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ACTIVE CONTROL AND POWER MANAGEMENT OF DFIG IN AC/DC MICROGRID

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ABSTRACT

This paper 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. 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.

Keywords: Energy management, grid control, grid operation, hybrid Microgrid, PV system, wind power generation.

I. INTRODUCTION

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. Recently more renewable power conversion systems are connected in low voltage ac distribution systems as distributed generators or ac micro grids due to environmental issues caused by conventional fossil fueled power plants. On other hand, more and more dc loads such as light-emitting diode (LED) lights and electric vehicles (EVs) are connected to ac power systems to save energy and reduce CO_2 emission. When power can be fully supplied by local renewable power sources, long distance high voltage transmission is no longer necessary [1]. AC micro grids [2]–[5] have been proposed to facilitate the connection of renewable power sources to conventional ac systems. However, dc power from photovoltaic (PV) panels or fuel cells has to be converted into ac using dc/dc boosters and dc/ac inverters in order to connect to an ac grid. In an ac grid, embedded ac/dc and dc/dc converters are required for various home and office facilities to supply different dc voltages. AC/DC/AC converters are commonly used as drives in order to control the speed of ac motors in industrial plants.

Recently, dc grids are resurging due to the development and deployment of renewable dc power sources and their inherent advantage for dc loads in commercial, industrial and residential applications. The dc microgrid has been proposed [6]–[10] to integrate various distributed generators. However, ac sources have to be converted into dc before connected to a dc grid and dc/ac inverters are required for conventional ac loads.

Multiple reverse conversions required in individual ac or dc grids may add additional loss to the system operation and will make the current home and office appliances more complicated. The smart grid concept is currently prevailing in the electric power industry. The objective of constructing a smart grid is to provide reliable, high quality electric power to digital societies in an environmentally friendly and sustainable way. One of most important futures of a smart grid is the advanced structure which can facilitate the connections of various ac and dc generation systems, energy storage options, and various ac and dc loads with the optimal asset utilization and operation efficiency. To achieve those goals, power electronics technology plays a most important role to interface different sources and loads to a smart grid.

A hybrid ac/dc microgrid 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 renew-able ac and dc sources and loads to power system. Since energy management, control, and operation of a hybrid grid are more complicated than those of an individual ac or dc grid, different operating modes of a hybrid 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 hybrid 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.

II. SYSTEM CONFIGURATION AND MODELING:

A. Grid Configuration

Fig. 1 shows a conceptual hybrid 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 hybrid grid is tied to the utility grid.

A compact hybrid grid as shown in Fig. 2 is modeled using the Simulink in the MATLAB to simulate system operations and controls. Forty kW PV arrays are connected to dc bus through a dc/dc boost converter to simulate dc sources. A capacitor C_{pv} 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 bidirectional dc/ac main converter with R-L-C filter connects the dc bus to the ac bus through an isolation transformer.

