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ENHANCEMENT OF MICROGRID CONTROL IN DISTRIBUTION SYSTEM USING FUZZY LOGIC TECHNIQUE

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ABSTRACT

Three phase ac power systems have existed for over 100 years due to their efficient transformation of ac power at different voltage levels and over long distance as well as the inherent characteristic from fossil energy driven rotating machines. The proposed system presents power-control strategies of a grid-connected Micro grid generation system with versatile power transfer. This Micro grid system allows maximum utilization of freely available renewable energy sources like wind and photovoltaic energies. For this, an adaptive MPPT P&O Controller along with standard perturbs and observes method will be used for the system.

In This paper proposes a ac/dc micro grid to reduce the processes of multiple dc–ac–dc or ac–dc–ac conversions in an individual ac or dc grid. The Micro grid consists of both ac and dc networks connected together by multi-bidirectional converters. AC sources and loads are connected to the ac network whereas dc sources and loads are tied to the dc network. Energy storage systems can be connected to dc or ac links.

The proposed Micro grid can operate in a grid-tied or autonomous mode. The coordination control algorithms are proposed for smooth power transfer between ac and dc links and for stable system operation under various generation and load conditions. This Micro grid system operates under normal conditions which include normal room temperature in the case of solar energy and normal wind speed at plain area in the case of wind energy. The Power Balancing Control simulation results are presented to illustrate the operating principle, feasibility and reliability of Micro grid proposed system.

Index Terms:-Energy management, grid control, grid operation, micro-grid, PV system, wind power generation.

I. INTRODUCTION

Increasing electrification of daily life causes growing electricity consumption, rising number of sensitive/critical loads demand for high-quality electricity, the energy efficiency of the grid is desired to be improved, and considerations on climate change are calling for sustainable energy applications .All these factors are driving the conventional electricity grid to the next generation of grid, i.e. smart grid, which is expected to appear and coexist with the existing grid, adding to its capacity, reliability, and functionalities .Consequently, the applications of distributed generation(DG) systems are emerging, and most will be interfaced to the grid through

power-electronics converters. However, the grid will become much more complex due to the increasing number of DG systems. For instance, the traditional one way power flow is broken by the bidirectional power flow.
The top-down centralized control changes to the bottom up decentralized control. Furthermore, more voltage quality problems may be introduced if the DG systems are not well controlled and organized. It has been implicated that power electronics-based converters not only can service as interfaces with the utility grid, but also have the potential for mitigating power quality problems .Some auxiliary functions such as active filtering have been reported Other works such as voltage unbalance compensation, grid support, and ride-through control under voltage dips have been presented in .Therefore, to adapt to future smart grid application, it will be a tendency of grid interfacing converters to integrate voltage quality enhancement and DG together. This paper focuses on the grid-interfacing architecture, taking into account how to interconnect DG systems in the future grid with enhanced voltage quality The desirable approach should be able to maintain high-quality power transfer between DG systems and the utility grid, even in disturbed grids, and be able to improve the voltage quality at both user and grid side. Figure 1 shows an example of the future application of grid-interfacing converters.

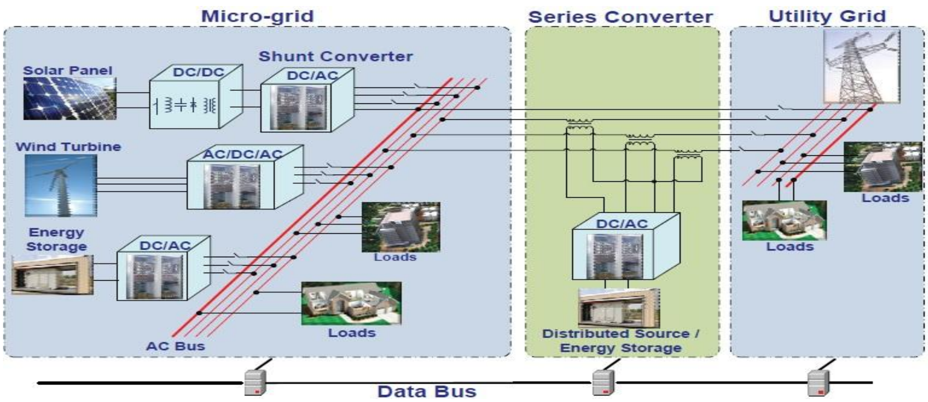

Fig. 1.1. An example of the future application of grid-interfacing converters for connecting multiple DG systems to the utility grid.

