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Performance Analysis of Grid Connected Hybrid AC/DC Microgrid Using Various Renewable Energy Sources

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ABSTRACT
We in no time appreciate a dominatingly AC electrical distribution system, the engineering reason for which was designed more than 100 years back. While AC distribution system have served us well, we ought to intermittently respite to survey what opportunities we have acknowledged or been precluded by overpowering prevalence from claiming AC electrical power distribution system. What openings could be acquired by designing DC distribution into at any rate parts of our present system? What favorable circumstances of the present AC distribution system ought to be perceived and ensured? This paper proposes a Hybrid AC/DC Microgrid in organization together with Photo Voltaic (PV) energy, Wind Energy and Proton Exchange Membrane (PEM) Fuel cells. The Microgrids are turning out to be progressively appealing to the researchers as a result of the less greenhouse gasses, low running expense, and adaptability to work regarding utility grid. This paper concentrates on distribution within premises and low-voltage distribution system. In particular, this paper tended to the change productivity expenses of receiving different premise AC and DC distribution system topologies. Hybrid AC/DC Microgrid constitutes free AC and DC subgrids, where every comparing source and loads are associated with their particular transports and these transports are interfaced utilizing an interfacing converter. Hybrids AC/DC Microgrid builds system productivity by reducing numerous turn around transformations required in ordinary Renewable Energy Sources (RES) mix to grid. A Small Hybrid AC/DC Microgrid in grid associated model was modelled and simulated in MATLAB/SIMULINK environment. Simulation results are utilized to demonstrate the steady operation considering the vulnerability of generations and loads.

Keywords: hybrid power systems, micro grids, solar energy, wind energy, fuel cells, interfacing converter

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INTRODUCTION

Microgrid is a little network developed by saving many different energy resources and loads to upgrade overall reliability and independent advantages. Presently a-days, it is more liked to coordinate renewable energy sources to Microgrid to reduce the CO2 discharge and fossil fuel utilization. Saved Microgrid can be operated either in connection to main grid or operated like isolated “islanded” [1]. Presently a-days, DC loads like LED’s, Electric Vehicles and other Electronic Gadgets are being greatly used because of their inherent advantages. Three Phase AC Power systems have existed for over 100 years because of their efficient transformation at different voltage levels and transmission over long distances. Also, inherent features of rotating machines make it possible for larger period.

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

Recently, DC grids are resurging because of development and deployment of renewable DC resources and their inherent gain for DC loads in residential, commercial and industrial applications. Hence, DC Microgrid has been proposed [3]. Anyhow, for conventional AC loads DC/AC inverters are recommended and AC sources are connected using AC/DC Converters.

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

This research paper concentrates on Hybrid AC/DC Microgrid concept, which is proposed to reduce processes of multiple reverse conversions in an individual AC or DC grid and to facilitate connections for various energy sources, storage devices and loads [5]. Advanced power electronic devices and control techniques are utilized to harness maximum power from renewable power sources, to reduce power transfer between AC and DC networks. PV system, Proton Exchange Membrane Fuel Cell (PEMFC) constitutes the DC Energy Sources; Wind system constitutes the AC energy source, though Battery and Conventional Grid are used as storage devices whenever required.

SYSTEM CONFIGURATION AND MODELLING

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

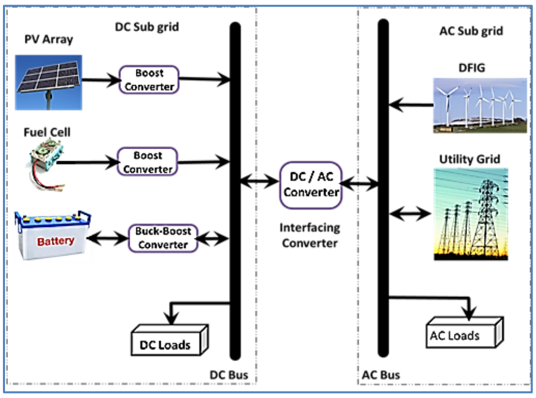


Fig. 1. *A Compact representation of the proposed Hybrid Microgrid [1].*

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

Proposed Hybrid Microgrid Configuration

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

Also, a wind turbine generator (WTG) with Doubly Fed Induction Generator (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 linked as energy storages to DC bus via buck-boost (DC/DC) converter. DC load was taken as pure resistive load and AC loads are considered with RLC which are random in nature. Both the loads are variable between 20kW – 40kW. The rated voltages for both buses are considered as 400V. Parameters of Hybrid Microgrid are tabulated in Table 1 as depicted below.

