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Implementation of Hybrid AC/DC Micro Grid to Reduce the Processes of Multiple Conversions

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Abstract:

This project proposes a hybrid 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 hybrid 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 hybrid 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. Uncertainty and intermittent characteristics of wind speed, solar irradiation level, ambient temperature, and load are also considered in system control and operation.

A small hybrid grid has been modeled and simulated using the Simulink in the MATLAB. The simulation results show that the system can maintain stable operation under the proposed coordination control schemes when the grid is switched from one operating condition to anotherSince 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.

Keywords:

Micro grid, Conversions, Hybrid grid, PV, Renewable power sources.

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) light sand electric vehicles (EVs) are connected to ac power systems to save energy and reduce CO emission. When power can be fully supplied by local renewable power sources, long distance high voltage transmission is no longer necessary. AC micro grids 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.

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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 micro grid has been proposed 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.

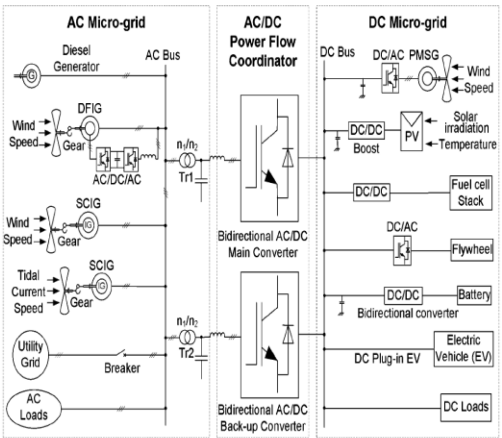

Figure1 hybrid ac/dc micro grid system

A hybrid ac/dc micro grid is proposed in this project 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 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 project will make a future power grid much smarter.

Hybrid system configuration:

The figure 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.

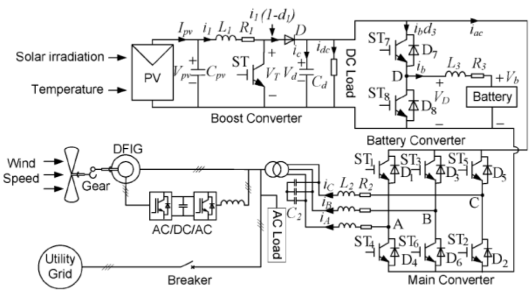

Figure 2 proposed hybrid grid compact representation

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A capacitor 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.

Wind power:

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

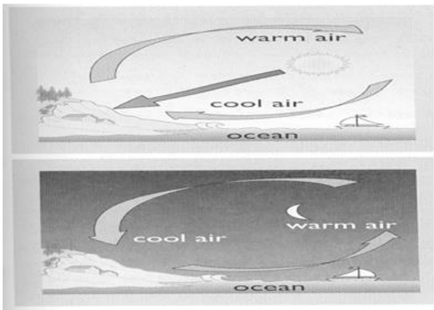

Fig 3: Formation of wind due to differential heating of land and sea

Features of wind power systems:

There are some distinctive energy end use features of wind power systems

- Most wind power sites are in remote rural, island or marine areas. Energy requirements in such places are distinctive and do not require the high electrical power.
- A power system with mixed quality supplies can be a good match with total energy end use i.e. the supply of cheap variable voltage power for heating and expensive fixed voltage electricity for lights and motors.
- Rural grid systems are likely to be weak (low voltage 33 KV). Interfacing a Wind Energy Conversion System (WECS) in weak grids is difficult and detrimental to the workers' safety.
- There are always periods without wind. Thus, WECS must be linked energy storage or parallel generating system if supplies are to be maintained.

Photovoltaic Technology

Photovoltaic's is the field of technology and research related to the devices which directly convert sunlight into electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation.The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice.

For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers. On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a

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diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction. Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load. When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart(electrons). In this way an electrical current is extractedonce the circuit is closed on an external load.

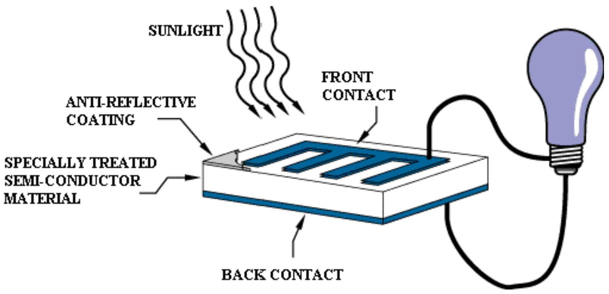

Figure 4: photovoltaic arrangement

AC-DC Converter: A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components. A device which performs the opposite function (converting DC to AC) is known as an inverter. When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper (I) oxide or selenium rectifier stacks were used.