On the left-hand side, multiple DG systems together with energy storage and local loads are interconnected to construct a micro grid. Energy storage systems (e.g., super capacitor, battery, fuel cell, etc.) re used to store excess energy from the micro grid and send the stored energy back to the grid when needed, which are necessary for micro grid applications. As a basic structure of the smart grid, plug-and-play integration of micro grids is essential, which can function whether they are connected to or separate from the electricity grid.. On the right-hand side, a bidirectional series converter, which is supplied with distributed source and energy storage, interfaces the micro grid to a utility grid (can be another micro grid) for exchanging power and isolates grid disturbances from each of the grids. The data bus indicates network-scale communication path for variable collection and exchange in smart grid.
A ac/dc micro grid is proposed in this paper to reduce processes of multiple reverse conversions in an individual ac or dc grid and to facilitate the connection of various renewable ac and dc sources and loads to power system. Since energy management, control, and operation of a Micro Grid grid are more complicated than those of an

individual ac or dc grid, different operating modes of a Micro Grid ac/dc grid have been investigated. The coordination control schemes among various converters have been proposed to harness maximum power from renewable power sources, to minimize power transfer between ac and dc networks, and to maintain the stable operation of both ac and dc grids under variable supply and demand conditions when the Micro Grid operates in both grid-tied and islanding modes. The advanced power electronics and control technologies used in this paper will make a future power grid much smarter. The proposed Micro grid can operate in a grid-tied or autonomous mode. The coordination control algorithms are proposed for smooth power transfer between ac and dc links and for stable system operation under various generation and load conditions. This Micro grid system operates under normal conditions which include normal room temperature in the case of solar energy and normal wind speed at plain area in the case of wind energy. The Power Balancing Control simulation results are presented to illustrate the operating principle, feasibility and reliability of Micro grid proposed system.

II. SYSTEM CONFIGURATION AND MODELING

2.1. Grid Configuration

Fig. 1 shows a conceptual Micro Grid system configuration where various ac and dc sources and loads are connected to the corresponding dc and ac networks. The ac and dc links are connected together through two transformers and two four-quadrant operating three phase converters. The ac bus of the Micro Grid is tied to the utility grid. A compact Micro Grid as shown in Fig. 2.1 is modeled using the Simulink in the MATLAB to simulate system operations and controls. 40 KW PV arrays are connected to dc bus through a dc/dc boost converter to simulate dc sources. A capacitor C_v is to suppress high frequency ripples of the PV output voltage. A 50 KW wind turbine generator (WTG) with doubly fed induction generator (DFIG) is connected to an ac bus to simulate ac sources. A 65 Ah battery as energy storage is connected to dc bus through a bidirectional dc/dc converter. Variable dc load (20 kW–40 kW) and ac load (20 kW–40 kW) are connected to dc and ac buses respectively. The rated voltages for dc and ac buses are 400 V and 400 V RMS respectively. A three phase bi directional dc/ac main converter with R-L-C filter connects the dc bus to the ac bus through an isolation transformer.

