INTEGRATION OF MULTIPLE RENEWABLE ENERGY SOURCES FOR DC MICROGRID

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Received on: 15.08.2016
Accepted on: 20.09.2016

Abstract

A new topology of a hybrid distributed generator based on photovoltaic and wind-driven permanent magnet synchronous generator is proposed. In this generator, the sources are together connected to the grid with the help of only a single boost converter followed by an inverter. Thus, compared to earlier schemes, the proposed scheme has fewer power converters. Model of the proposed scheme in d-q axes reference frame is developed. Two low cost controllers are also proposed for the new hybrid scheme to separately trigger the DC-DC converter and the inverter for tracking the maximum power from both the sources.

The integrated operations of both the proposed controllers for different conditions are demonstrated through simulation and experimentation. Steady-state performance of the system and transient response of the controllers are also presented to demonstrate the successful operation of the new hybrid system. Comparison of experimental and simulation results are given to validate the simulation model.

1. Introduction:

A new topology of a hybrid distributed generator based on photovoltaic and wind-driven permanent magnet synchronous generator is proposed. In this generator, the sources are together connected to the grid with the help of only a single boost converter followed by an inverter. Thus, compared to earlier schemes, the proposed scheme has fewer power converters.

Model of the proposed scheme in d-q axes reference frame is developed. Two low cost controllers are also proposed for the new hybrid scheme to separately trigger the DC-DC converter and the inverter for tracking the maximum power from both the sources. The integrated operations of both the proposed controllers for different conditions are demonstrated through simulation and experimentation. Steady-state performance of the system and transient response
of the controllers are also presented to demonstrate the successful operation of the new hybrid system. Comparison of experimental and simulation results are given to validate the simulation model.

2. Objective:

- To extract maximum power at high efficiency from the integrated energy source.
- Renewable sources of energy such as wind, battery and solar panels have attracted much attention because they are environmentally friendly, do not consume fossil fuels.

3. The following are the issues addressed by several authors:

- Voltage regulation of DC bus. Circulating current due to difference in Instantaneous values of voltages Load sharing among sources.
- Power balance between source and load.
- Maximum power extraction from the DGs.

In this paper, a DC micro-grid with multiple energy sources is considered which addresses maximum power extraction from the sources with reduced circulating current. System configuration and different operating modes are discussed in the following sections. The effectiveness of the proposed

![Fig. 2: PV characteristic block diagram.](image)

![Fig. 3: Single diode equivalent circuit of a PV cell.](image)
4. System Description:
The block diagram of proposed DG scheme is given where a direct driven PMSG and a PV array are the sources. The PMSG output is rectified and fed into a DC-DC boost converter. The rectifier output voltage varies with the wind-speed. The PV array terminals are connected to the output of the DC-DC converter to form a common DC link for the proposed system. The inverter input terminals are tied to this common DC link. The PV array voltage (VPV) is fixed to the output voltage of the DC-DC converter (VDC) since the output terminals of both the PV array and the DC – DC converter are tied together. The output voltage of the DC-DC converter is automatically varied by a PV MPPT controller (Controller 1) to PV array’s maximum power point voltage. Under this condition, the maximum current for the given irradiation is drawn from the PV array by the action of current controller (controller 2) of the inverter. The basic Perturb & Observe (P&O) algorithm is employed albeit with an inverted duty-cycle adjustment in controller 1. This revised adjustment in the proposed scheme is because of the DC-DC boost converter being fed by a stiff DC source (rectifier output) instead of the PV array.

Energy Sources:
Distributed generations typically use renewable energy sources, including solar power, wind power, small hydro, biomass, biogas and geothermal power. In this paper solar energy systems are considered as the DGs. Different models of solar panel have already been developed. Most commonly used one is the single diode equivalent circuit, which is shown in Fig.3.

The circuit consists of a current source, a diode in parallel with the current source, and series resistance. The current (I) - voltage (V) characteristics of a typical solar cell is shown in Fig.3. This equivalent circuit is considered in this paper for simulation studies.
5. Residential Microgrid System:

This section presents the residential microgrid system under study. The next subsections describe the system (DG sources, storage devices, types of load and types of buses), operation modes (including the operation flowchart), converters topology, converters specifications and bus voltages levels.

