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COORDINATION CONTROL OF AC/DC MICROGRID

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ABSTRACT

Micro-grid conception exploits as a resolution to integrate liberal amounts of micro generation without obstructing the operation of utility grid. Generation of power from renewable energy sources like solar, wind, micro-turbines, fuel cells etc will give eloquent energy in near future. Consequently, AC/DC micro-grid will be the perfect resolution to moderate multiple reverse conversions (dc-ac-dc or ac-dc-ac) in an exclusive ac or dc grid. The contemplated micro grid contained both AC and DC networks coherent to distribution generation by using the multi-bidirectional converters. AC sources and loads are coherent to AC network whereas DC sources and loads are connected with the DC network. DC or AC links are connected by energy storage systems. This micro-grid can conduct in a grid-tied or isolated mode. For smooth power exchange between AC and DC links during multifarious supply and demand conditions, the coordination control schemes are contemplated. Modelling and simulation of a small micro grid is done using the Simulink in the MATLAB. The results of simulation shows that the system can prolonged stable operation under the contemplated coordination control schemes when the grid is commutated from one operating condition to another.

KEYWORDS: Micro Grid, Energy Management, Grid Operation, Grid Control, PV System

INTRODUCTION

In recent years, the renewable energy resources are attractive incentive for providing electric power in areas where the utility network connection is either unworkable or highly priced. New technologies in electric distribution system is developing and many directions are becoming perceptible that will compensate the requisite transformation of energy. Accumulating in the consumption of energy, inadequate complexion of fossil fuels and elevated cost, and the interest have created in green power generation systems due to the aggravate global environment. Due to swift desolation in fossil fuels with growing energy demand, Renewable sources attain extensive immersion. To extricate energy and to moderate CO emission, progressively dc loads such as electric vehicles (EVs) and light-emitting diode (LED) lights are coherent to ac power systems. When power can be fully provided by local renewable power sources, [1] high voltage transmission with long distance is no lasting obligatory. AC micro grids have been contemplated to promote the connection of renewable resources to prevalent ac systems. Although, by using dc/dc boost converter, dc power generated from photovoltaic (PV) panels or fuel cells has to be converted into ac and in order to connect to an ac grid dc/ac inverters are used [2]–[5]. The impacted dc/dc and ac/dc converters are prescribed for assorted office and home facilities to supply dc voltages in an ac grid. In order to control the speed of ac motors, AC/DC/AC converters consistently used in industrial plants as drives. Latterly, due to the progression and disposal of renewable dc power sources, dc grids are resurging and their intrinsic mastery for dc loads in industrial, residential and commercial applications. Multifarious distributed generators are integrated in dc micro grid. Although, before the connection made with a dc grid, ac sources required to be converted into dc and for conventional ac loads, dc/ac inverters are enforced. In an individual ac or dc grids, there is requirement of multiple reverse conversions that may cause adjunct loss to the system operation and more complication in current office and home appliances. In the electric power industry, the concept of smart grid is currently influential. The ambition of design a smart grid is to grant reliable, electric power with high quality to digital societies in an environmentally familiar and conceivable way [6]–[10]. The smart grid has one of most important features, the advanced structure which can reinforce the connections of multifarious energy storage options, ac and dc generation systems and peculiar ac and dc loads with the optimal eminence utilization and efficiency of operation. To accomplish those targets, power electronics technology plays a crucial role to consolidate different sources and loads to a smart grid. A ac/dc micro grid is contemplated in this paper to moderate multiple reverse conversions processes in an individual dc or ac grid and to expedite the connection of multifarious renewable ac and dc sources and loads to power system. The control, energy management and operation of a hybrid grid are more intricate than those of an individual ac or dc grid, distinct operating modes of ac/dc grid have been examined. The coordination control contrivance among multifarious converters have been contemplated to minimize power transfer between ac and dc networks, to exploit maximum power from renewable power sources, and the stable operation of both ac and dc grids is maintained under volatile supply and demand conditions when both grid-tied and islanding modes operates by the micro-grid. In this paper, a future power grid will make much smarter by the use of advanced power electronics and control technologies.