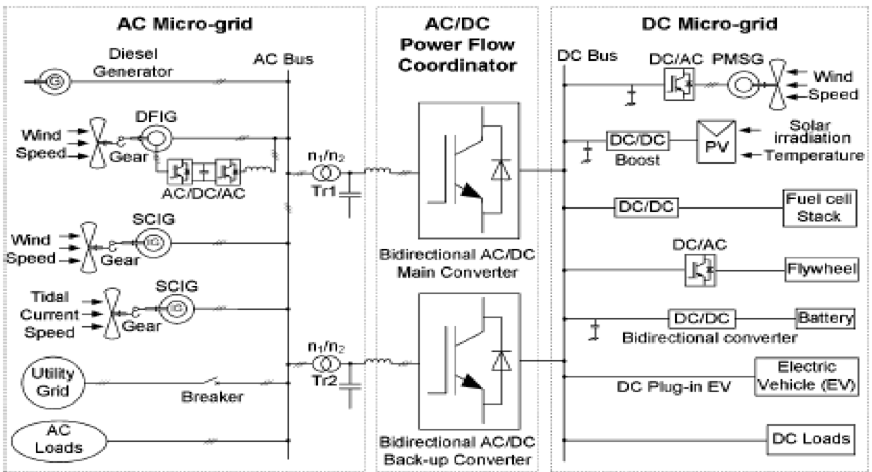

Fig.2.1 A hybrid ac/dc micro grid system

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2.2. Grid Operation

The Micro Grid can operate in two modes. In grid-tied mode, the main converter is to provide stable dc bus voltage and required reactive power and to exchange power between the ac and dc buses. The boost converter and WTG are controlled to provide the maximum power. When the output power of the dc sources is greater than the dc loads, the converter acts as an inverter and injects power from dc to ac side. When the total power generation is less than the total load at the dc side, the converter injects power from the ac to dc side. When the total power generation is greater than the total load in the Micro Grid grid, it will inject power to the utility grid. Otherwise, the Micro Grid will receive power from the utility grid.

In the grid tied mode, the battery converter is not very important in system operation because power is balanced by the utility grid. .In autonomous mode, the battery plays a very important role for both power balance and voltage stability. Control objectives for various converters are dispatched by energy management system. DC bus voltage is maintained stable by a battery converter or boost con-verter according to different operating conditions. The main converter is controlled to provide a stable and high quality ac bus voltage. Both PV and WTG can operate on maximum power point tracking (MPPT) or off-MPPT mode based on system operating requirements. Variable wind speed and solar irradiation are applied to the WTG and PV arrays respectively to simulate variation of power of ac and dc sources and test the MPPT control algorithm.

2.2. Modeling of PV Panel

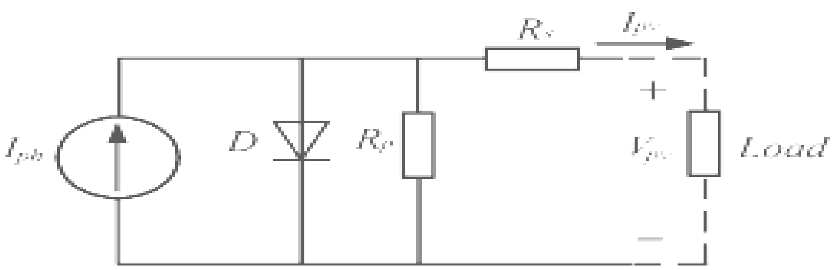

Fig. 2.2.Equivalent circuit of a solar cell.

Fig. 3 shows the equivalent circuit of a PV panel with a load. The current output of the PV panel is modeled by the following three equations

$$I_{pv} = n_p I_{ph} - n_p I_{sat} \times \left[\exp\left(\left(\frac{q}{AkT}\right)\left(\frac{V_{pv}}{n_s} + I_{pv}R_s\right)\right) - 1\right] \quad (1)$$

$$I_{ph} = (I_{sso} + k_i(T - T_r)) \cdot \frac{S}{1000} \quad (2)$$

$$I_{sat} = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left(\left(\frac{qE_{gap}}{kA}\right) \cdot \left(\frac{1}{T_r} - \frac{1}{T}\right)\right). \quad (3)$$

2.3. Modeling of Battery

Two important parameters to represent state of a battery are terminal voltage and state of charge (SOC) as follows

$$V_b = V_o + R_b \cdot i_b - K\frac{Q}{Q+\int i_b dt} + A \cdot \exp\left(B\int i_b dt\right) \quad (4)$$

$$\mathrm{SOC} = 100\left(1 + \frac{\int i_b dt}{Q}\right) \quad (5)$$

where R_b is internal resistance of the battery, V_o is the open circuit voltage of the battery, i_b is battery charging current, K is polarization voltage, Q is battery capacity, A is exponential voltage, and B is exponential capacity.

2.4. Modeling of Wind Turbine Generator

Power output P_m from a WTG is determined by (6)

$$P_m = 0.5\rho A C_p(\lambda,\beta)V_w^3 \quad (6)$$

where ρ is air density, A is rotor swept area, V_w is wind speed, and $C(\lambda\beta)$ is the power coefficient, which is the function of tip speed ratio λ and pitch angle β.

