International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 5, No. 2, October 2014, pp. 195~202
ISSN: 2088-8694

Operation and Control of Grid Connected Hybrid AC/DC Microgrid using Various RES

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Article Info

Article history:

Received Apr 30, 2013
Revised Jan 10, 2014
Accepted Feb 24, 2014

Keyword:

Fuel Cells
Hybrid Power Systems
Interfacing Converter
Micro grids
Solar Energy
Wind Energy

ABSTRACT

This paper proposes a Hybrid AC/DC Microgrid in alliance with Photo Voltaic (PV) energy, Wind Energy and Proton Exchange Membrane (PEM) Fuel cells. Microgrids are becoming increasingly attractive to the researchers because of the less greenhouse gases, low running cost, and flexibility to operate in connection with utility grid. The Hybrid AC/DC Microgrid constitutes independent AC and DC subgrids, where all the corresponding sources and loads are connected to their respective buses and these buses are interfaced using an interfacing converter. The Hybrid AC/DC Microgrid increases system efficiency by reducing the multiple reverse conversions involved in conventional RES integration to grid. A Small Hybrid AC/DC Microgrid in grid connected mode was modeled and simulated in MATLAB-SIMULINK environment. The simulation results prove the stable operation considering the uncertainty of generations and loads.

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1. INTRODUCTION

A Microgrid is a small grid formed by banking multiple energy resources and loads to enhance overall reliability and independent advantages. Now-a-days, it is more preferred to integrate renewable energy resources to Microgrid to lessen the CO_2 emission and fossil fuel consumption. The banked Microgrid can be operated either in connection to main grid or operated like isolated “islanded” [1]. Now-a-days, DC loads like LED’s, Electric Vehicles and other Electronic Gadgets are being increasingly used due to their inherent advantages. Three Phase AC Power systems have existed for over 100 years due to their efficient transformation at different voltage levels and transmission over long distances. The inherent characteristics of rotating machines make it feasible for larger period.

To connect the conventional AC system to the renewable resources, AC Microgrids have been proposed and DC power from the various resources like PV panel, Fuel cells etc., are converted into AC in order to connect to an AC grid, which are implanted by AC/DC Converters and DC/DC Converters [2]. In an AC Grid, several converters are required for various home and office facilities to provide required DC voltages. AC/DC/AC converters are commonly used as drives in order to control the speed of AC motors in industries.

Recently DC grids are resurging due to development and deployment of renewable DC resources and their inherent advantage for DC loads in residential, commercial and industrial applications. The DC Microgrid has been proposed [3]. However, for conventional AC loads DC/AC inverters are required and AC sources are connected using AC/DC Converters.

Multiple reverse conversions required in individual AC or DC grid may add additional loss to the system operation and will make the current home and office appliances more complicated in design and operation [4]. The current research in the electric power industry is smart grid. One of the most important futures of a smart grid is the advanced structure which can facilitate the connections of different AC and DC generation systems, energy storage options and various AC and DC loads with the optimal asset utilization and operational efficiency. The power electronics converter plays a most important role to interfacing AC and DC grids, which makes future grid much smarter.

A Hybrid AC/DC Microgrid is proposed to reduce processes of multiple reverse conversions in an individual AC or DC grid and to facilitate the connection of various energy sources, storage devices and loads [5]. The advanced power electronic devices and control techniques are used to harness maximum power from renewable power sources, to minimize power transfer between AC and DC networks. PV system, PEMFC constitutes the DC Energy sources; Wind system constitutes the AC energy source, whereas Battery and Conventional Grid are used as storage devices whenever required.

2. SYSTEM CONFIGURATION AND MODELING

Figure 1 illustrates the compact representation of proposed Hybrid Microgrid Configuration. The Hybrid Microgrid was formed by a DC sub grid and an AC sub grid. Each sub grid has its own sources elements, storage elements and loads of the same category grouped together so as to reduce the amount of power conversion required. Both sub grids are interfaced using interfacing converters. Interfacing converters are the bidirectional converters, and their major role is to provide bidirectional energy transfer between the sub grids, depending on the prevailing internal supply – demand conditions.