Table 1. *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	F

Modelling of PV Panel

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

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

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

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

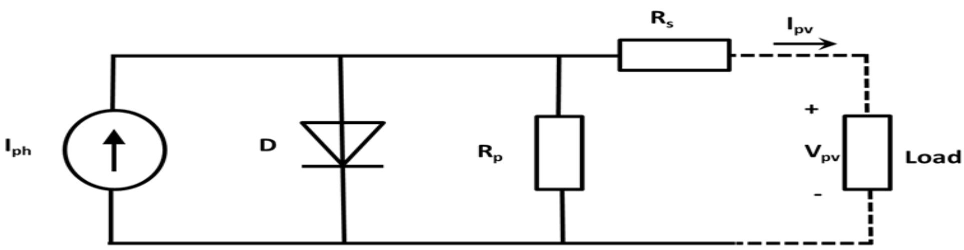


Fig. 2. *Equivalent circuit of a PV panel.*

Table 2. *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	

Modelling of Fuel Cell

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

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

Output voltage of the PEMFC is given by (5)

$$V_{fc} = E - V_c - V_{act} - V_{ohmic} \qquad (5)$$

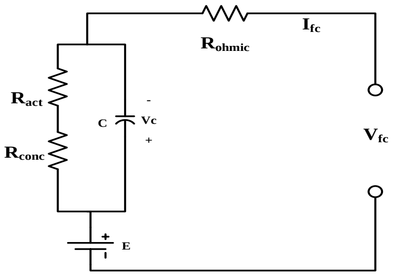


Fig. 3. *Equivalent circuit of PEM Fuel cell.*

Modelling of Battery

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

$$SOC\% = 100\left(1 + \frac{\int itdt}{Q}\right) \qquad (6)$$

where, it is the extracted capacity and Q is the Maximum capacity if battery.

Modelling of Wind Turbine Generator With DFIG

In this paper, DFIG was examined 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 3 [8].

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

Table 3. *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

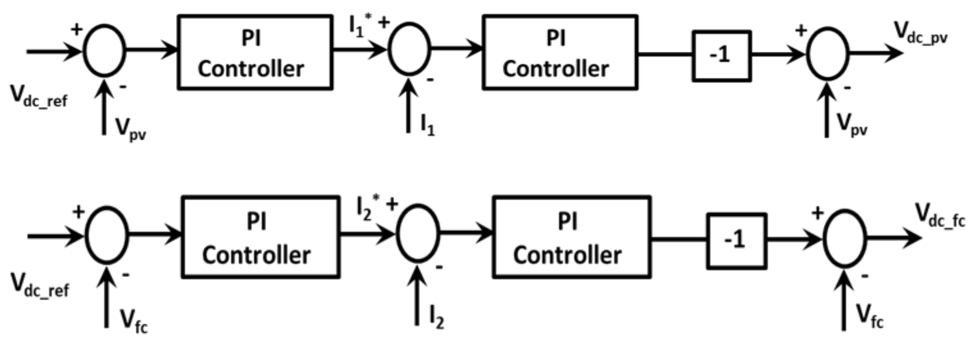
R_r	Rotor resistance	0.005 pu
L_r	Rotor inductance	0.156 pu
L_m	Mutual inductance	2.9 pu
J	Rotor inertia constant	3.1 s
n_p	Number of poles	6
V_{dc_nom}	Nominal DC voltage of AC/DC/AC converter	800 V
P_m	Nominal Mechanical power	45 W

CONTROLLERS

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

Boost Converter

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



(a)

(b)