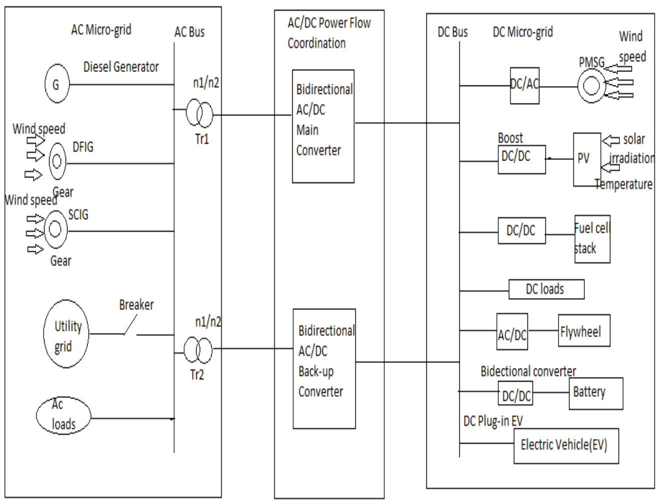

Figure 1: The AC/DC Micro Grid System

CONFIGURATION AND MODELING OF SYSTEM

A. Configuration of Grid

Figure 1 shows a conceptual micro grid system configuration where multifarious ac and dc sources and loads are interconnected to the analogous dc and ac networks. The ac and dc links are linked together through two transformers and two four-quadrant operating three phase converters. The ac bus of the micro-grid is connected to the utility grid.

In Figure 2, a compact micro-grid is modelled using the Simulink in the MATLAB to simulate system operations and controls. For the simulation of dc sources PV arrays of forty kW are coherent to dc bus through a dc/dc boost converter. A capacitor is used to clamp high frequency ripples from the PV output voltage. Energy is store by using a 65 Ah battery and is coherent to dc bus through a bidirectional dc/dc converter. Variable dc load (20 kW–40 kW) is connected to dc buses and ac load (20 kW–40 kW) are connected to ac buses respectively. The rated voltages for dc buses are 400V and ac buses are 400 V_{rms} respectively. A three phase dc/ac main converter (bidirectional) with R-L-C filter couples the dc bus to the ac bus through an isolation transformer.

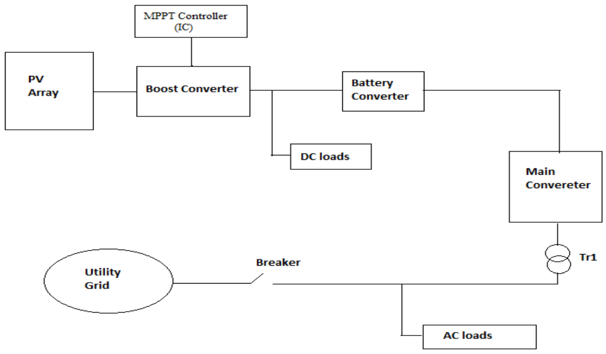

Figure 2: A Compact Representation of Proposed Micro Grid

B. Operation of Grid

The operation of micro grid can be done in two modes. In grid-connected mode, a stable dc bus voltage is provided by the main converter and imperative reactive power and to interchange power between the ac and dc buses. The maximum power is contribute for controlling of the boost converter. The converter works as an inverter, when the output power of the dc sources exceeds the dc loads and implants power from dc to ac side. The converter implants power from the ac to dc side, when the total power generation is smaller than the total load at the dc side. When the total power generation exceeds the total load in the micro grid, it will implants power to the utility grid. Contrarily, the micro-grid will inherit power from the utility grid. In the grid tied mode, there is no role of the battery converter in system operation because utility grid balanced the power. In autonomous mode, voltage stability and power balance both are controlled by the battery plays. Control aspirations for distinct converters are accelerate by energy management system. DC bus voltage is prolonged stable by a boost converter or battery converter according to distinct operating conditions. A stable and high quality ac bus voltage is provided by controlling of the main converter. PV can contrive on maximum power point tracking (MPPT) or off-MPPT mode depends on system operating requirements.