The formed Hybrid grid can be tied to Utility grid using an Intelligent Transfer Switch at point of common coupling as in conventional AC grids. In grid tied mode of operation, surplus energy in the internal sub grids if any can be injected to the utility grid without violating the local utility rules. Similarly, the shortfall in both the sub grids if any can be absorbed from the utility grid.

Figure 1. A Compact representation of the proposed Hybrid Microgrid

2.1. Proposed Hybrid Microgrid Configuration

PV Array(40kW) and PEM Fuel Cell (50kW) are connected to DC bus through independent DC/DC boost converter to simulate DC sources. Capacitors C_{pv} and C_{fc} are used to suppress the high frequency ripples of the PV and FC output voltage.

Also, a wind turbine generator (WTG) with DFIG (50kW) and utility grid are connected to AC bus to simulate AC Sources. In addition, a battery (65Ah) and super capacitor (0.5F) are individually connected as energy storages to DC bus through buck-boost (DC/DC) converter. The DC load was considered as pure resistive load and AC loads are considered with RLC which are dynamic in nature. Both the loads are variable between 20kW – 40kW. Rated voltages for both buses are considered as 400V. The parameters of the Hybrid Microgrid are tabulated in Table 3

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2.2. Modeling of PV Panel

Figure 2 shows the equivalent circuit of a PV Panel modeled by a controlled current source. I_{pv} and V_{pv} are the terminal current and voltage of the PV panel, respectively. The current output of the panel is modeled using three Equation (1), (2), (3) [6]-[7]. The parameters that were taken into consideration for simulation are shown in Table 1.

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

$$I_{pv} = \left(I_{sso} + K_i (T - T_r)\right) . \frac{S}{100} \tag{2}$$

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

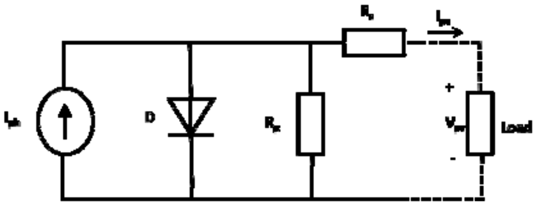

Figure 2. Equivalent circuit of a PV Panel

Table 1. Parameters of Photovoltaic Panel

Symbol	Description	Value
V_{oc}	Rated open circuit voltage	403 V
I_{ph}	Photocurrent	
I_{sat}	Module reverse saturation current	
Q	Electron charge	1.602×10^{-19} C
A	Ideality factor	1.50
K	Boltzmann Constant	1.38×10^{-23} J/K
R_s	Series resistance of a PV cell	
R_p	Parallel resistance of a PV cell	
I_{sso}	Short-circuit current	3.27 A
k_i	SC Current temperature Coefficient	$1.7\ e^{-3}$
T_r	Reference Temperature	301.18 K
I_{rr}	Reverse Saturation current at T_r	$2.0793e^{-6}$ A
E_{gap}	Energy of the band gap for silicon	1.1 eV
n_p	Number of cells in parallel	40
n_s	Number of cells in series	900
S	Solar Irradiation Level	0 ~ 1000 W/m
T	Surface temperature of the PV	

2.3. Modeling of Fuel Cell

Figure 3 shows the equivalent circuit of PEM Fuel cell. The ohmic, activation and concentration resistances are represented with R_{ohmic}, R_{act}, R_{conc} respectively. C is the membrane capacitance. The Membrane voltage equation is given by Equation (4).