The mathematical models of a DFIG are essential requirements for its control system. The voltage equations of an induction motor in a rotating d-q coordinate are as follows.

$$\begin{bmatrix} u_{ds} \\ u_{qs} \\ u_{dr} \\ u_{qr} \end{bmatrix} = \begin{bmatrix} -R_s & 0 & 0 & 0 \\ 0 & -R_s & 0 & 0 \\ 0 & 0 & R_r & 0 \\ 0 & 0 & 0 & R_r \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} + p\begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} + \begin{bmatrix} -\omega_1\lambda_{qs} \\ \omega_1\lambda_{ds} \\ -\omega_2\lambda_{qr} \\ \omega_2\lambda_{dr} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} \lambda_{ds} \\ \lambda_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} = \begin{bmatrix} -L_s & 0 & L_m & 0 \\ 0 & -L_s & 0 & L_m \\ -L_m & 0 & L_r & 0 \\ 0 & -L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix}. \quad (8)$$

$$\frac{J}{n_p}\frac{d\omega_r}{dt} = T_m - T_{em} \quad (9)$$

$$T_{em} = n_p L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \quad (10)$$

where the subscripts d, q, s, and r denote d-axis, q-axis, stator, and rotor respectively, L represents the inductance, λ is the flux linkage, u and i represent voltage and current respectively, ω_1 and ω_2 are the angular synchronous speed and slip speed respec-tively, $\omega_2 = \omega_1 - \omega_r$, T_m is the mechanical torque, T_{em} is the electromagnetic torque .

If the synchronous rotating d-q reference is oriented by the stator voltage vector, the d-axis is aligned with the stator voltage vector while the q-axis is aligned with the stator flux reference frame. Therefore, $\lambda_{ds}=0$ and $\lambda_s=\lambda_s$. The following equations can be obtained in the stator voltage oriented reference frame as [14]:

$$i_{ds} = -\frac{L_m}{L_s} i_{dr} \quad T_{\mathrm{em}} = n_p \frac{L_m}{L_s} \lambda_s i_{dr}$$

$$\sigma = \frac{L_s L_r - L_m^2}{L_s L_r} \quad (11)$$

$$u_{dr} = R_r i_{dr} + \sigma L_r \frac{di_{dr}}{dt} - (\omega_1 - \omega_r)(L_m i_{qs} + L_r i_{qr}) \quad (12)$$

$$u_{qr} = R_r i_{qr} + \sigma L_r \frac{di_{qr}}{dt} + (\omega_1 - \omega_r)(L_m i_{ds} + L_r i_{dr}). \quad (13)$$

III. COORDINATION CONTROL OF THE CONVERTERS

There are five types of converters in the Micro Grid grid. Those converters have to be coordinately controlled with the utility grid to supply an uninterrupted, high efficiency, and high quality power to variable dc and ac loads under variable solar irradiation and wind speed when the Micro Grid grid operates in both isolated and grid tied modes. The control algorithms for those converters are presented in this section.

A. Grid-Connected Model

When the Micro Grid operates in this mode, the control objective of the boost converter is to track the MPPT of the PV array by regulating its terminal voltage. The back-to-back ac/dc/ac converter of the DFIG is controlled to regulate rotor side cur-rent to achieve MPPT and to synchronize with ac grid. The energy surplus of the Micro Grid can be sent to the utility system. The role of the battery as the energy storage becomes less important because the power is balanced by the utility grid. In this case, the only function of the battery is to eliminate frequent power transfer between the dc and ac link. The dc/dc converter of the battery can be controlled as the energy buffer using the technique.The main converter is designed to operate directionally to incorporate complementary characteristic of wind and solar sources. The control objectives of the main converter are to maintain a stable dc-link voltage for variable dc load and to synchronize with the ac link and utility system.

Power flow equations at the dc and ac links are as follows:

$$P_{pv} + P_{\mathrm{ac}} = P_{dcL} + P_b \quad (14)$$

$$P_s = P_w - P_{acL} - P_{\mathrm{ac}} \quad (15)$$

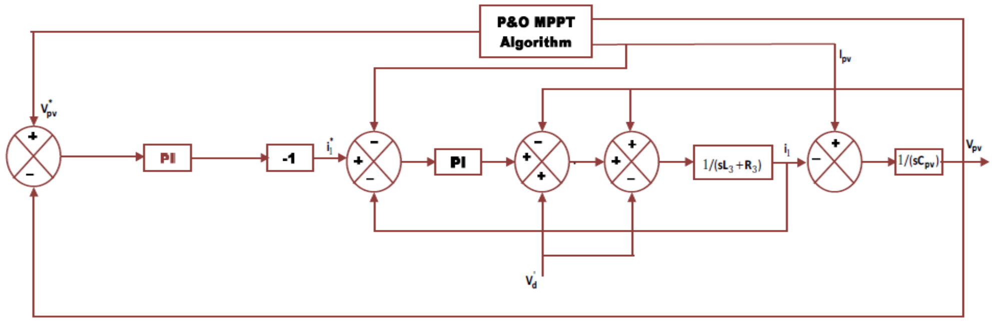

Fig. 3.1.Time average model for the booster and main converter.