C. PV Panel Modelling

Usually, In PV system there is an interconnection of modules that formed with many PV cells in series or parallel. Single module produced power is very less and not plentiful to meet requisite the commercial applications, thus to supply the load the modules are coupled to form array. Modelling of PV panel is done with the help of these three equations [11], [12].

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

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

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

D. Battery Modelling

In PV array, Battery exploits as a homogeneous voltage load line and is energised with the help of PV array. The modelling of battery is done as a nonlinear voltage source whose output voltage level based the current and the battery state of charge (SOC), that is non linear function of time and current. Terminal voltage and SOC (state of charge) are the two important parameters to characterize the state of a battery are as follows:

$$V_b = V_o + R_b.i_b - K\frac{Q}{Q+\int i_b dt} + A.\exp(\mathrm{B}\int i_b dt) \tag{4}$$

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

Where R_b is internal resistance, i_b is the battery charging current, V_o is open circuit voltage, K is the polarization voltage of battery, B is the exponential capacity, Q is the battery capacity, and A is the exponential voltage [13].

Converters Coordination Control

The Micro-Grid consist five types of converters. And these converters must be coordinately controlled with the utility grid to replenish an interminable, high quality power and high efficiency to multifarious dc and ac loads under multifarious wind speed and solar irradiation when the micro grid percolate in both isolated and grid tied modes. For the converters, the control algorithms are manifest in this section.

A. Grid-Connected Mode

When the micro grid percolates in this mode, the control ambition of the boost converter is to groove the MPPT of the PV array by modulate its terminal voltage. The energy surplus of the micro grid can be sent to the utility system. As the energy storage, the function of the battery becomes less valuable because the power is balanced by the utility grid. In this mode of operation, the function of the battery is to only remove frequent power translation between the dc and ac link. By using the technique, the battery converter (dc/dc converter) is controlled as the energy buffer [14]. The design of the main converter is to work bidirectionally to associate corresponding characteristic of solar sources [15]. For variable dc load, the maintenance of a stable dc-link voltage and the synchronization with the ac link and with utility system is the control aim of the main converter [16] [17].

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

$$P_{pv} + P_{ac} = P_{dcL} + P_b \tag{6}$$

Where power P_{pv} is produced by PV system, and P_{dcL} is real power load which is connected with dc link. P_b Is the injection of power to battery [18]-[21].

B. Islanding Mode

When the micro-grid runs in the isolated mode, the boost converter may operate in the on-MPPT or off-MPPT snide on energy constraints and power balance system. The main converter interpret like a voltage source to furnish a stable frequency and voltage for the ac grid and for the smooth power exchange between ac and dc bus it operates either in converter or inverter mode. The battery converter runs either in charging or discharging mode depends on power balance in the system. The dc-bus voltage is maintained balance by either the battery or the boost converter depends on the system operating condition. Powers in multifarious load and supply conditions should be maintained balance with the following equation:

$$P_{pv} = P_{acL} + P_{dcL} + P_{loss} + P_b \tag{7}$$

Where P_{loss} is the total grid loss.

The coordination controls for two levels are used for the maintenance of stable system operation. In the system level, the energy management system (EMS) determines the operation modes of the individual converters that depend on the net power of system P_{net} and energy constraints and also the charging/discharging rate of battery.