$$V_c = \left(1 - \frac{dV_c}{dt}\right) (R_{act} + R_{conc}) \tag{4}$$

The output voltage of the PEMFC is given by (5):

$$V_{fc} = E - V_c - V_{act} - V_{ohmic} \tag{5}$$

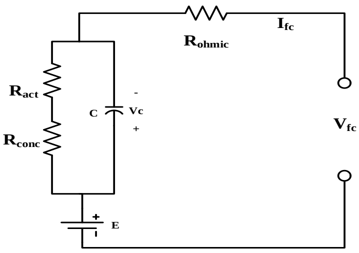

Figure 3. Equivalent circuit of PEM Fuel cell

2.4. Modeling of Battery

Battery is not very important in grid-tied mode. But, provides an energy storage in DC subgrid, which can reducethe multiple reverse conversion, whenever required. In emergency i.e., Grid Failed Condition, they plays a vital role in power balance and voltage stability. The battery was modeled using a controlled nonlinear source in series with a constant resistance. The State Of Charge (SOC) of the battery is given by Equation (6).

$$SOC\% = 100\left(1 + \frac{\int it\,dt}{Q}\right) \tag{6}$$

Where it is the extracted capacity and Q is the Maximum capacity if battery.

2.5. Modeling of Wind Turbine Generator with DFIG

In this paper, DFIG was considered as a wound rotor induction machine. The power output P_m from a WT is determined by [3]. A 50kW DFIG parameters, used in this paper are shown in Table 2.

$$P_m = 0.5\rho A C_p(\lambda, \beta) V_w^3 \tag{7}$$

Table 2. Parameters of DFIG

Symbol	Description	Value
P_{nom}	Nominal power	50 kW
V_{nom}	Nominal Voltage	400 V
R_s	Stator resistance	0.00706 pu
L_s	Stator inductance	0.171 pu
R_r	Rotor resistance	0.005 pu
L_r	Rotor inductance	0.156 pu
L_m	Mutual inductance	2.9 pu
J	Rotor inertia constant	3.1 s
n_p	Number of poles	6
V_{dc_nom}	Nominal DC voltage of AC/DC/AC converter	800 V
P_m	Nominal Mechanical power	45 W

3. CONTROLLERS

The Hybrid Microgrid contains six types of converters. All the converters have to be coordinately controlled with the utility grid to supply reliable, high efficiency, high quality power for variable DC and AC loads. The controllers are presented in this section are coordinated successfully in both grid-tied. A Direct Torque Control Strategy(DTC) with feed forward voltage compensation is selected for DFIG control system [9].

3.1. Boost Converter

In grid tied mode, the control objective of the boost converter is to track the MPPT of the PV panel and Fuel Cell. The PV Panel and Fuel Cell boost converters are designed to support the DC bus voltage as shown in Figure 4. To achieve maximum power, P & O Method proposed in [6].

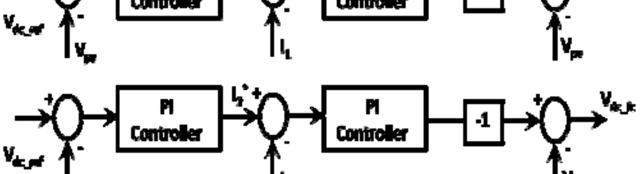

Figure 4. Control Scheme of PV Cell and PEM Fuel cell

3.2. Control of Battery

Battery has high energy density with slow charging and discharging speeds. Control scheme of Battery is shown in Figure 5.

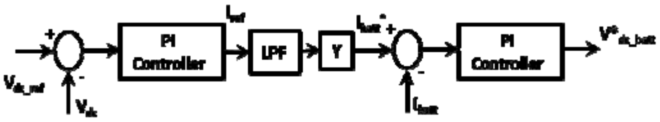

Figure 5. Control Scheme for Battery

3.3. Interfacing Converter

The objective of the interfacing converter is to interface both the sub grids i.e., AC grid and DC grid. The major role of the interfacing converter is to exchange power between the AC bus and DC bus. When operating in grid tied mode, the converter supplies given active and reactive power. The interfacing converter acts DC/AC inverter when supplying power from DC grid to AC grid and acts as AC/DC rectifier when supplying power from AC grid to DC grid whenever required. The interfacing converter works based on droop control [11]. The control scheme of interfacing converter is shown in Figure 6.

