Abstract—Microgrid concept acts as a solution to integrate large amounts of micro generation without disrupting the operation of utility grid. Power generation from renewable energy sources like wind, solar, fuel cells, microturbines etc will give significant momentum in near future. Thus, hybrid AC/DC microgrid will be the best solution to reduce multiple reverse conversions (dc-ac-dc or ac-de-ac) in an individual ac or dc grid. The proposed hybrid grid consists of both AC and DC networks connected to distribution generation through the multi-bidirectional converters. AC sources and loads are connected to AC network whereas DC sources and loads are tied to the DC network. Energy storage systems can be connected to dc or ac links. This microgrid can operate in a grid-tied or isolated mode. The coordination control schemes are proposed for smooth power transfer between AC and DC links during various supply and demand conditions. This paper presents a simulation of small hybrid microgrid and its modeling in the MATLAB/SIMULINK environment.

Keywords—Coordination control operation, grid control, grid operation, hybrid microgrid, isolated mode, PV System, wind power generation.

I. INTRODUCTION

Recently renewable energy sources are attractive options for providing power in places where a connection to the utility network is either impossible or unduly expensive. As electric distribution technology steps into next century, many trends are becoming noticeable that will change the requirements of energy delivery. The ever increasing energy consumption, soaring cost and exhaustible nature of fossil fuels, and the worsening global environment have created increased interest in green power generation systems. Renewable sources have gained worldwide attention due to fast depletion of fossil fuels along with growing energy demand. On other hand, more and more dc loads such as light-emitting diode (LED) lights and electric vehicles are connected to ac power systems to save energy and reduce CO₂ emission. Long distance high voltage transmission is not necessary when power is fully supplied by local renewable power sources [1]. The concept of the microgrid has been evolved for smooth integration and control of distributed generations with the utility grid. AC microgrids [2]-[5] have been proposed to facilitate the connection of renewable power sources to conventional AC systems.

DC power from photovoltaic panels (PV) 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. Recently, DC micro 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 to incorporate various distributed generators and ac sources have to be converted into dc before connected to a dc grid and dc/ac inverters are required for conventional ac loads [6]-[10]. DC microgrid cannot completely eliminate losses occurring in multiple stage conversions, though losses occurring in dc/ac conversions are lesser than those occurring in dc/dc conversions.

Multiple reverse conversions are required in an individual ac or dc grids may add additional loss to the system operation and will make current home and office appliances more complicated. Thus, a hybrid microgrid is more beneficial to reduce the processes of multiple reverse conversions in an individual ac or dc micro grid to facilitate the connection of variable renewable ac and dc sources and loads with the power system in order to minimize the conversion losses. Since the operational issues of hybrid grid is more complicated than those of an individual ac and dc microgrids. A microgrid comprises of low voltage distributed systems with distributed generations, storage devices, loads and interconnecting switches. The operation of microgrids provide advantages of higher flexibility, better power quality, controllability, efficiency of operation, and bidirectional power flow between the utility grid and the microgrid in the grid connected mode of operation.

This paper presents an analysis and performance of hybrid grid and various issues such as operating modes, coordination control algorithms among various converters to harness maximum power and stable operation of both ac and dc grids. Operating modes of microgrid are discussed. The advanced power electronics and control technologies used in this paper will make a future power grid much smarter.
II. CONFIGURATION OF HYBRID GRID

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 bus of the hybrid grid is tied to the utility grid. In the proposed system, PV arrays are connected to 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 solar panel alters. A capacitor \( C_{pv} \) is added to PV terminal inorder to suppress high frequency ripples of the PV output voltage. The converters share a common dc bus. A wind generation system consists of doubly fed induction generator 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 transformer and a main bidirectional power flow converter to exchange power between dc and ac sides.

When the total power generation is less than the total load at the dc side, the converter injects power from ac to dc side. Similarly, when the total power generation is greater than the total load in hybrid grid, it will inject power to the utility grid. Otherwise it receives power from utility grid.

C. Isolated Mode

In this islanding mode, hybrid grid becomes electrically isolated from the remainder of the utility grid. The battery plays a very important role for both power balance and voltage stability. DC bus voltage is maintained stable by a battery or boost converter according to different operating conditions. The main converter is controlled to provide a stable and high quality ac bus voltage.

III. MATHEMATICAL MODELING OF SYSTEM

D. Modeling of PV Panel

Generally, PV system is an interconnection of modules which in turn made up of many PV cells in series or parallel. The power produced by single module is not enough to meet requirements of commercial applications, so modules are connected to form array to supply the load. The equation of a solar cell describes the relationship between current and voltage of the cell as

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

\[
I_{ph} = (I_{sat} + K_s(T - T_r)) \frac{S}{1000} \tag{2}
\]

\[
I_{sat} = I_r \left( \frac{T_r}{T} \right) \exp \left( \frac{qE_{gap}}{KA} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right) \tag{3}
\]

E. Modeling of Battery

Battery acts as a constant voltage load line on PV array and is charged both by PV array and induction generator. The battery is modeled as a nonlinear voltage source whose output voltage depends not only on the current but also on the battery state of charge (SOC), which is non linear function of the current and time.
\[ V_b = V_0 + R_b \cdot i_b - K \frac{Q}{Q + \int \exp(B) \cdot dt} + A \cdot \exp(B) \cdot i_b \cdot dt \]  \tag{4}

\[ \text{SOC} = 100 \left( 1 + \int \frac{i_b}{Q} \cdot dt \right) \]  \tag{5}

\section*{F. Modeling of Wind Turbine Generator}

The power output of wind turbine generator (WTG) is determined by

\[ P_m = 0.5 \rho 4 C_p(\lambda, \beta) V_o^3 \]  \tag{6}

Where \( \rho \) is air density, \( A \) is rotor swept area, \( V_0 \) is wind speed, and \( C_p(\lambda, \beta) \) is the power coefficient, which is the function of tip speed ratio \( \lambda \) and \( \beta \) is pitch angle.