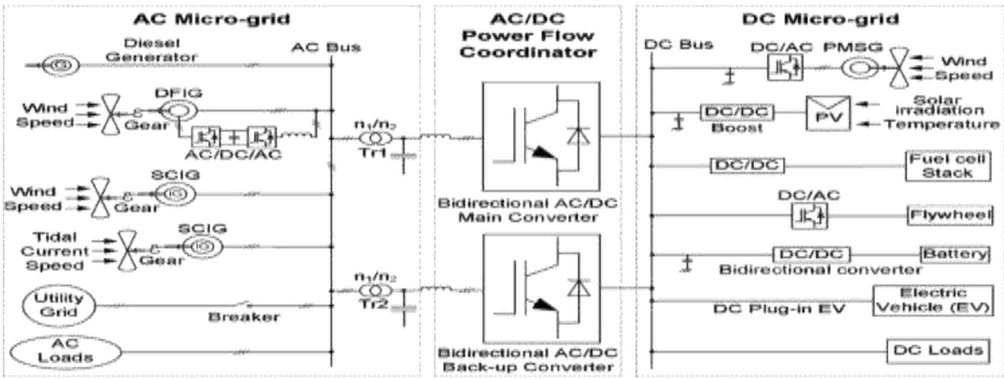

Fig.1. A hybrid ac/dc microgrid system

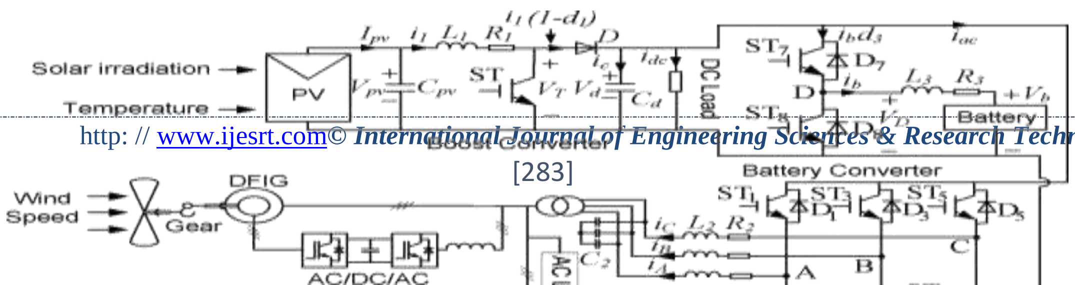

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Fig. 2. A compact representation of the proposed hybrid grid.

B. Grid Operation

The hybrid 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 hybrid grid, it will inject power to the utility grid. Otherwise, the hybrid 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 converter 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.

C. Modeling of PV Panel

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 [11], [12]. All the parameters are shown in Table I:

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

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

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

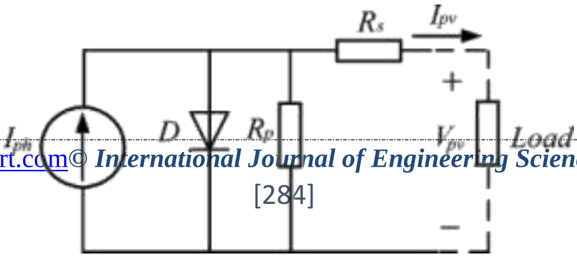

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Fig.3. Equivalent circuit of solar cell.

Table I parameters for photovoltaic panel

Symbol	Description	Value
P_{nom}	Nominal power	50 kW
V_{nom}	Nominal voltage	400 V
R_s	Stator resistance	0.00706 pu
L_s	Stator inductance	0.171 pu
R_r	Rotor resistance	0.005 pu
L_r	Rotor inductance	0.156 pu
L_m	Mutual inductance	2.9 pu
J	Rotor inertial constant	3.1 s
n_p	Number of poles	6
V_{dc_nom}	Nominal DC voltage of AC/DC/AC converter	800 V
P_m	Nominal mechanical power	45 kW

III. RESULTS AND DISCUSSION

In the proposed system, PV arrays are connected to the DC bus through boost converter to simulate DC sources. A DFIG wind generation system is connected to AC bus to simulate AC sources. A battery with bidirectional DC/DC converter is connected to DC bus as energy storage. A variable DC and AC load are connected to their DC and AC buses to simulate various loads. PV modules are connected in series and parallel. As solar radiation level and ambient temperature changes the output power of the solar panel alters. A capacitor C is added to the PV terminal in order to suppress high frequency ripples of the PV output voltage. The bidirectional DC/DC converter is designed to maintain the stable DC bus voltage through charging or discharging the battery when the system operates in the autonomous operation mode. The three converters (boost converter, main converter, and bidirectional converter) share a common DC bus. A wind generation system consists of doubly fed generator (DFIG) with back to back AC/DC/AC PWM converter connected between the rotor through slip rings and AC bus. The AC and DC buses are coupled through a three phase transformer and a main bidirectional power flow converter to exchange power between DC and AC sides. The transformer helps to step up the AC voltage of the main converter to utility voltage level and to isolate AC and DC grids.

Table II. Component parameters for the hybrid grid

Symbol	Value
C	110 µF
L_6	2.5 mH
C_T	4700 µF
L	0.43 mH
R	0.3 ohm
C	60 µF
$L_{\%}$	3 mH

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R%	0.1 ohm
F	50 Hz
f?	10 kHz
V_T	400 V
V⩤ _@—	400 V

The operations of the Micro Grid grid under various source and load conditions are simulated to verify the proposed control algorithms.

A. Grid-Connected Mode

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.

