Microgrid: Future Key to Intelligent Power Network

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***Abstract*—Microgrids are small scale version of the power grid in which distributed energy resources, storage devices and loads are localized in a defined geographical area. A microgrid offers an alternate solution to the grid stress problem. Microgrids are building blocks of the Smart Electrical Grid. Microgrids can be operated in grid tied and islanded mode. Power quality is a very important issue in a microgrid because it directly affects the operation of a microgrid. In this paper operational behavior of microgrid under various modes and loading conditions has been studied. Various issues and challenges are presented. Multi loop Control structure has been employed for the controller design to improve the performance of the microgrid. The purpose of this research work is to understand the dynamics of microgrid in grid tied and islanded mode to ensure reliable and secure operation. Simulation results for various conditions are performed to evaluate the performance of microgrid. It is shown that proposed control strategy improves the performance of microgrid.**

Keywords—Smart power network; microgrid ; grid tied mode

I. INTRODUCTION

Grid stress is a major issue in today's power system network. A microgrid offers an alternate solution to the grid stress problem.The growing energy demand in developing nations has also triggered the issue of energy security.Microgrids can address both environmental and security issues through the introduction of local power generation or on site power generation. Here are microgrid definitions developed by two groups. As per U.S. Department of Energy Microgrid Exchange Group a microgrid is defined as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [1].Microgrid concept assumes a groupof loads and microsources less than 100 kW operating as a single controllable system. As per CIGRÉ C6.22 group micro gridsare electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded [1]. Selection of a distributed energy sources depends on geographic position of the area. To enhance power quality and power reliability, microgrid is required to operate in grid tied mode and Islanded mode. In this paper microgrid with photovoltaic (PV) source has been considered but the inherent intermittency of the solar resources in solar power generation poses a great challenge in design and implementation of microgrid and hence future smart grid. Microgrids are building blocks of future smart electrical grid. To overcome this difficulty a microgrid may include battery energy storage systems. These storage systems can mitigate issues with solar power sources such as ramp rate, frequency and voltage [1, 4]. Microgrids are categorized as ac, dc, and hybrid ac /dc types. Fig. 1 shows structure of hybrid microgrid and Fig. 2 shows microgrid structure considered in this paper.

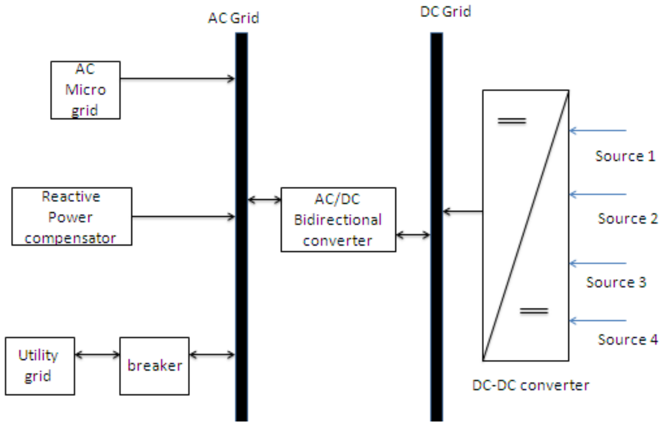


Fig. 1 Hybrid Microgrid structure

The main or utility grid is balancing the power between the distributed generators and the local load demand. When the main power grid is not sufficient to supply, then the distributed generators continues to supply power. Depending on the degree of power difference It can cause voltage and frequency transients. When the voltage and frequency variations have reached certain levels, it is assumedthat an islanding is occurring. For detection of shift in voltage and frequency phase locked loop (PLL) loop has been employed.When the voltage at thepoint of common coupling has reached below 0.88 p.u. or beyond 1.1 p.u., the main utility grid should be disconnected as per IEEE standard. 1547. The technical challenges in the operation of micro grid are Voltage and frequency control, Islanding and Protection [1-14].

To enhance power quality and power reliability, microgrid is required to operate in grid tied mode and Islanded mode. The stability of microgrid is not affected because of its capacity being sufficiently small under grid tied mode. Withmore number of distributed energy sources integrated in the structure, the stability and security of the utility grid will be more affected.