The controlled logic diagram of the system is shown in Fig. 3. P_{net} is the total maximum power generation minus the total load and minusP_{loss}. Determination of the energy constraints of the battery are depending on the state of charge (SOC) limits by using $SOC_{min} < SOC \leq SOC_{max}$. It should be notorious that SOC of battery cannot be calculated directly, but can be achieved among some evaluation methods as depicted in [22], [23]. The charging and discharging rate constraint is: $P_b \leq P_{bmax}$. The peculiar converters operation depends on mode commands from the EMS at local level. PV system operates in the off-MPPT mode for Case 1 and Case 2 and for other cases, operates in the on-MPPT mode. The battery converter percolates in the charging, discharging or idle mode for distinct cases. There is requirement of Load shedding to maintain power balance when the power supply is lower than

Table I: Component Parameters for Micro Grid

C_1	Capacitor across the solar panel	1000uF
L_1	Inductor for the boost converter	72uH
C_2	Capacitor across the dc-link	6700uF
L_2	Filtering inductor for the inverter	80uH
R_2	Equivalent resistance of the inverter	20ohm
C_2	Filtering capacitor for the inverter	8uF
L_3	Inductor for the battery converter	3mH
R_3	Resistance of L3	0.1ohm
F	Frequency of the AC grid	50Hz
f_s	Switching frequency of power converters	10kHz
V_d	Rated DC bus voltage	400V
V_{ll_rms}	Rated AC bus line voltage(rms value)	400V
n_1/n_2	Ratio of transformer	2:1

Demand and In this case, the battery is at the minor SOC [24]-[27].

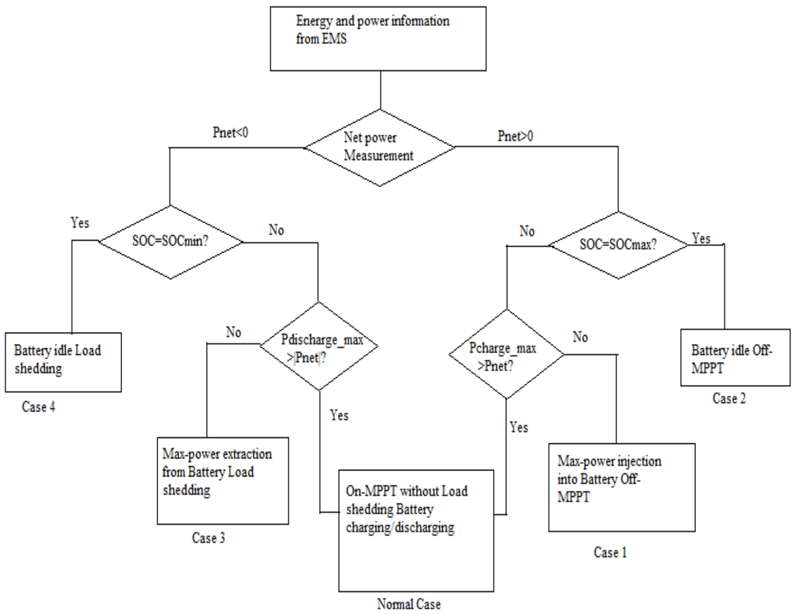

Figure 3: Control Mode Diagram for the Isolated Micro Grid [28]

SIMULATION RESULTS

The exertion of the micro-grid under multifarious source and load conditions are simulated also the verification of designed control algorithms. The exertion is carried out for grid connected mode and isolated mode. Furthermore, the performance of photovoltaic system is analyzed in micro-grid. The performance dissection is done with the help of simulated results by using MATLAB/SIMULINK. For the study of grid, the solar irradiation and cell temperature are taken into deliberation.