Fig. 4. *Control scheme of PV cell and PEM fuel cell.*

Control of Battery

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

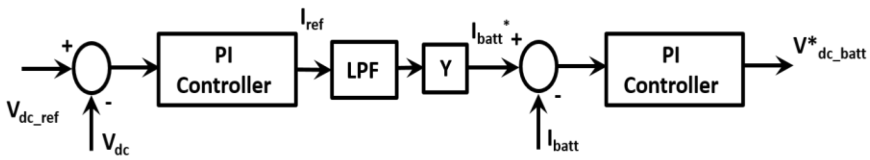


Fig. 5. *Control scheme for battery.*

Interfacing Converter

Major objective of interfacing converter is to interface both sub grids i.e., AC grid and DC grid. Major role of interfacing converter is to exchange power between AC bus and DC bus. When operating in grid tied mode, converter supplies given active and reactive power. 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. Interfacing converter works based on droop control [10]. Control scheme of interfacing converter is shown in Figure 6.

Advantages of interfacing converter cannot be realized by just relying on the droop controlled sources. Interlinking control challenges have to be carefully addressed [11].

(1) Unlike unidirectional sources, interlinking converters have to manage bidirectional active and reactive power flows between sub grids.
(2) At any one instant, 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.

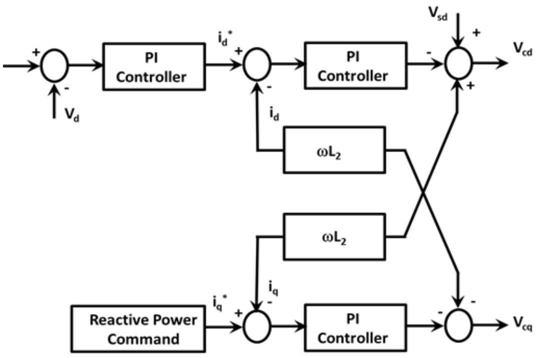


Fig. 6. *Control scheme for interfacing converter.*

SIMULATION RESULTS

Operations 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. 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.

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. Slow tracing speed of the standard P&O algorithm is optimized by using fuel cell in DC subgrid.

Figures 8 and 9 show the curves of PV panel power output and solar irradiation respectively. It was observed that the Power output varies from 4.85 to 13.5 kW, which closely follows solar irradiation curve assuming fixed ambient temperature.

Figure 10 shows the voltage and current responses on AC side of interfacing converter with a fixed DC load of 20 kW. It was noticed 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 to [5].