\section*{IV. Coordination Control of Converters}

There are five types of converters in this microgrid. Those converters have to be coordinately controlled with the utility grid to supply an uninterrupted, high efficiency, and high reliability power to variable dc and ac loads under variable solar irradiation and wind speed when the grid operates in both isolated and grid tied modes. In grid tied mode, the control objectives of the main converter are to maintain a stable dc-link voltage for variable dc load and to synchronize with ac link and utility system. Power flow equations at the dc and ac links are as follows:

\[ P_{pv} + P_{ac} = P_{dcL} + P_b \]  \tag{7}

\[ P_s = P_w - P_{acL} - P_{ac} \]  \tag{8}

In isolated mode, the battery converter operates either in charging or discharging mode based on power balance in the system. The dc-link voltage is maintained by either battery or boost converter based on system operating conditions. Power under various load and supply conditions should be balanced as follows:

\[ P_{pv} + P_w = P_{acL} + P_{dcL} + P_{loss} + P_b \]  \tag{9}

Where \( P_{loss} \) is the total grid loss.

\section*{V. Simulation Results}

The performance analysis is done using simulated results which are found using MATLAB. The solar irradiation, cell temperature and wind speed are also taken into consideration for the study of grid.

\subsection*{A. Grid-Connected mode}

The operations of the hybrid grid under various source and load conditions are simulated and to verify the proposed control algorithms. The operation is carried out for both operating modes. Along with hybrid microgrid the performance of doubly fed induction generator (DFIG), photovoltaic system is analyzed.

In this mode, the main converter operates in PQ mode and 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. The optimal terminal voltage is determined using the basic P&O algorithm based on the corresponding the solar irradiation. The voltages for different solar irradiations are shown in Fig.5.

Solar irradiation level is set as 400W/m² from 0.0s to 0.1s, increases linearly to 1000W/m² from 0.1s to 0.2s, and keeps constant until 0.3s. The initial voltage for the P&O is set at 250V. It can be seen that the P&O is continuously tracing the optimal voltage from 0 to 0.2s. The algorithm only finds the optimal voltage at 0.2s due to the slow tracing speed. The algorithm is searching the new optimal voltage from 0.3s.
It can be seen that the basic algorithm can correctly follows 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. 6 shows the curve of output power of the PV panel. The output power varies which closely follows the solar irradiation when the ambient temperature is fixed.

Fig. 4. Simulink model of PV panel

Fig. 5. Terminal voltage of solar panel

Fig. 6. PV output power

Fig. 7. AC side voltage and current of the main converter with variable solar irradiation level and constant dc load

Fig. 8. AC side voltage and current of main converter with constant solar irradiation level and variable dc load

Fig. 9. DC bus voltage transient response

B. Isolated Mode

In this mode dc bus voltage is maintained stable by the battery converter and ac bus voltage is provided by the main converter.
The main converter acts as a voltage source to provide a stable voltage and frequency for the ac grid and operates either in inverter or converter mode for the smooth power exchange between ac and dc links. When the grid operates in the islanding mode, the boost converter and back-to-back ac/dc/ac converter of DFIG may operate in on-MPPT or off-MPPT based on the system power balance and energy constraints.

Fig. 10. Simulink model of grid in isolated mode

Fig. 11. Simulink model of Doubly Fed Induction Generator

Fig. 12. Shows the dynamic responses at the ac side of the main converter when the ac load increases with a fixed wind speed 15m/s. It is shown clearly that the ac grid injects power to the dc grid before 0.3s and receives power from the dc grid after 0.3s.

Fig. 13 also shows the transient process of the DFIG power output, which becomes stable after 0.45s due to the mechanical inertia. Fig. 14 shows the current and SOC of the battery. The SOC increases and decreases before and after 0.3s respectively. Fig. 15 shows the dc bus voltage in isolated mode.
VI. CONCLUSION

In this paper, the hybrid grid system configuration is done in MATLAB/SIMULINK environment. The process of multiple reverse conversions in an individual AC or DC grid can be reduced. The simulation results show that the hybrid grid can operate stably in the grid-tied or isolated mode. Here proposed controllers are developed for all converters to maintain stable system under various resource and load changing conditions. The total system efficiency depends on the reduction of conversion losses and 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.

APPENDIX

Component Parameters for Hybrid Grid

- Capacitor across the solar panel: 110uF
- Inductor for the boost converter: 2.5mH
- Capacitor across the dc-link: 4700uF
- Filtering inductor for the inverter: 0.43mH
- Equivalent resistance of the inverter: 0.3ohm
- Filtering capacitor for the inverter: 60uF
- Inductor for the Battery converter: 3mH

REFERENCES