Microgrids are categorized as ac, dc and hybrid ac/dc types. Hybrid structure can ensure a sustainable configuration blending both ac and dc forms. Hybrid Microgrid utilizing diversity of various energy resources is found better than single source Microgrid system [1, 5].Problem associated with

optimal sizing and allocation of distributed Energy storage systems (DESSs) with reference to battery energy storage system (BESS) are addressed [1]. The operation and control issues in microgrid (both modes Grid –connected and Island) are addressed [3].
To reduce processes of multiple reverse connections in an individual grid and to facilitate the connection of various renewable ac and dc sources and loads to power system a hybrid grid is proposed [11,12].
Droop controllers are adopted as power sharing controllers for dispatchable DG units in a microgrid. In [2] matrix perturbation theory is proposed for the optimization of the droop coefficients. Influence of droop coefficients on the system state matrix is also studied by applying parameter perturbation on the system. An objective function based on Eigen values is also proposed to ensure the stability of the system. It is shown that sensitivity of the output power of droop controlled DG units to fluctuations of frequency or voltage is directly proportional to the value of droop coefficients.
The inherent intermittency of the solar resources in a grid tied solar power generation poses a great challenge in design and implementation of future smart grid. To overcome this difficulty a microgrid may include a battery energy storage systems,flywheel or fuel cell system. These battery energy storage systems can mitigate issues with solar power such as ramp rate, frequency and voltage. A battery energy storage system is connected to the grid in parallel with the sources or loads to which it is providing benefit, whereas UPS are installed in series with their loads. Real time control modes including such issues are presented in [8]. Island mode of operation of an inverter has been demonstrated in a control scheme to have parallel operation. A disturbance rejection controller for VSC is designed to maintain the stability of the dc link voltage [4]. The design is based on the singular – values synthesis approach. A typical model (the four zones) of DC –Energy Pool Based Hybrid Microgrid is simulated and analyzed in the MATLAB environment for various events. Control performances of the controller under parametric uncertainty conditions are also shown. A centralized control system based on model predictive control (MPC) algorithm for parallel operation of DG inverters allows faster computational time for large power systems [6]. Connection of a single phase loads to the islanded microgrid causes voltage unbalance. Under islanded operation, the maintenance of voltage and frequency are the responsibility of DG units. Time domain technique for the purpose of maintenance of voltage and frequency is discussed [9]. VPD / FQB control schemes that allows multiple VSCs to operate in parallel in a microgrid are discussed. It is shown that this technique is robust to both grid and islanding operation [10]
To enhance the performance of the grid Smart Fault Current Controller is proposed [5].Previously it was difficult to change the setting of the controller during operation. Smart FCC can not only limit but also control the current when a fault occurs. Different technologies are combined together, such as power converters, control, communications, optimization, and so on. Various control techniques (Master / Slave configuration, Current power sharing control and Droop control) are reviewed and compared in [7].The control strategy in grid tied mode is based on the use of a phase locked loop [8] to measure the microgrid frequency at the inverter terminals, and to provide regulation of the inverter phase relative to the microgrid. This control strategy allows microgrid transition between two modes in smooth way.

The literature survey reveals that little attention has been given so far to the control and operational aspects of microgrids in grid tied mode with nonlinear load. In this paper the behavior of grid tied and islanded microgrid under nonlinear load is presented and a smart controller is designed to improve the dynamic performance of the system under consideration.

This paper is organized as follows. In Section I introduction and literature survey is presented. In section II description of various components of the system is given. In section III control strategy for the system is discussed. In Section IV microgrid system under consideration is simulated to test the performance of the controller, and Section V presents simulation and results. Conclusions are provided in Section VI.

II. SYSTEM CONFIGURATION

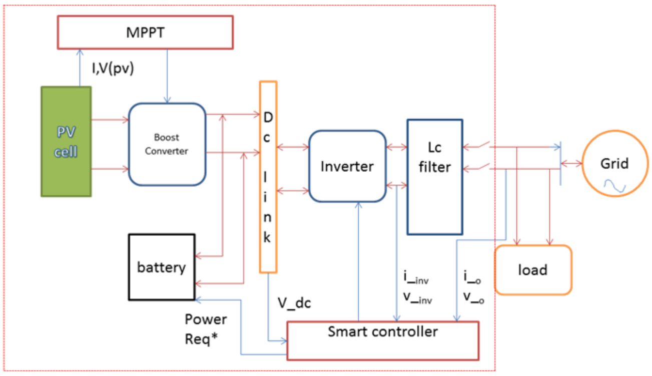
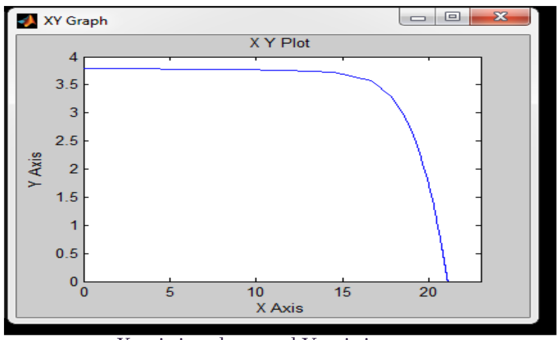