where real power P_{pv} and P_w are produced by PV and WTG respectively, P_{acL} and P_{dcL} are real power loads connected to ac and dc buses respectively, P_{ac} is the power exchange between ac and dc links, P_b is power injection to battery, and P_s is power injection from the Micro Grid to the utility.

The current and voltage equations at dc bus are as follows:

$$V_{pv} - V_T = L_1 \cdot \frac{di_1}{dt} + R_1 i_1 \tag{16}$$

$$I_{pv} - i_1 = C_{pv} \cdot \frac{dV_{pv}}{dt} \tag{17}$$

$$V_T = V_d \cdot (1 - d_1) \tag{18}$$

$$i_1(1 - d_1) - C_d\frac{dV_d}{dt} - \frac{1}{R_L}V_d - i_b - i_{ac} = 0 \tag{19}$$

where d_1 is the duty ratio of switch ST.

Equations (20) and (21) show the ac side voltage equations of the main converter in ABC and d-q coordinates respectively [20]

$$L_2\frac{d}{dt}\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + R_2\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} v_{CA} \\ v_{CB} \\ v_{CC} \end{bmatrix} - \begin{bmatrix} v_{SA} \\ v_{SB} \\ v_{SC} \end{bmatrix} \tag{20}$$

$$L_2\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -R_2 & \omega L_2 \\ -\omega L_2 & -R_2 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} v_{cd} \\ v_{cq} \end{bmatrix} - \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} \tag{21}$$

is determined by the basic perturbation and observation (P&O) algorithm based on solar irradiation and temperature to harness the maximum power .Dual-loop control for the dc/dc boost converter is described in

,where the control objective is to provide a high quality dc voltage with good dynamic response. This control scheme is applied for the PV system to track optimal solar panel terminal voltage using the MPPT algorithm with minor modifications. The outer voltage loop can guarantee voltage reference tracking with zero steady-state error and the inner current loop can improve dynamic response.

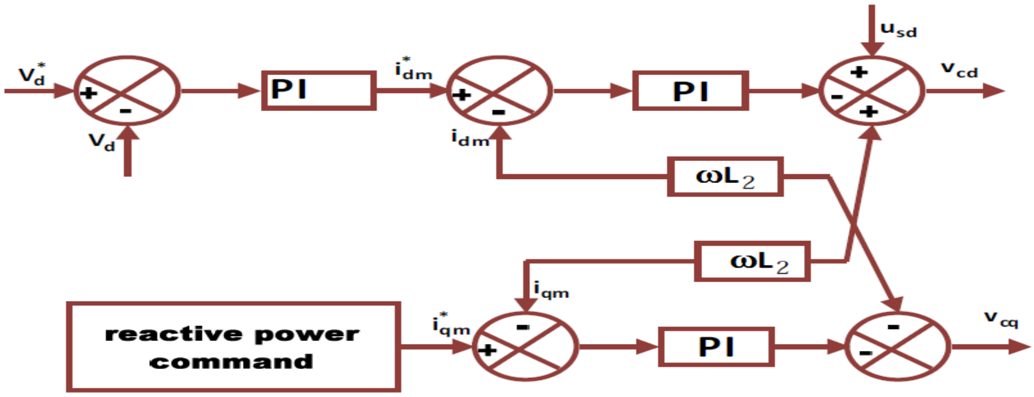

Fig. 3.2.The control block diagram.

3.2 Fuzzy Logic Controllers

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A. Zahed propounded the fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing handwritten characters are some common instances where fuzziness manifests. Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as "FUZZY SETS".