A. Grid-Connected Mode

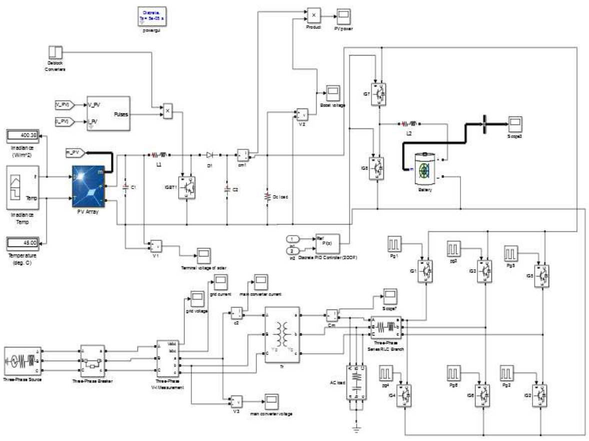

Figure 4: Simulink Model of Micro Grid in Grid Connected Mode

In grid connected mode of operation, the main converter percolates in the PQ mode. Power is maintained balance with the utility grid. In this case there is no role of battery and operates in rest mode, also the battery is fully charged. The utility grid maintained balance AC bus voltage and the main converter maintained balance dc bus voltage. The peak terminal voltage is persistent using the basic Incremental conductance(IC) algorithm depends on the analogous solar irradiation. The voltages for distinct solar irradiations are shown in Figure 5.

From 0.0 s to 0.1 s the irradiation level of solar is obstinate as 400W/m^2, from 0.1 s to 0.2 s growths linearly to 1000W/m^2, and remain constant until 0.3 s, from 0.3 s to 0.4 s diminishing to 400W/m^2 and remains that value until the supreme time 0.5 s. The initial voltage for the IC is obstinate at 350 V. It can be noted that the IC is continuously tracing the peak voltage from 0 to 0.25 s. Due to the slow tracing rate, the algorithm only search the peak voltage at 0.25s. The new peak voltage is finding by algorithm from 0.33 s and finds the optimal voltage at 0.49 s. The primitive algorithm can accurately follow the change of solar irradiation but require some time to find the peak voltage. With fast alternation in solar irradiation, the reformed IC methods with fast tracing rate should be used in the PV sites.

The solar radiation curves and the output power of the PV panel are shown in Figure 6 and Figure 7 and the variation of output power from 14 kW to 40 kW, when the ambient temperature is fixed and approximately follows the solar irradiation. The output voltage of boost converter is shown in Figure 8. The solar terminal voltage level is boost up by boost converter. In boost converter the load voltage is always greater than the source voltage ($V_{load} > V_{source}$).

At the ac side of the main converter, the voltage and current responses are shown in Figure 9 and Figure 10 when the solar irradiation level reduces from 1000W/m^2 at 0.3 s to 400W/m^2 at 0.4 s with a fixed dc load of 32 kW. It can be noted from the direction of current that the injected of power from dc to ac grid before 0.02 s and after 0.1 s it is reversed.