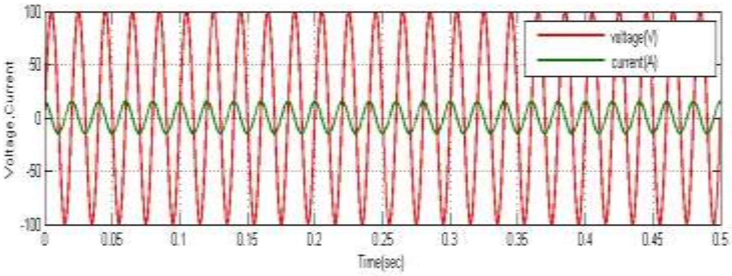

Fig.4. Microgrid voltage and current

The optimal terminal voltage is determined using the basic P&O algorithm based on the corresponding solar irradiation. The voltages for different solar irradiations with Micro grid are shown in Fig.4. The solar irradiation level is set as 400 W/m^2 from 0.0 s to 0.1 s, increases linearly to 1000 W/m^2 from 0.1 s to 0.2 s, keeps constant until 0.3 s, decreases to 400 W/m^2 from 0.3 s to 0.4 s and keeps that value until the final time 0.5 s. The initial voltage for the P&O is set at 250 V. It can be seen that the P&O is continuously tracing the optimal voltage from 0 to 0.2 s. The algorithm only finds the optimal voltage at 0.2 s due to the slow tracing speed. The algorithm is searching the new optimal voltage from 0.3 s and finds the optimal voltage at 0.48 s. It can be seen that the basic algorithm can correctly follow the change of solar irradiation but needs some time to search the optimal voltage. The improved P&O methods with fast tracing speed should be used in the PV sites with fast variation of solar irradiation.

Fig. 5 shows the curves of the solar radiation (radiation level times 30 for comparison) and the output power of the PV panel. The output power varies from 13.5 kW to 37.5 kW, which closely follows the solar irradiation when the ambient temperature is fixed.

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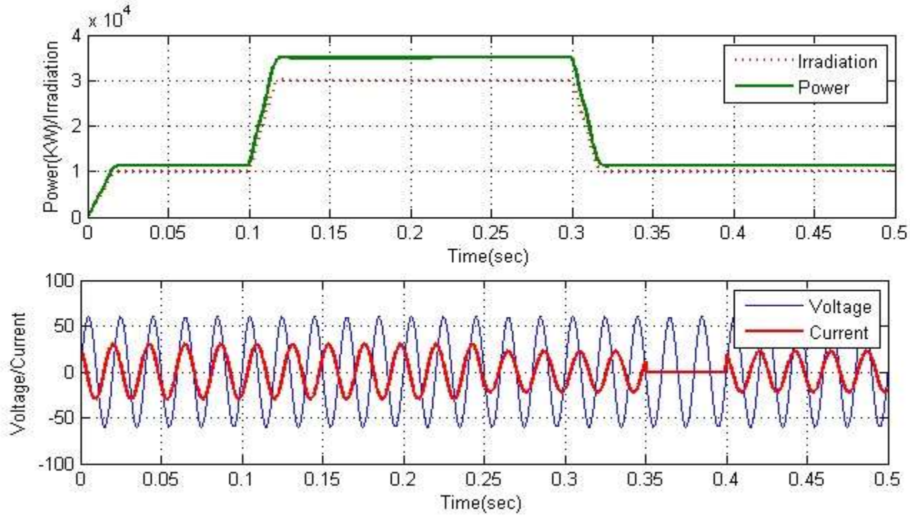

Fig. 5 & 6 PV output power versus solar irradiation and AC side voltage and current of the main converter with variable solar irradiation level and constant dc load

Fig. 6 shows the voltage (voltage times 0.2 for comparison) and current responses at the ac side of the main converter when the solar irradiation level decreases from 1000 W/m^2 at 0.3 s to 400 W/m^2 at 0.4 s with a fixed dc load 20 kW. It can be seen from the current directions that the power is injected from the dc to the ac grid before 0.3 s and reversed after 0.4 s.