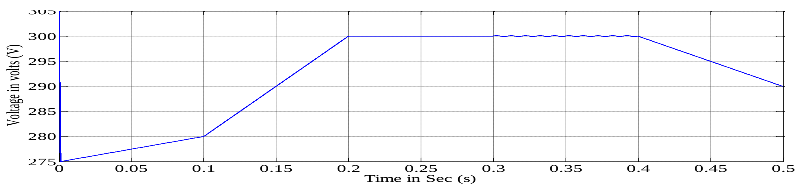


Fig. 7. *Terminal voltage of PV panel.*

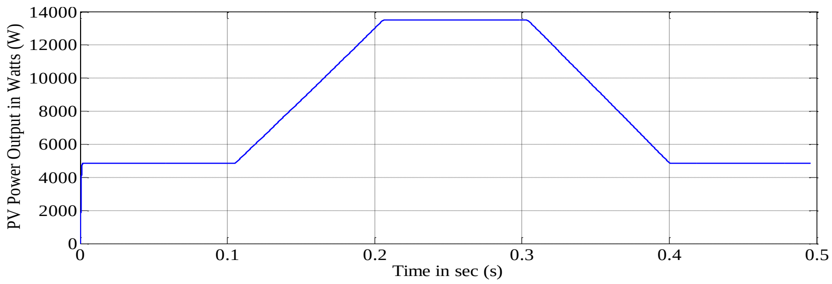


Fig. 8. *Power output of PV panel.*

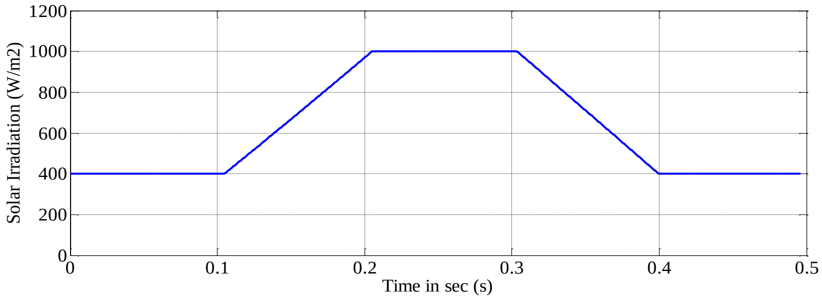


Fig. 9. *Solar irradiation.*

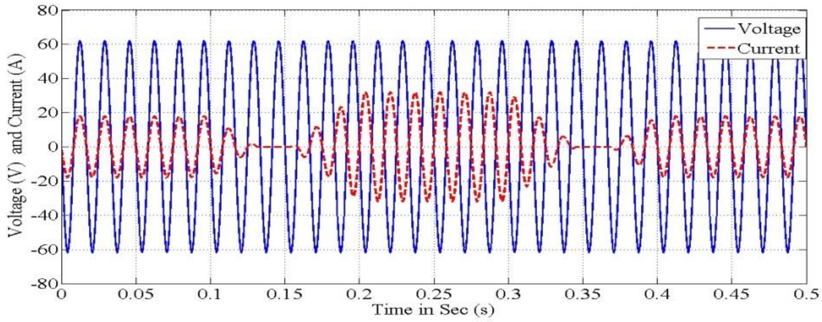


Fig. 10. *AC side voltage and current of the interfacing converter with variable solar irradiation and constant DC load.*

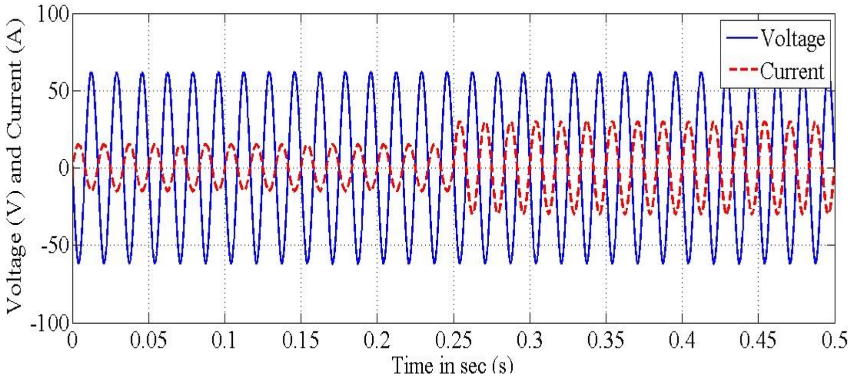


Fig. 11. *AC side voltage and current of the interfacing converter with constant solar irradiation and variable DC load.*

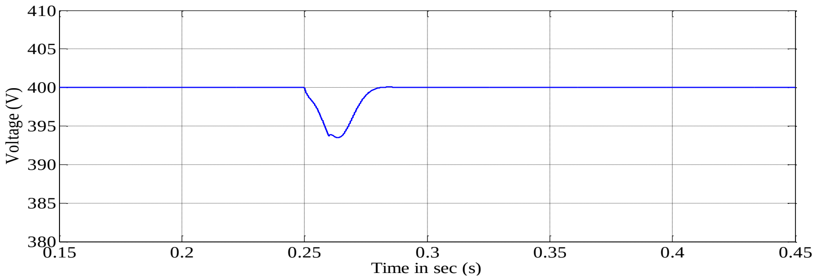


Fig. 12. *DC bus transient response with fuel cell.*

CONCLUSIONS AND FUTURE SCOPE

A Hybrid AC/DC Microgrid has proposed and comprehensively studied in this paper. Control strategies are concisely stated to maintain stable system operation under various load and resource conditions. 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.

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. Hybrid AC/DC Microgrid has to be tested for various faults on subgrids and their effects on the other grid. Hybrid AC/DC Microgrid is only feasible for new construction either in remote location or industries.

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BIOGRAPHIES

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