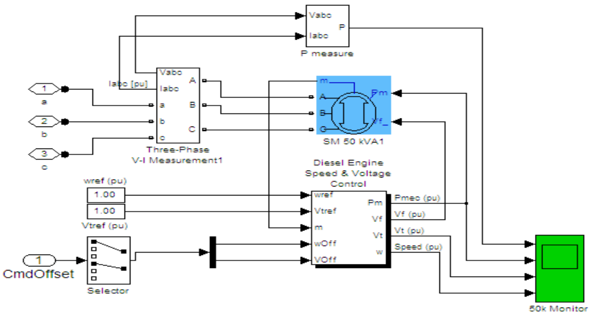
The mechanical part of the wind turbine driven induction generator is given by

$$T = J\frac{d\omega}{dt} + D\omega + T_c \qquad (6)$$

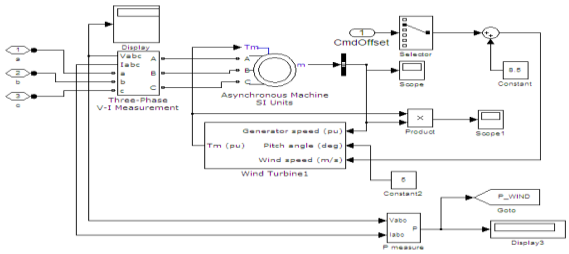
Where Tc is the torque of the turbine, J is the combined inertial coefficient of the wind turbine, gearbox and generator, and D is the combined friction coefficient of the gearbox and generator.

IV. SIMULATION MODEL AND RESULT

The Soft synchronization simulation performed in Matlab/simulink shown in fig.6 For the simulation of an electrical power system contain some equipment , such as three phase machines, transformers, three phase breakers, RLC loads, transmission lines MATLAB supports the users with a physical modeling product is known as sim power system. This tool box design and easily simulates power system. The fig 5 shows the dynamic model of diesel generator and wind system respectively. In the diesel generator Synchronous machine block is connected to diesel engine voltage and speed controller. The voltage and speed controller block input terminal present for the speed and voltage offset signal from the MCC. This both offset signal added to nominal reference signal and send to each controller. The governor and diesel engine block made up of lead –lag compensator, an actuator diesel engine used for time delay. Excitation block used for voltage controller and excitation the output is mechanical power and field voltage which gives to the synchronous generator. In the wind system asynchronous machine block used as asynchronous generator is connected to wind turbine. The wind turbine block has three input terminal generator speed, wind speed and pitch angle control. The generator speed is for permanent magnet is speed producing for nominal voltage at no load. From the wind turbine power characteristic pitch angle can be controlled and wind speed is in m/s. The output of the block is mechanical torque which is applied to the generator.



(a) Diesel Generator



(b) Wind Turbine

Fig. 5 Dynamic model of a) Diesel generator b) wind turbine.

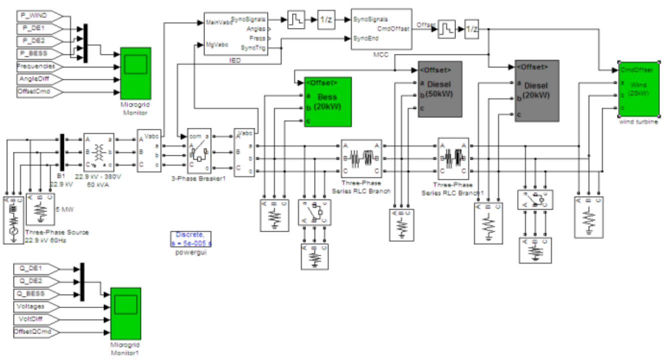
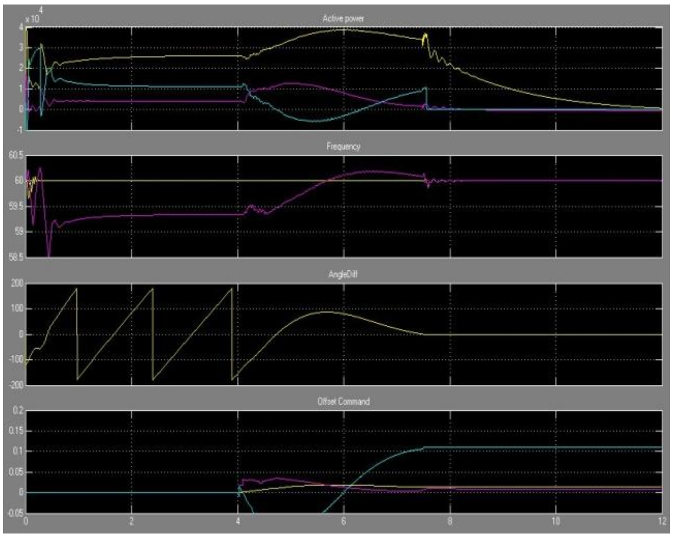
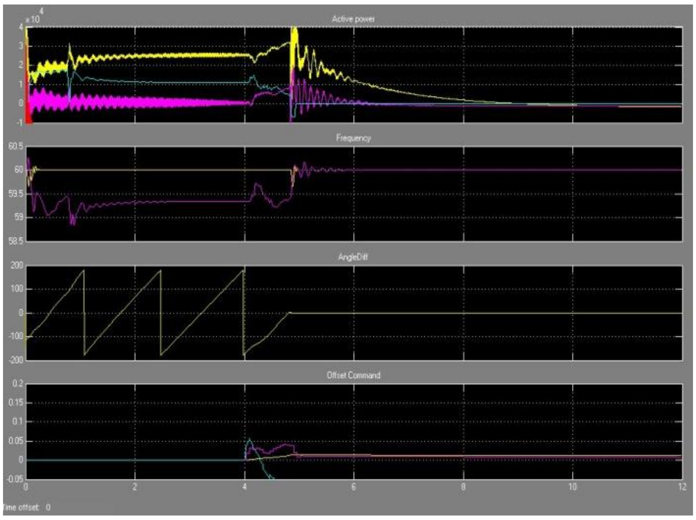