DC-DC Converter

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC-to-DC converter topologies.

MATLAB DESIGN OF CASE STUDY AND RESULTS

SIMULATION DIAGRAM OF PROPOSED HYBRID GRID IN GRID CONNECTED MODE FOR CASE1:

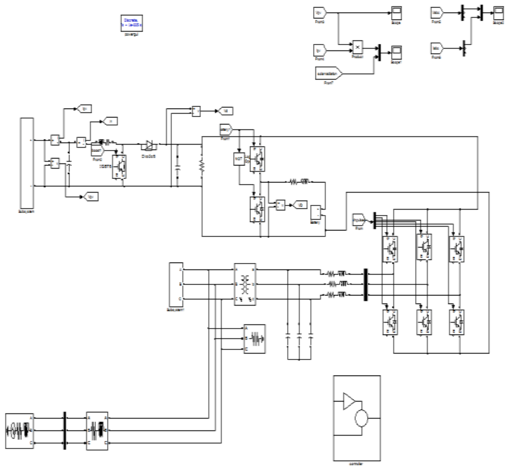

Fig.5simulink circuit for grid connected mode of hybrid grid

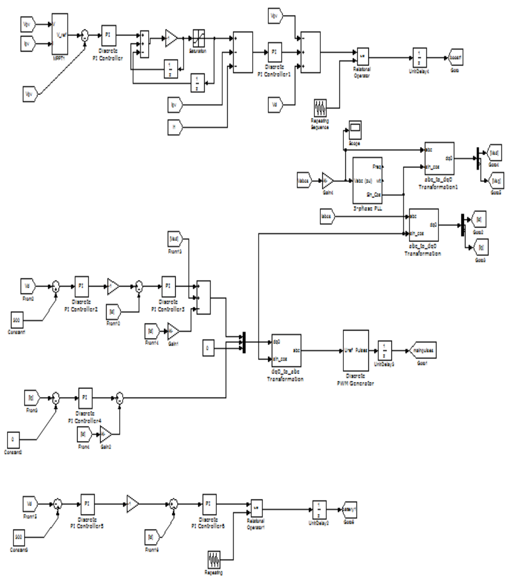

Fig.6 controller circuit for grid connected mode

In order to maintain stable operation of the hybrid grid under various supply and demand conditions, a coordination control algorithm for booster and main converter is proposed based on basic control algorithms of the grid interactive inverter. The control block diagram is shown in Fig.6

Simulation results for case1

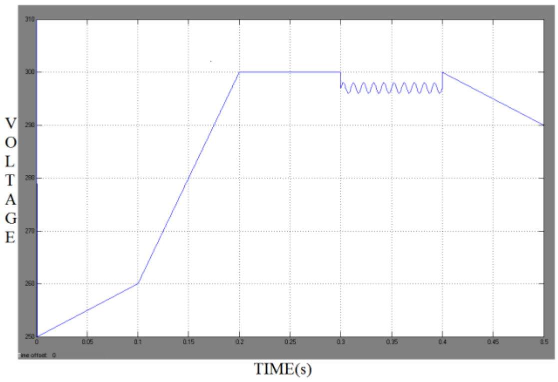

Fig.7 terminal voltage of solar panel

The optimal terminal voltage is determined using the basic P&O algorithm based on the corresponding solar irradiation. The voltages for different solar irradiations are shown in Fig.7. The solar irradiation level is set as 400W/m from 0.0 s to 0.1 s, increases linearly to 1000W/m from 0.1 s to 0.2 s, keeps constant until 0.3 s, decreases to 400W/m 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.

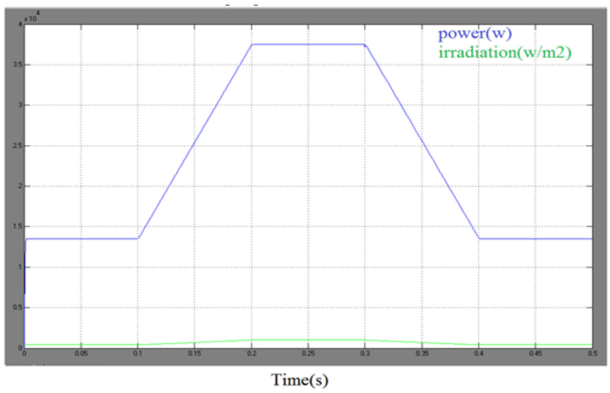

Fig.9 PV output power versus solar irradiation

Fig.9 shows the curves of the solar radiation 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.