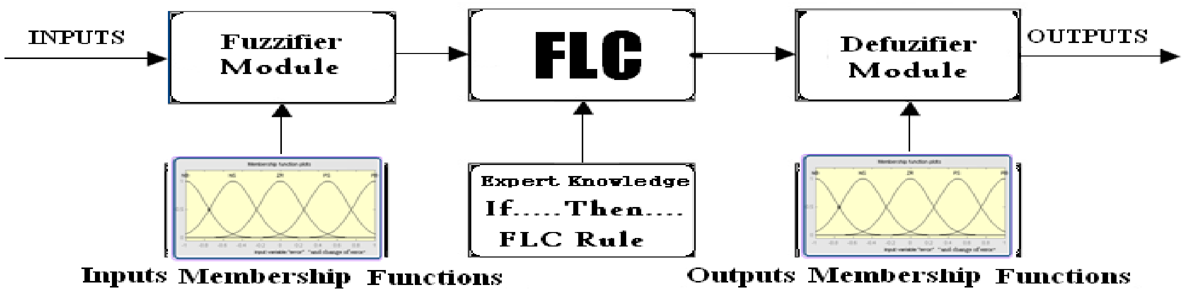

Fig.5.1 .FUZZY BASIC MODULE

Fuzzy set comprises from a membership function which could be defines by parameters. The value between 0 and 1 reveals a degree of membership to the fuzzy set. The process of converting the crisp input to a fuzzy value is called as "fuzzificaton." The output of the Fuzzier module is interfaced with the rules. The basic operation of FLC is constructed from fuzzy control rules utilizing the values of fuzzy sets in general for the error and the change of error and control action.

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The results are combined to give a crisp output controlling the output variable and this process is called as "DEFUZZIFICATION."

3.3. FUZZY RULES

Control

e \ Δe	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NL	NL	NL	NL
NM	NL	NL	NM	NM	NS	NS	NS
NS	NL	NM	NM	NS	NS	NS	ZR
ZR	ZR	ZR	ZR	ZR	ZR	ZR	ZR
PS	ZR	PS	PS	PS	PM	PM	PL
PM	PS	PS	PS	PM	PM	PL	PL
PL	PL	PL	PL	PL	PL	PL	PL

Fig. 5.2 control strategy based on Fuzzy controls Rule with combination of seven error states multiplying with seven change of error states.

IV. SIMULATION RESULTS

The operations of the Micro Grid grid under various source and load conditions are simulated to verify the proposed control algorithms. In this mode, the main converter operates in the PQ mode. Power is balanced by the utility grid. The battery is fully charged and operates in the rest mode in the simulation. AC bus voltage is maintained by the utility grid and dc bus voltage is maintained by the main converter

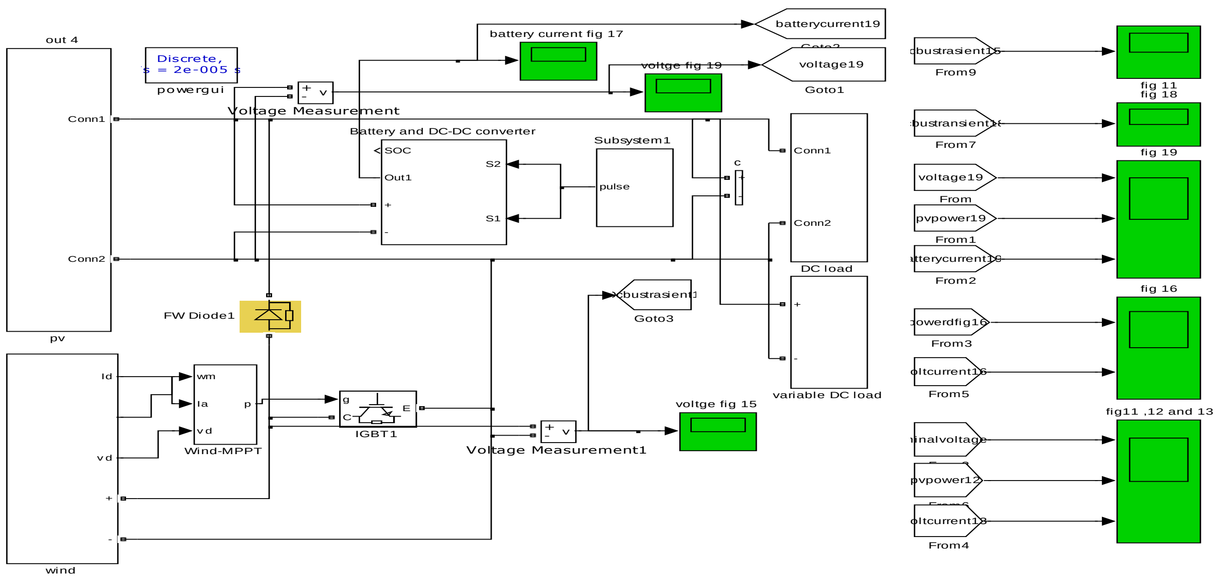

Fig.4.1 Grid-Connected Model for photo voltaic, wind and fuel cell in MATLAB/simulink