Fig.6 shows the dynamic model of soft synchronizer with wind connected microgrid.

The result of the soft synchronization without wind of a microgrid is shown in fig.7 (a) first row graph shows the variation in the active power (yellow: DE1, indigo: DE2,pink: BESS) second and third row graph shows frequency variation and angle difference (yellow: EPS , pink: Microgrid) Four row graph shows offset command variation. In the fig.7(b) shows the result of soft synchronization with wind the variations of active power is same as without generator (red: Wind) it satisfied the synchronizing criteria in which angle difference and frequency graph is same as without wind generation. The variation in the offset command is shown. For the 64ms the simulation shows the smooth synchronization is achieved.



(a) Without Wind



(b) With Wind

Fig.7 shows the simulation result for cases a) without wind b) with wind.

V. CONCLUSION

The soft synchronizing technique is used for the synchronization of microgrid. In this technique control of multiple DGs to adjust the frequency and voltage of microgrid. Wind energy is erratic in nature. It can be operated in maximum power point tracking mode. It maximizes the generation efficiency. This paper shows the wind energy is remote controllable and not creating disturbances to maintaining the stable voltage and frequency.

APPENDIX

The parameters in the simulation and experimental study are as follows.

- Diesel generator 1

a) Rating: 50 kW, 380/220 V, 3Φ 4 wire, 1800 r/min, 60 Hz.
b) F-controller: gain (Kpr = 004) integral (Tn = 2.0).

c) V-controller: gain (Kpr = 005) integral (Tn = 2.0).

d) P-controller: gain (Kpr = 002) integral (Tn = 8.0) Ramp (002%/s).

- Diesel generator 2

a) Rating: 20 kW, 380/220 V, 3Φ 4 wire, 1800 r/min, 60 Hz.

b) Exciter: brushless self-excited.

c) MOP: control range (±10%), speed (90 s/span).

d) AVR gains: Kp = 1.2, Ki = 3.4.

e) Power controller: Kp = 0.4, Kd = 14, Droop = 1.0%.

- Battery energy storage system

a) Rating: 20 kW, V dc link = 700 V, V Battery = 450 V, 3Φ 4 wire.

b) Battery: lead-acid, 36 serial 2 parallel, 500 A·h, 200 kW·h.

c) F controller: Kp = 50, Ki = 30.

d) Power controller: Kp = 1.5, Ki = 150, Droop = 2.0%.

- Wind turbine

a) Rating: 10 kW, 3 blade.

b) Wind speed: cut-in 3.3 m/s, nominal 13 m/s, max 40 m/s.

c) Generator type: PMSG.

- Load simulator

a) Rating: resistive 193 kW, reactive 95.1 kVar.

- Distribution line simulator

a) Type: solid copper wire 60 mm 2 .

b) Fivesections,100m×1,50m×4(0.301+j0.445Ω/km).

- Soft synchronizing controller

a) Digital filter: sampling time 62 ms.

b) Low-pass filter: F cutoff = 0.1 Hz.

c) Band-pass filter 1: F center = 0.3162 Hz, F bandwidth = 9.99 Hz.

d) Band-pass filter 2: F center = 3.1623 Hz, F bandwidth = 99.9 Hz.

e) Weight factors: w1 = 0.2, w2 = 1.0, w3 = 1.0.
f) Frequency PI controller gains: Kp = 2.0, Ki = 0.9.

g) Phase difference PI controller gains: Kp = 5.0, Ki = 0.9.

h) Voltage difference PI controller gains: Kp = 3.0, Ki = 0.9.

i) Synchronizing criteria.

1) Estimated phase-difference angle <±2 ◦ [19].

2) Slip frequency <±0.1 Hz.

3) Voltage difference <±3%

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