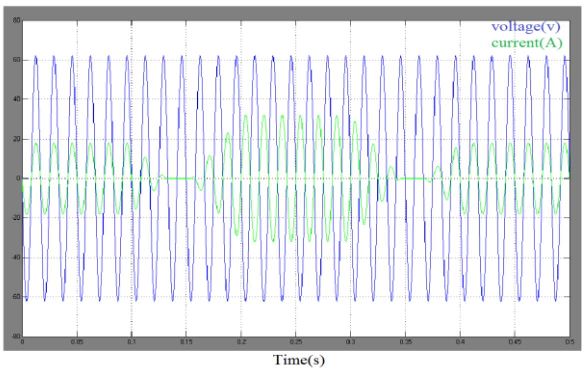

Fig.10 AC side voltage and current of the main converter with variable solar irradiation level and constant DC load

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Fig.10 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 1000W/m at 0.3 s to 400 W/m 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.

SIMULATION DIAGRAM OF PROPOSED HYBRID GRID IN GRID CONNECTED MODE FOR CASE2:

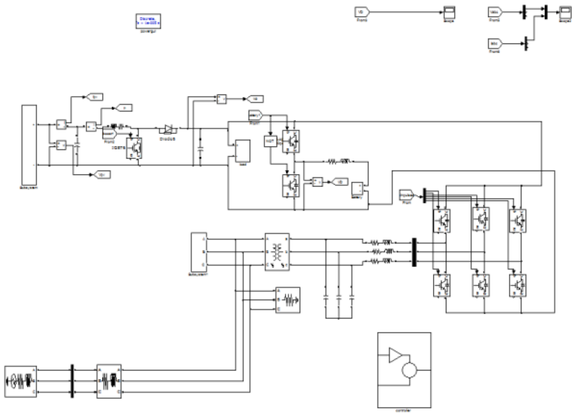

Fig 11simulink circuit for case 2

Simulation results for case1

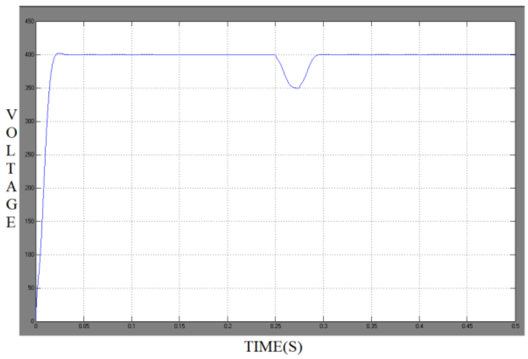

Fig.12 DC bus voltage transient response

The above output ie. Fig.12 shows the voltage response at dc side of the main converter under the same conditions. This shows that the voltage drops at 0.25 s and recovers quickly by the controller.

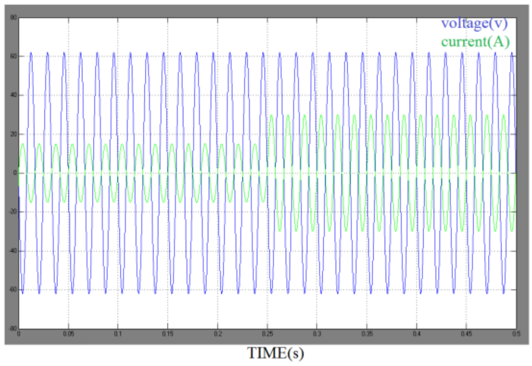

Fig.13 AC side voltage and current of the main converter with constant solar Irradiation level and variable dc load.

Fig.13 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 750W/m. 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.