A. System Design:

The proposed residential microgrid is composed of two DG sources (photovoltaic panels and biofuel generator) and one battery bank, and is able of supplying both AC and DC loads, including a PHEV. The microgrid has two buses: one main DC bus in which the DG sources, storage device and DC loads are connected, and one AC bus in which AC loads are connected and the point of common coupling (PCC) with the utility grid is located. Illustrates the microgrid system. The arrows beside each converter indicate the possible power flow directions.

B. Operation Modes:

This subsection presents considerations to define the system operation modes and operation flowchart. This is a very important stage, because it describes in which manner the microgrid will operate in each possible situation, depending on some input variables.

It is important to highlight that the microgrid can operate in both grid connected and island modes. The considerations are listed next.

1) The photovoltaic (PV) panels rated power is lower than the microgrid total installed load.
2) The generator presents a starting time until begin the energy generation.
3) The battery bank can be charged through the main grid or photovoltaic panels.
4) The battery bank only discharges to supply loads or to maintain the buses voltages, never to export energy to the main grid.
5) In grid connected mode, the battery bank is always fully charged or being charged.

C. Converters Topologies: The converter used to connect the energy storage device to the DC link presents a wide range of possibilities, according to a bibliographic review. As an example, the interleaved half-bridge converter is used. The traditional half-bridge converter is used. Some papers, a comparison among several topologies, in order to highlight their advantages and limitations.

Regarding these analysis, the half-bridge converter is chosen to connect the battery bank to the DC bus, due to advantages like requirement of only one inductor, lower current and voltage semiconductor stress levels, and higher
efficiency in consequence of lower switching and conduction semiconductor losses and lower inductor losses. A detailed analysis on the energy storage system converter focusing the proposed residential microgrid in under analysis and will generate content for next publications. A single phase unidirectional rectifier is used to connect the biofuel generator to the DC link due to its simplicity. A boost converter is used to connect the PV panels to the DC link due to its simplicity, high efficiency and possibility of voltage boost required to this situation. Finally, a single phase full-bridge inverter/rectifier is used to connect the DC bus to the AC bus. It is rated to the total DGs and battery bank power, resulting in 7.24 kW.

6. Block Diagram:

![Block Diagram]

7. Modules Description: Circuit Diagram:

![Circuit Diagram]

8. Simulation Design:

The complete schematic of controller 2 is given in Fig. 6. High frequency op-amps (LM-318) are used to construct the hysteresis-current-controller. IPV and Ib are sensed by the current transducers and digitized by the internal ADC module of the microcontroller. Based on (15), Iref is determined and available as digital output from the microcontroller. This digital value is subsequently processed by a Digital to Analog Conversion (DAC) IC to obtain a DC value which corresponds to the peak value of Iref. This DC value is multiplied with the sine wave reference extracted from the grid voltage, by a multiplier IC and fed to the hysteresis current- controller as the reference current signal. When PV array (or PMSG) alone generates power, Ib (or IPV) will be zero and Iref is perturbed and adjusted...
automatically to extract the maximum power from PV array (or PMSG). When both the sources are generating, $I_{ref}$ will be perturbed based on (15) and adjusted to maximize the DC link current $I_{DC}$ for the corresponding irradiation and wind-speed conditions. As the sine wave reference is taken from the grid, the inverter output current will have grid frequency and will be in phase with the grid voltage.

![Diagram of the system](image)

6. Conclusion:

This paper presented a DC micro-grid based power generation system with multiple energy sources. A new control method is proposed to extract maximum power from the sources and to suppress the circulating current simultaneously. The simulated results have been verified. Different cases considered in this paper have proven that the system performance is fast and accurate. The transient time for the system when a sudden variation has been applied is less than 0.1s. The results clarified that each source worked according to the control, and maximum power has been extracted from the sources with reduced circulating current.

9. Output Voltage Waveform:

![Output Voltage Waveform](image)

References