Fig. 2 Block diagram representation of microgrid under study



X-axis is voltage and Y-axis is current

Fig. 3 Static characteristics of photovoltaic cell

A. Photovoltaic cell and Maximum power point tracking

A photovoltaic cell is a voltage controlled current source. Its characteristics are shown in Fig. 3. It is shown in Fig. 3 that the boost converter is connected to the photovoltaic array to raise the voltage to desired level. The first stage is the boost converter, which will control photovoltaic voltage for maximum power generation and will raise the relatively low solar voltage to a suitable level of 500 V for the dc link directly connected to the inverter. The second stage is the DC to AC converter that operates in a current controlled mode which will inject current to the grid. The inverter should be able to supply a continuous power from the dc link bus to a single phase utility grid line (230 V, 50 Hz). An output filter is employed to reduce the ripple components due to PWM switching operation.

Maximum Power Point Tracking (MPPT) includes a charge controller which is used for extracting maximum power availability from PV module. The voltage at which maximum power is getting produced is called peak power voltage .or Maximum Power Point. Typically PV module outputs maximum power at voltage approximately equal to 18 volt when measured at a 25° C cell temperature [9].

B. Boost Converter

Function of boost regulator is to keep PV voltage such that it produces maximum power or current as seen in Fig. 3 and to raise the relatively low solar voltage to a suitable level of 500 V for the dc link.

Condition for maximum power is $d(P) / d(V) = 0$ (1)

In general , $P = V*I$

$$d(P) / d(V) = I+V*d(I)/d(V) = 0 \quad (2)$$

If not equal to zero, integral controller will execute the required action.

C. DC Link

A DC link capacitor is used to couple boost regulator and inverter. Associated equations are shown in this section

$$d(V_c) / d(t) = 1/C*(I_{dc} - I\ inverter) \quad (3)$$

Open loop equation can be given by

$$V(S) / I(S) = 1 / (C*s) \quad (4)$$

Close loop equation can be given by

$$Ci(S) = 1/ (1 + C*s) \quad (5)$$

Above equation will give the reference current for ac side.

$$I_{ref} = (500 - V_{dc}) * Ci(S) \quad (6)$$

D. Inverter and Filter

A two leg arrangement of inverter with four MOSFET switches has been used in the system to convert dc power to ac it works in two mode islanded and grid tied mode. It has a harmonic filter at its terminal to reduce the current distortion. Multi loop strategy for inverter control has been employed in this paper which controls dc link voltage and also synchronizes ac voltage with grid voltage. At the time of start transient current will be very high which will affect the performance of the system. It is considered here that as and when total harmonic distortion factor (THD) of load current is more than 7% then inverter will work in active filter mode as well as it will supply the load.

Harmonic control or active filter mode will only be activated when THD of load current is more than 7%

$$I_H(t) = I(t) - I_{fl}(t) \quad (7)$$

$I_H(t)$ is the harmonic current to be reduced. To control dc link voltage, dc link equation is used.

E. Storage and Loads

Condition for storage devices is to provide the amount of power required to balance the system afterhaving been subjected to any disturbance. For analyzing the behavior of microgrid, storage devices such as batteries are modeled as constant dc voltage sources using power electronic interfaces to be coupled with the circuit. Linear as well as nonlinear loads are considered

III. CONTROL STRATEGY

During normal operation, the microgrid becomes a part of a distribution system. Then, the utility grid maintains the voltage of the point of common coupling and the system frequency. When a fault occurs in the utility grid, the microgrid operates in the island mode to enhance the reliability [1-5].Three control modes of operation are studied here. These are current control for grid tied mode, voltage control for Islanded and DC link voltage or charging/ discharging mode of battery for grid tied and islanded mode. In grid tied mode the voltage and frequency of microgrid is decided by utility grid parameters and distributed generators have to follow the utility grid. During fault condition or maintenance work microgrid controls voltage and frequency of its own mode. Fig. 4 shows the control part or structure under islanded mode. Since there are three loops involved in the control strategy so name is given as multi loop controller. The inverter is modeled as an ideal gain for determination of transfer function.