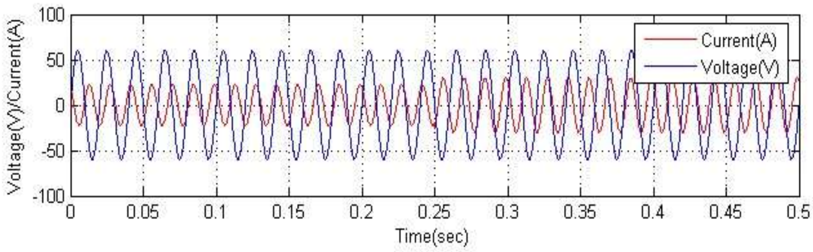

Fig.7.Lower: AC side voltage versus cur-rent (Voltage times 1/3 for comparison)

Fig. 7 shows the voltage (voltage times 0.2 for comparison) and current responses at the ac side of the main converter when the dc load increases from 20 kW to 40 kW at 0.25 s with a fixed irradiation level 750 W/m^2. It can be seen from the current direction that power is injected from dc to ac grid before 0.25 s and reversed after 0.25 s. Fig. 15 shows the voltage response at dc side of the main converter under the same conditions. The figure shows that the voltage drops at 0.25 s and recovers quickly by the controller.

B. Isolated Mode

The control strategies for the normal case and Case 1 are verified. In the normal case, Fig.8 dc bus voltage is maintained stable by the battery converter and ac bus voltage is provided by the main converter. The reference of dc-link voltage is set as 400 V. Fig.9 shows the dynamic responses at the ac side of the main converter when the ac load increases from 20 kW to 40 kW at 0.3 s with a fixed wind speed 12 m/s. It is shown clearly that the ac grid injects power to the dc grid before 0.3 s and receives power from the dc grid after 0.3 s. The voltage at the ac bus is kept 326.5 V constant regardless of load conditions. The nominal voltage and rated capacity of the battery are selected as 200 V and 65 Ah respectively. Fig. 16 also shows the transient process of the DFIG power output, which becomes stable after 0.45 s due to the mechanical inertia.

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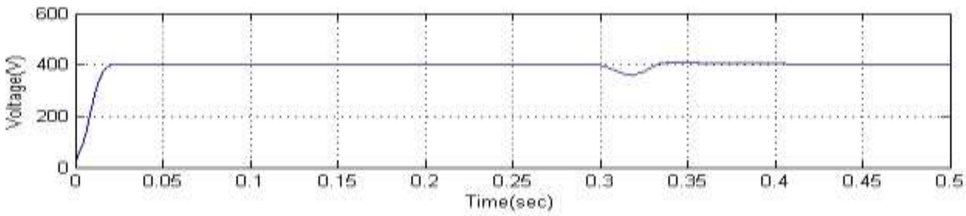

Fig.8. DC bus voltage transient response

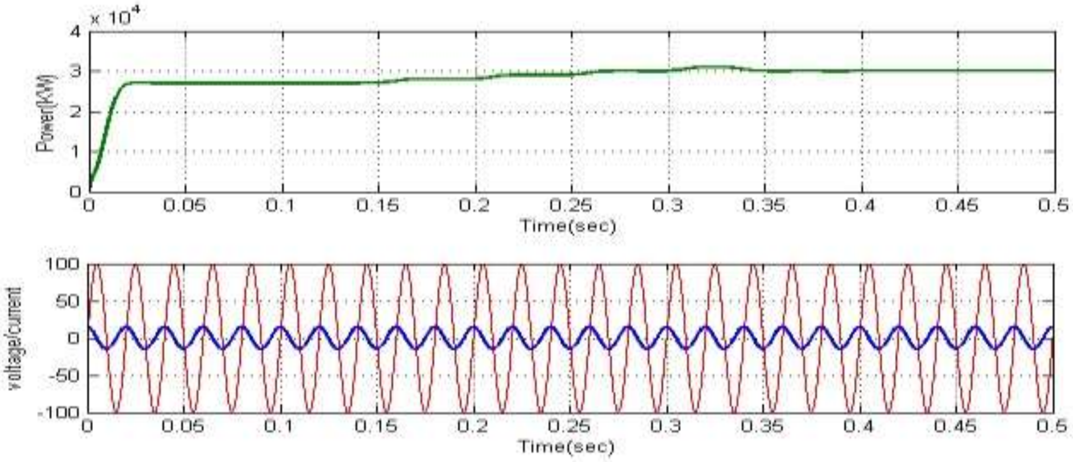

Fig. 9. Upper: output power of the DFIG; Lower: AC side voltage versus cur-rent (Voltage times 1/3 for comparison)

The SOC increases and decreases before and after 0.3 s respectively. Fig. 12 shows that the voltage drops at 0.3 s and recovers to 400 V quickly. When the system is at off-MPPT mode in Case 1, the dc bus voltage is maintained stable by the boost converter and ac bus voltage is provided by the main converter. Fig. 10 shows the dc bus voltage, PV output power, and battery charging current respectively when the dc load decreases from 20 kW to 10 kW at 0.2 s with a constant solar irradiation level 1000 W/m^2. The battery discharging current is kept constant at 65 A. The dc bus voltage is stabilized to 400 V after 0.05 s from the load change. The PV power output drops from the maximum value after 0.2 s, which means that the operating modes are changed from MPPT to off-MPPT mode. The PV output power changes from 35 kW to 25 kW after 0.2 s.