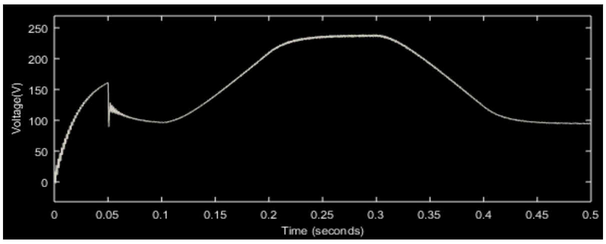

Figure 5: Terminal Voltage of Solar Panel

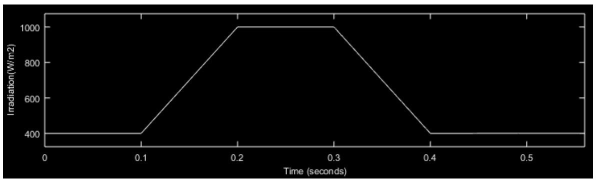

Figure 6: Solar Irradiation

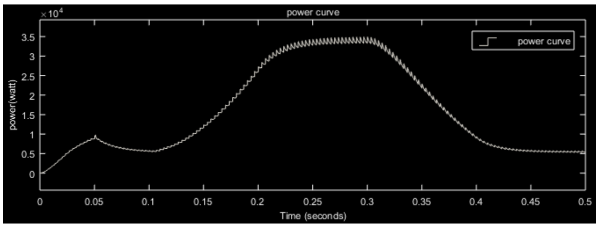

Figure 7: PV Output Power

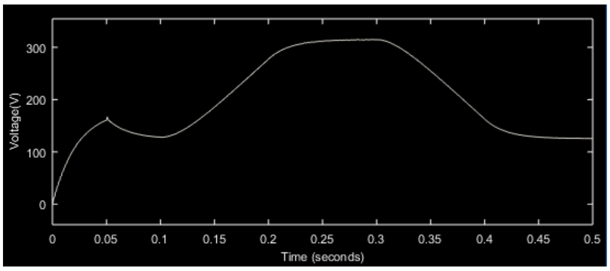

Figure 8: Output Voltage of Boost Converter

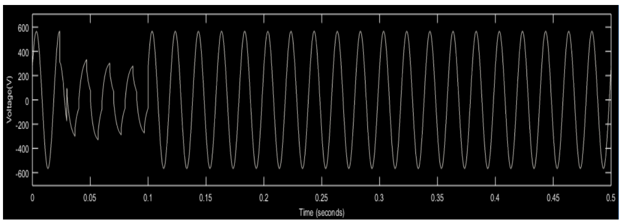

Figure 9: AC Side Voltage of the Main Converter with Variable Solar Irradiation Level and Constant DC Load

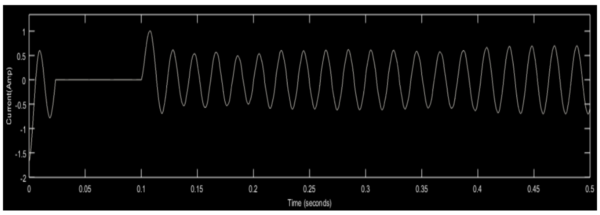

Figure 10: Ac Side Current of the Main Converter

B. Islanding Mode

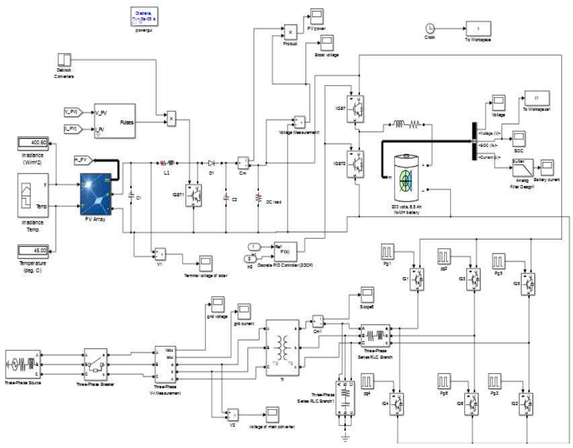

Figure 11: Simulink Model of Micro Grid in Islanding Mode

The strategies for control are verified in the normal case and Case 1. In the normal case, the battery converter maintained the dc bus voltage stable and the main converter provide voltage to the ac bus. The dc-link voltage reference is set as 400V. Due to load conditions, the voltage at ac bus is maintained 325 V constant. The battery nominal voltage and rated capacity are preferred as 200 V and 65 Ah respectively.

In Case 1, when the system mode is at off-MPPT, the boost converter maintained the dc bus voltage stable and the main converter balanced the ac bus voltage.

Figure 12 and Figure 13 show the AC side voltage of the main converter during the isolated mode, here the main converter balanced the AC load and battery converter balanced the DC load when the DC load is variable with constant solar irradiation level. The injection of power is done from DC to Ac grid after 0.1 s.

The PV power output drops from the maximum value after 0.1 s, which means that the operating modes are changed from MPPT mode to off-MPPT mode. The PV output power varies from 40 kW to 25 kW after 0.1 s.