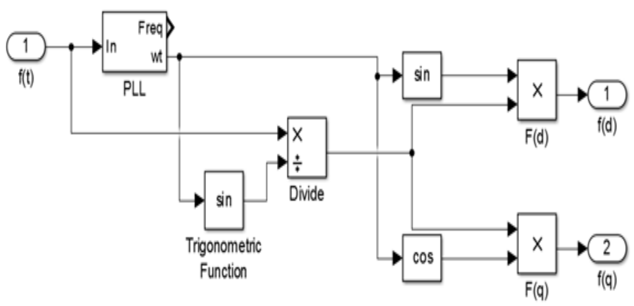


Fig. 4 Control Structure in Islanded mode

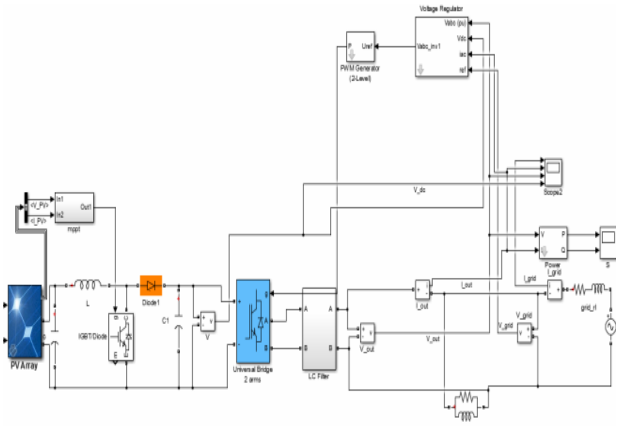


Fig. 5 Simulated Microgrid System

IV. SIMULATION AND RESULTS

In this paper simulation based analysis of behavior of microgrid in grid tied and islanded mode is presented. Simulated microgrid system is shown in Fig. 5.