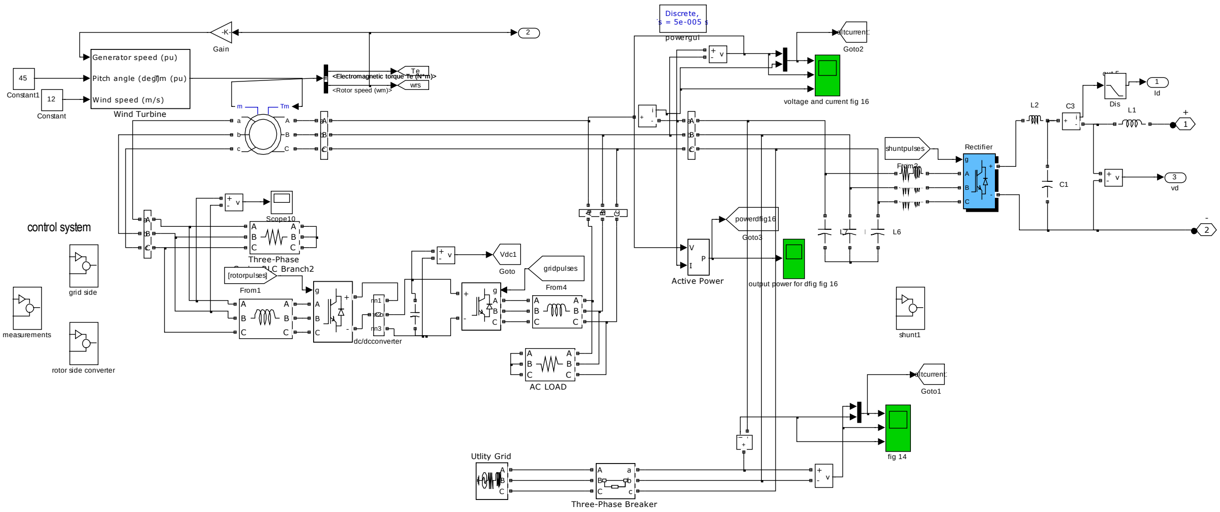

Fig4.2 double fed induction generator with series and shunt converters

4.2. Out put results

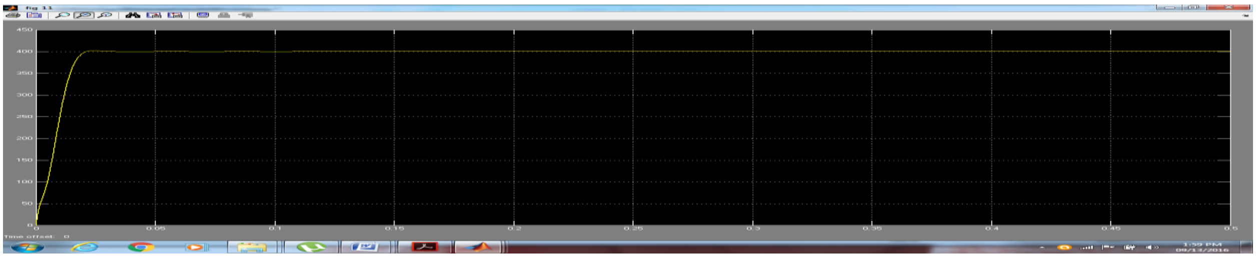

Fig.4.3.Wind turbine dc output voltage

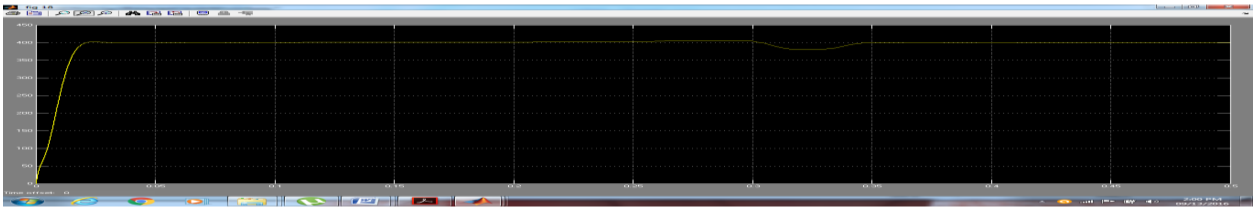

Fig.4.4.Output voltage of photovoltaic cell

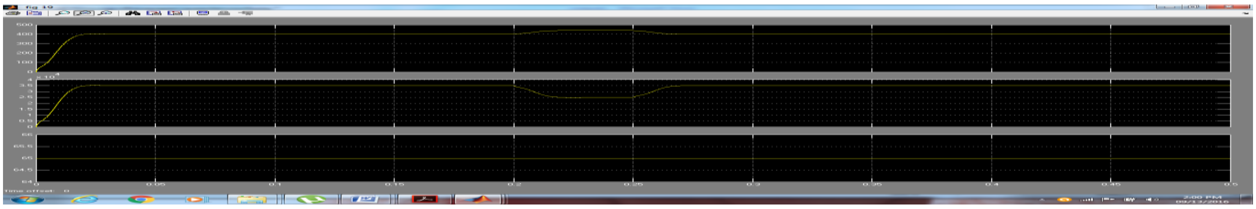

Fig.4.5.Battery Output Voltage, Solar Power, Fuel Cell Current

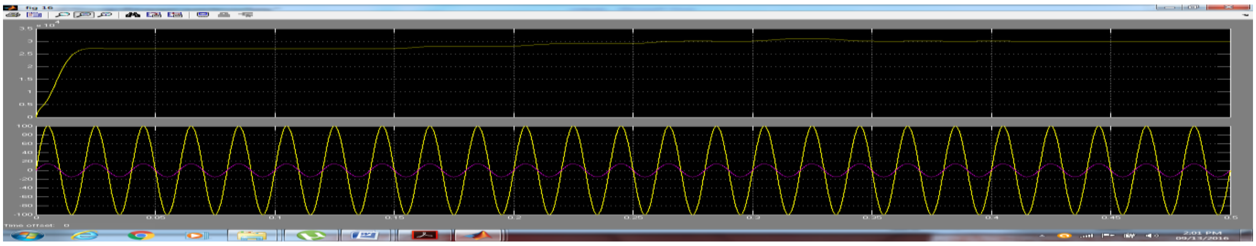

Fig.4.6Wind turbine power, voltage and current

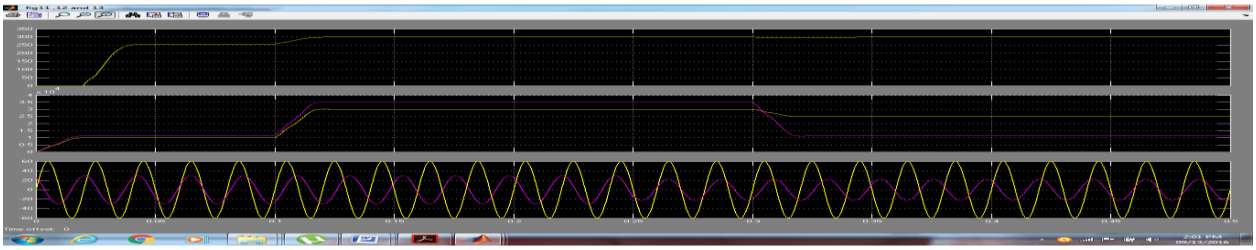

Fig.4.7.solar cell power, voltage and current

V. CONCLUSION

In this paper a micro grid and coordination at different control schemes are proposed. Fuzzy logic control scheme for fuel cell was proposed. For the all the converters to maintain stable system operation condition under various loads. The coordinated control strategies are designed and verified in Matlab/Simulink. The simulation results show that the Micro Grid can operate stably in the grid-tied or isolated mode. Stable ac and dc bus voltage can be guaranteed when the operating conditions or loads are changed. In this paper load demand was met from the combination of PV array, wind turbine and the fuel cell. An inverter is used to convert output from solar into AC power output. This Micro Grid system is controlled to give maximum output power under all operating conditions (through MPPT controller) to meet the desired load. For dc loads either wind or solar system is supported to charge the battery.

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