SIMULATION DIAGRAM OF PROPOSED HYBRID GRID IN ISOLATEDTED MODE FOR CASE3:

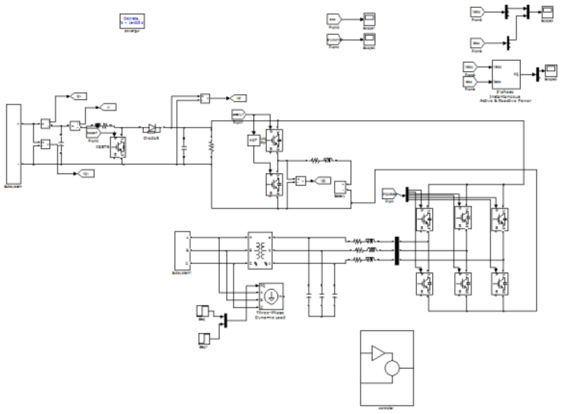

Fig.14simulink circuit for isolated mode of hybrid grid

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Simulation results for case3

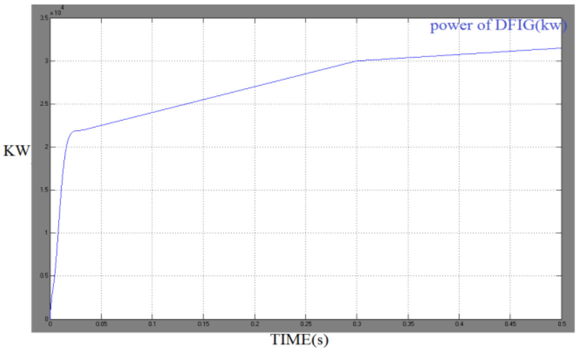

Fig.15 Output power of the doubly fed induction generator

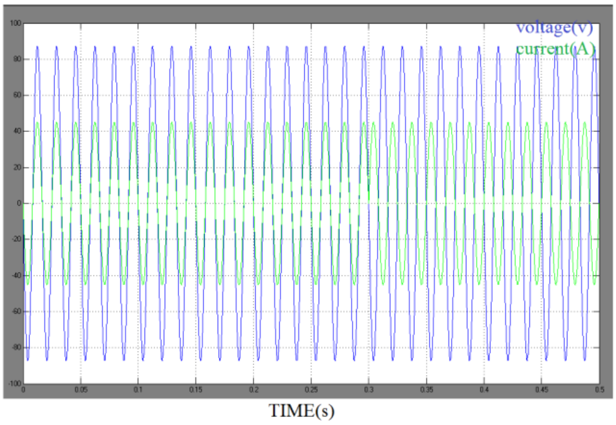

Fig.16 AC side voltage versus current

The control strategies for the normal case and Case 1 are verified.In the normal case, dc bus voltage is maintained stableby the battery converter and ac bus voltage is provided by themain converter. The reference of dc-link voltage is set as 400V. Fig.8.11shows the dynamic responses at the ac side of themain converter when the ac load increases from 20 kW to 40kW at 0.3 s with a fixed wind speed 12 m/s.

It is shown clearlythat the ac grid injects power to the dc grid before 0.3 s and receivespower from the dc grid after 0.3 s. The voltage at the acbus is kept 326.5 V constant regardless of load conditions. Thenominal voltage and rated capacity of the battery are selected as200 V and 65 Ah respectively. Fig. 17 also shows the transientprocess of the DFIG power output, which becomes stable after0.45 s due to the mechanical inertia.

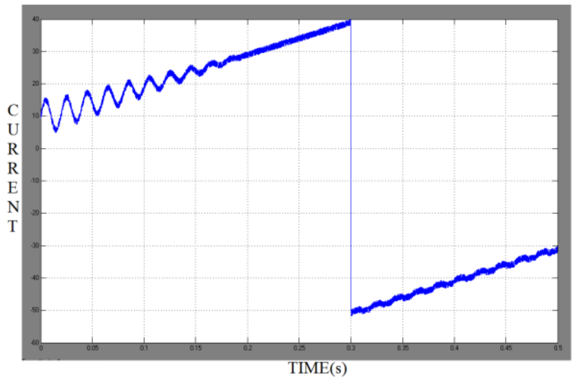

Fig.17 battery charging current

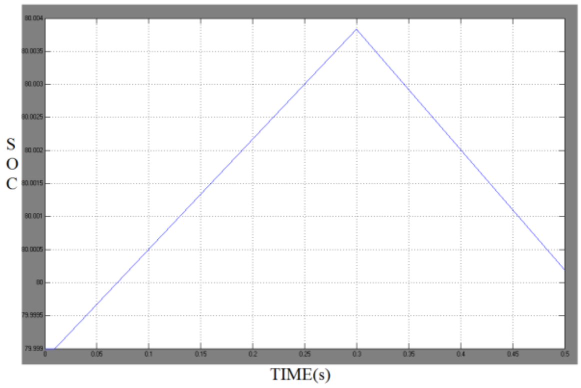

Fig.18 Battery state of charge

Fig.17 shows the current and fig.18 shows the SOC of the battery. It can be seen from Fig. 17 that the battery operates in charging mode before 0.3 s because of the positive current and discharging mode after 0.3 s due to the negative current. The SOC increases and decreases before and after 0.3 s respectively.