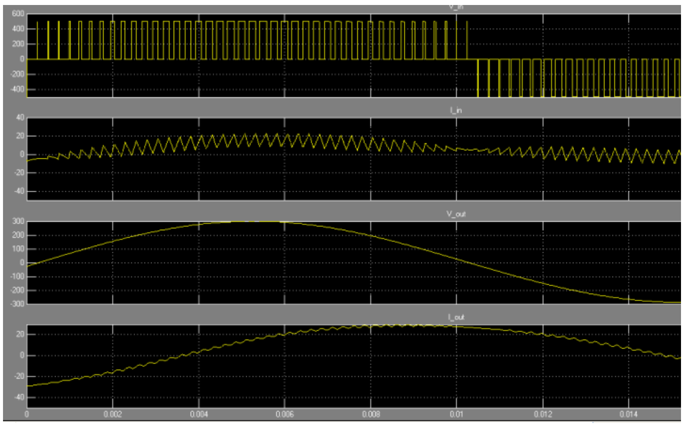


Fig. 6 Bidirectional converter output before and after filter stage

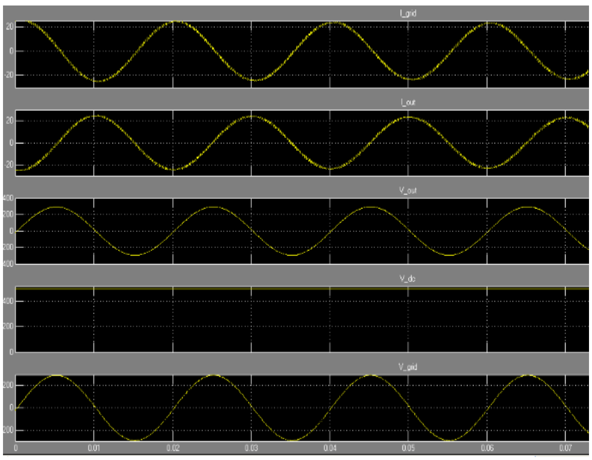


Fig. 7 Dynamic Response - Grid tied mode

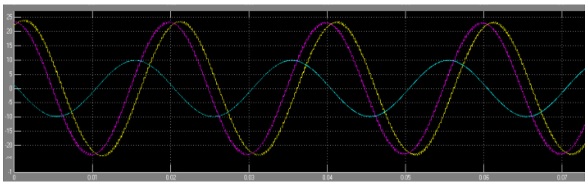


Fig. 8 Power factor improvement - Grid tied mode

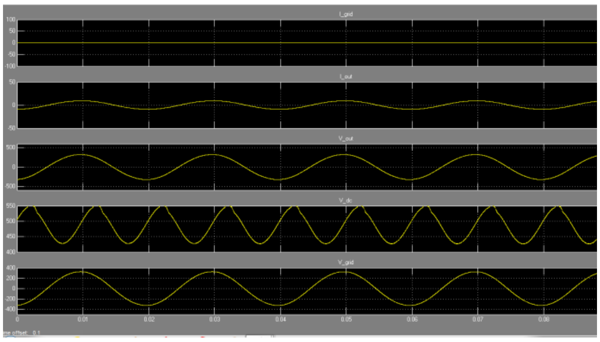


Fig. 9 Dynamic Response - Islanded mode

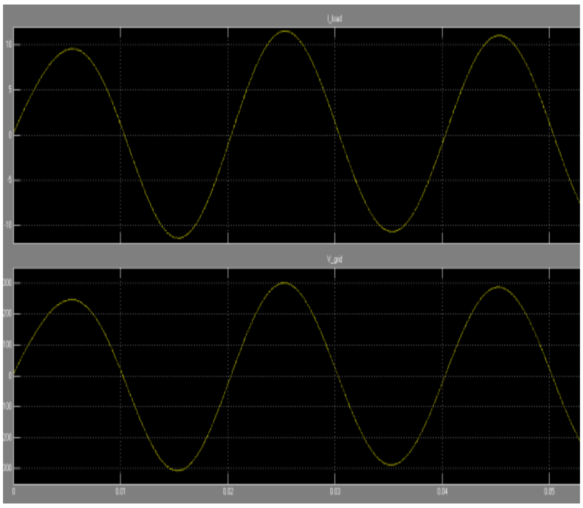


Fig. 10 Load Voltage and load current waveforms

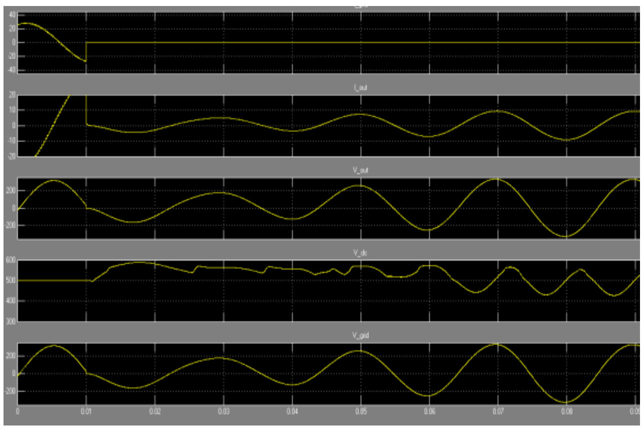


Fig. 11 Transition from grid tied mode to islanding mode

In Fig. 5 C1 represents battery for storing the charge. From Fig. (6-11), it is cleared that with the designed controller converter output has been improved and harmonic contents are also reduced. Fig. 6 shows converter output before and after filter stage. Fig. 7 represents that microgrid voltage and utility grid voltages are synchronized before putting the microgrid in grid tied mode. Fig. 8 represents that with microgrid connection to utility grid power factor has been improved. In Fig. 8, pink colored response is for microgrid current and yellow colored response is for microgrid current and green colored response is resultant of the two currents. Fig. 9 shows that in Islanded mode microgrid is supplying successfully the required power by the load. Fig. 10 shows the load waveforms. It is also shown that in grid tied mode phase detection loop is also performing well and phase of utility grid voltage and microgrid voltage has been synchronized and power factor is also improved and hence power quality is also improved. Load waveforms are also shown and it is cleared that load is getting supplied successfully under different modes of operation. In Fig. 11 it is shown that at 0.01 second, mode of operation of microgrid has been changed from grid tied to islanded mode. It is taking 0.05(2.5 cycles) second to settle down, which is under the limit given by IEEE (5cycles).

V. Conclusion

A controller is designed for grid tied as well as islanded mode of operation of microgrid. The simulation results reveal that the proposed control scheme is capable of improving power quality and stability of the system by maintaining the voltages and frequency within the standard permissible levels and also allows microgrid transition between two modes seamlessly.

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