The current and SOC of the battery are shown in Figure 14 and Figure 15. Before 0.1 s, the generated total power is larger than the total load and lower than the total load after 0.15 s. The battery works in charging mode before 0.38 s due to the positive current and discharging mode after 0.38 s due to the negative current. The SOC (state of charge) increases and decreases before and after 0.38 s.

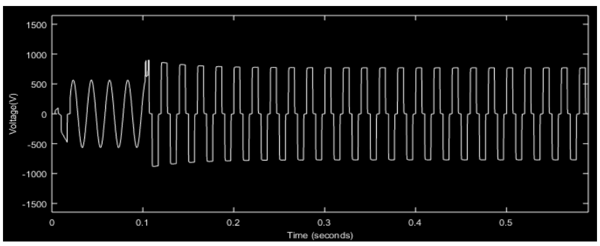

Figure 12: AC Side Voltage of the Main Converter with Constant Solar Irradiation Level and Variable DC Load

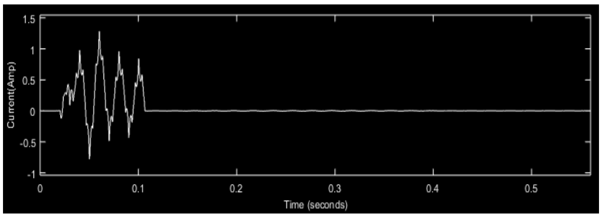

Figure 13: AC Side Current of Main Converter in Isolated Mode

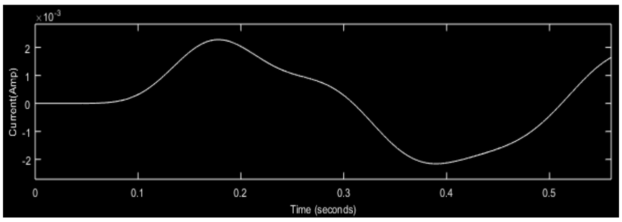

Figure 14: Battery Charging Current

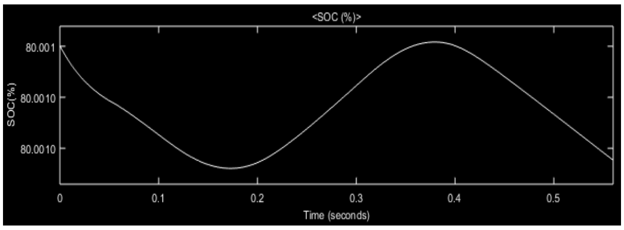

Figure 15: SOC of Battery

CONCLUSIONS

The ac/dc micro-grid is contemplated and comprehensively studied in this paper. The coordination control schemes of micro-grid and models are contemplated for converters to maintain the system stable operation under multifarious resource and load conditions. The verification of coordinated control strategies are done by Matlab/Simulink. Multifarious control strategy have been incorporated to exploit the maximum power from ac and dc sources and to coordinate the exchange of power between ac and dc grid. Distinct resource conditions and load capabilities are sampled to vindicate the control methods. The results of simulation demonstrate that the micro grid can work stably in the grid-connected mode or islanding mode. Stable ac and dc bus voltage can be covenant when the working conditions or load capabilities vary in the two distinct modes. During the load condition variation, the power is smoothly exchanged.

Whereas the micro-grid can reduce the processes of dc/ac and ac/dc conversions in a particular ac or dc grid, for implementation of the micro grid, there are many realistic problems that depend on the current ac controlled infrastructure. The total efficiency of system depends on the increment for a surplus dc link and deduction in conversion losses. The redesigning of the home and office products are very difficult for companies without using embedded ac/dc rectifiers whereas it is theoretically possible. Therefore, the micro grids may be executed when PV systems are install on the roofs by some small customers and are interested to use EV charging systems and LED lighting systems. The micro grid may also be attainable for some small isolated industrial plants with both PV systems as the leading power supply.

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