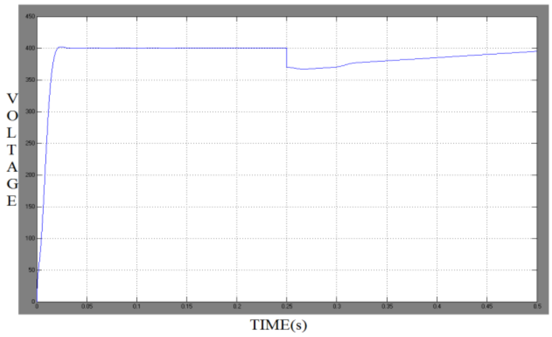

Fig.19 DC bus voltage transient response in isolated mode

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Fig. 19 shows the voltage of the battery. The total power generated is greater than the total load before 0.3 s and less than the total load after 0.3 s. Fig. 8.19 shows that the voltage drops at 0.3 s and recovers to 400V quickly.

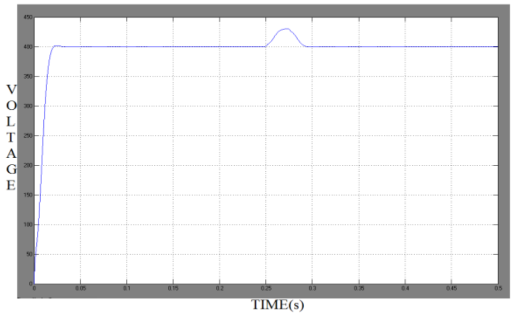

Fig.20 DC bus voltage

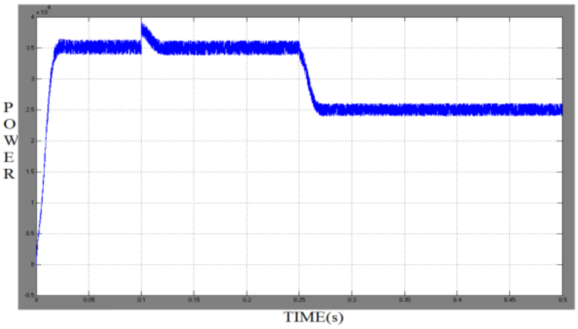

Fig.21 PV output power

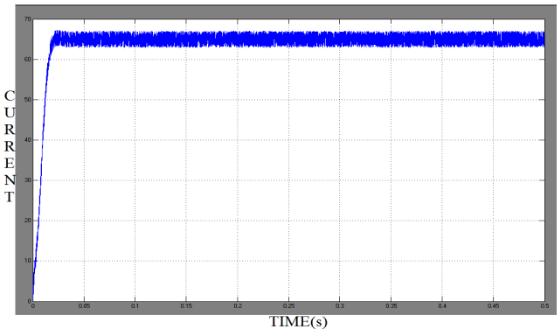

Fig.22 Battery current

Fig. 20 shows the dc bus voltage, Fig. 21 PV output power, and Fig. 22 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 1000W/m. The battery discharging current is kept constant at 65A. 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.

CONCLUSION:

A hybrid ac/dc micro grid is proposed and comprehensively studied in this project. The 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 MATLAB/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 hybrid 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. The power is smoothly transferred when load condition changes.Although the hybrid grid can reduce the processes of dc/ac and ac/dc conversions in an individual ac or dc grid, there are many practical problems for implementing the hybrid grid based on the current ac dominated infrastructure. The total system efficiency depends on the reduction of conversion losses and the increase for an extra dc link.

It is also difficult for companies to redesign their home and office products without the embedded ac/dc rectifiers although it is theoretically possible. Therefore, the hybrid grids may be implemented when some small customers want to install their own PV systems on the roofs and are willing to use LED lighting systems and EV charging systems. The hybrid grid may also be feasible for some small isolated industrial plants with both PV system and wind turbine generator as the major power supply.

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