The advantages of interfacing converter cannot be realized by just relying on the droop controlled sources. The interlinking control challenges has to be carefully addressed [12].

a) Unlike unidirectional sources, the interlinking converters has to manage bidirectional active and reactive power flows between sub grids.
b) At any one instant, the interlinking converters have two roles to play. They appear as load to one sub grid where energy is absorbed and appear as source to other grid where energy is injected.

Figure 6. Control Scheme for Interfacing Converter

Table 3. Parameters for the Hybrid Grid

Symbol	Description	Value
C_{pv}	Capacitor across the solar panel	110 µF
L_1	Inductor for the boost converter	2.5 mH
C_d	Capacitor across the dc-link	4700 µF
L_2	Filtering inductor for the inverter	0.43 mH
R_2	Equivalent resistance of the inverter	0.3 ohm
C_2	Filtering capacitor for the inverter	60 µF
L_3	Inductor for the battery converter	3 mH
R_3	Resistance of L3	0.1 ohm
F	Frequency of AC grid	60 Hz
f_s	Switching frequency of power converters	10 kHz
V_d	Rated DC bus voltage	400 V
V_{ll_rms}	Rated AC bus line voltage (rms value)	400 V
n1/n2	Ratio of the transformer	2:1
C	Capacity of Super Capacitor	0.5 F

4. SIMULATION RESULTS

The operation of Grid Connected Hybrid AC/DC Microgrid under various source and load conditions are simulated to verify the reliability.

DC RES power is supplied directly to the DC loads and AC RES power is supplied directly to AC loads. Power is balanced directly by the utility grid on AC bus and on DC bus through interfacing converter. The battery is assumed to be fully charged and operated in rest mode. DC bus voltage is controlled and maintained by utility grid through interfacing converter. AC bus voltage is directly maintained by utility grid.

The terminal voltage for change in solar irradiation is shown in Figure 7. Optimal terminal voltage of PV panel is obtained by using the standard P&O algorithm. The solar irradiance was set as 400W/m^2 from 0.0s to 0.1s, later it was linearly increased to 1000W/m^2 until 0.2s, kept constant to 0.3s, decreased to 400W/m^2 by 0.4s and keeps that value until final time 0.5s. The slow tracing speed of the standard P&O algorithm is optimized by using fuel cell in DC subgrid.

Figure 8 and Figure 9 shows the curves of the PV panel power output and solar irradiation respectively. The power output varies from 4.85kW to 13.5kW, which closely follows the solar irradiation curve assuming the fixed ambient temperature.

Figure 10 shows the voltage and current responses on AC side of interfacing converter with a fixed DC load of 20kW. It was observed that the current direction of interfacing converter was reversed before 0.3s and after 0.4s.

Figure 11 shows the voltage and current responses on AC side of interfacing converter with variable DC load from 20kW to 40kW at 0.25s with fixed solar irradiation at 750W/m^2. It can be seen that current direction was reversed at 0.25s.

Figure 12 shows the voltage response at DC bus of interfacing converter with Fuel cell shows an improved transient response when compared Figure 13 without fuel cell under same conditions