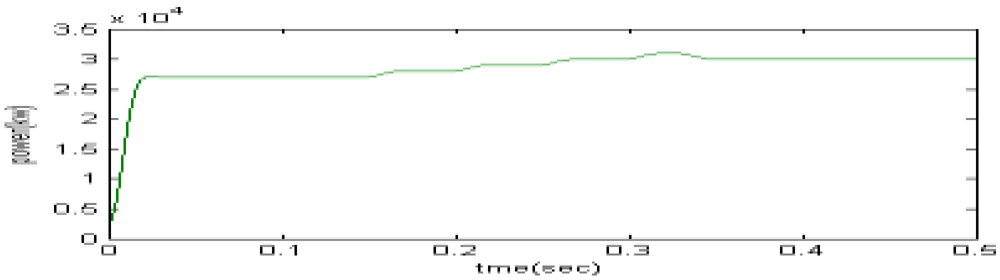

Fig. 12. DC bus voltage transient response in isolated mode

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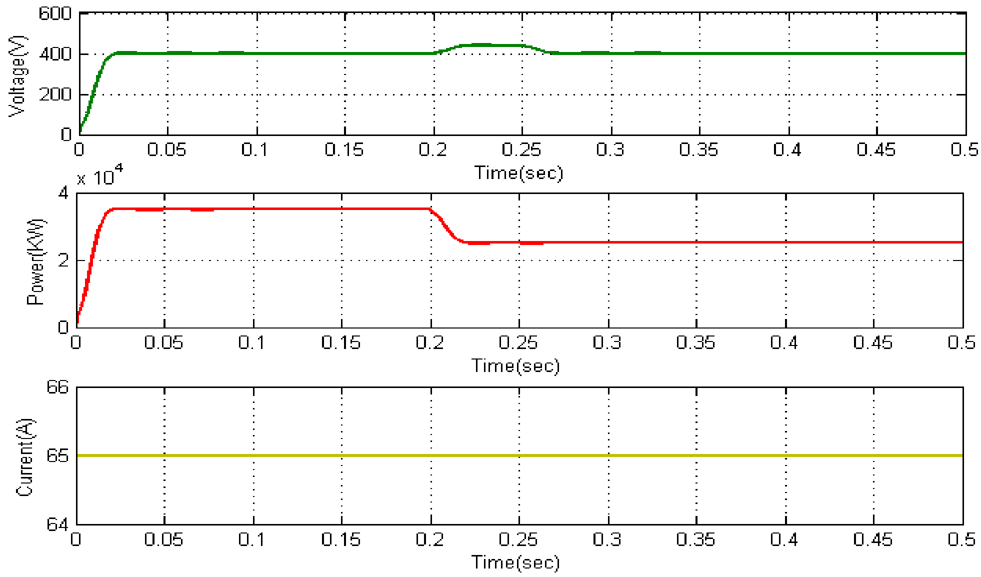

Fig.10. DC bus voltage, PV output power, and battery current for Case 1

IV. CONCLUSION& FUTHER SCOPE

A micro grid is proposed Analyses of models and coordination control schemes are proposed for the all the converters to maintain stable system operation under various load and resource conditions. The coordinated control strategies are verified by Mat-lab/Simulink. Various control methods have been incorporated to harness the maximum power from dc and ac sources and to coordinate the power exchange between dc and ac grid. Different resource conditions and load capacities are tested to validate the control methods. 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 load capacities change in the two modes. In the paper load demand is met from the combination of PV array, wind turbine and the battery. An inverter is used to convert output from solar & DFIG wind systems into AC power output. Circuit Breaker is used to connect an additional load is given in time. This Micro Grid system is controlled to give maximum output power under all operating conditions to meet the load. Either wind or solar system is supported by the battery to meet the load. Also, simultaneous operation of wind and solar system is supported by battery for the same load.

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