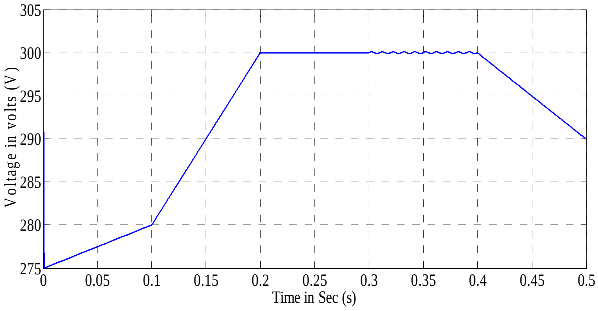

Figure 7. Terminal Voltage of PV Panel

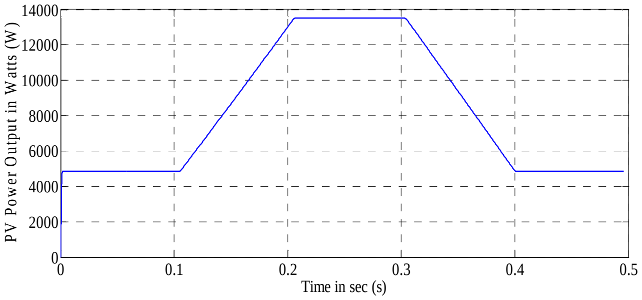

Figure 8. Power output of PV Panel

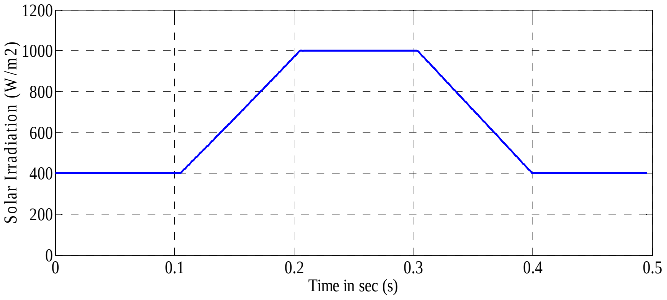

Figure 9. Solar Irradiation

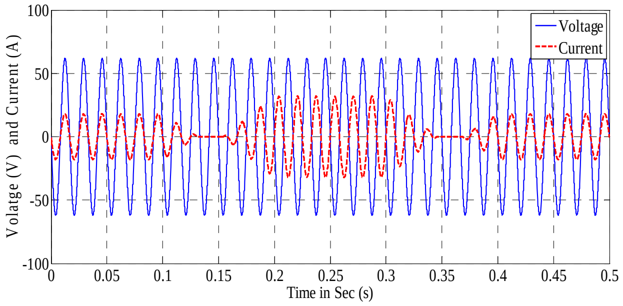

Figure 10. AC side Voltage and Current of the Interfacing Converter with Variable Solar Irradiation and Constant DC Load

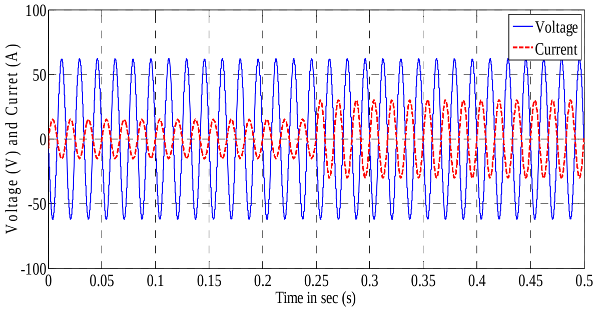

Figure 11. AC side Voltage and Current of the Interfacing Converter with Constant Solar Irradiation and Variable DC Load

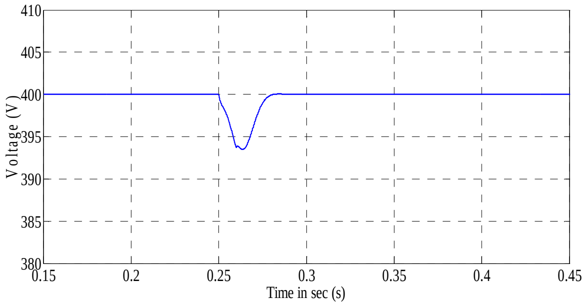

Figure 12. DC Bus Transient Response with Fuel Cell

5. CONCLUSION

A Hybrid AC/DC Microgrid is proposed and comprehensively studied in this paper. The control strategies are concisely stated to maintain stable system operation under various load and resource conditions. The control strategies are verified by using MATLAB/Simulink. Various control methods are incorporated to harness the maximum power from RES during grid connected mode and resembles stable operation.

The Interfacing Converter shows stable operation during load variations. However there will be some practical limitations, because of fast and continuous load variations. Even-though, the proposed Hybrid grid reduces the processes of DC/AC and AC/DC conversions in an individual sub grids, the theory is still challenging in the AC dominated infrastructure. The Hybrid AC/DC Microgrid has to be tested for various faults on subgrids and their effects on the other grid. The Hybrid AC/DC Microgrid is only feasible for new construction either in remote location or industries.

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