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Original Article

Hybrid AC/DC Microgrid Efficient Power Management in Islanded Mode Using Bidirectional AC-DC Converter by Novel Droop Control Technique

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Abstract *- AC microgrids and DC microgrids are more efficient and suitable energy systems that can operate independently or in conjunction with the main electric grid. A hybrid AC/DC microgrid structure combines AC microgrid and DC microgrid, which includes the combined benefits of AC and DC microgrids. These microgrids combine traditional and renewable energy sources to produce electricity from natural resources. Since natural resources fluctuate, the electricity generated by these microgrid sources is unstable. Because of this, sharing the power produced by these AC microgrids and DC microgrids is necessary to maintain distribution system load balance. The AC/DC microgrids, managed by an innovative enhanced PQ technique, are linked by an interlinking converter. Power management in such a grid is important for V&F control in the DC and AC grid. Individual grid control is required to achieve power management in a hybrid AC/DC microgrid and attention to control techniques used for interlinking converters. This study presents an overview of various Interlinking Converter (ILC) operating conditions under various generation and load demand conditions for hybrid AC/DC microgrids. In the proposed system, the DC microgrid is a hybrid system that involves PV, wind farms, and batteries, which are used to meet the demand for a DC load. AC microgrid is a hybrid system consisting of FC, wind farm, and SC to supply the AC load demand. These two grids are interconnected using the ILC, i.e. Voltage Source Converter, to transfer power between these grids according to the load demand on either side of the hybrid AC/DC microgrid. The power management strategy has been validated using MATLAB Simulink with variable load demand conditions.*

Keywords *- ILC, FC, SC, Wind farm, PV, Battery.*

1. Introduction

Conventional energy production techniques have contributed to global warming, which has led to terrible living conditions and natural disasters. We must now generate electricity from renewable natural resources, such as hydro, biogas, wind, sun radiation, and tides [1]. Distribution Generators (DGs) are renewable energy sources linked to the grid system's distribution side. When these DG units are integrated, a central control module governs power generation, creating a smart grid. The smart grid has to function independently when the traditional main grid is completely cut off or unavailable, especially in remote areas [2].

A microgrid is a standalone smart grid with many renewable energy sources and Energy Storage Units (ESU). The system operates independently; thus, the inclusion of ESUs is necessary. Since the system is operating independently, ESUs are required. The erratic fluctuations in renewable power generation might cause damage to the load in the absence of ESUs. The erratic fluctuations in renewable power generation might cause damage to the load in the absence of ESUs [3].

The Microgrid (MG) is a microgrid that exchanges power by connecting lower-rated modules at a Point of Common Coupling (PCC). Two categories of MGs exist: 1) AC MG and 2) DC MG, which are so-called because of how the system is built [4]. The AC MG comprises an AC PCC and several sources coupled by three-phase AC lines. A common DC connection that links each module in the DC MG is also built [5].

The proposed system of hybrid AC/DC microgrid is shown in Figure 1. A fuel cell facility, a wind farm, and a Super Capacitor (SC) storage module make up the AC MG, A wind farm, a battery storage module, and a PV source make up the DC MG. Unidirectional converters connect every renewable source to the DC or AC bus.

2. DC Microgrid Configuration

In the proposed hybrid AC/DC microgrid, DC Microgrid architecture is shown in the Figure 2 [6]. In the DC microgrid, two power generating sources, such as PV and wind farm, are present. For energy storage purposes, one battery module is connected to the system [7]. The complete system is designed to supply a variable DC load. In the proposed DC subsystem, solar wind is used as primary and auxiliary sources, respectively, whereas the battery is the main energy storing device [8]. PV module with incremental conductance MPPT is connected to the boost converter, and the battery module is connected to the Bidirectional DC-DC converter fed by the voltage controller. Wind form with power signal feedback MPPT with PMSG will generate AC power. This AC will be given to the Diode bridge rectifier. The output of DBR is given to the Buck-Boost converter. As shown in Figure 2, all three modules are connected to form a hybrid structure of the DC Microgrid [9].

3. AC Microgrid Configuration

In the proposed hybrid AC/DC microgrid, AC Microgrid architecture is shown in Figure 3. In the AC microgrid, two power generating sources, fuel cells and wind farms, are present [10]. For energy storage purposes, one supercapacitor is connected to the system. The system is designed to supply a variable AC load [11]. The proposed AC subsystem fuel cell and wind farm are primary and auxiliary sources, respectively, whereas super capacitor is the main energy storage device [12]. All three modules with their respective converters are connected, as shown in Figure 3, to form a hybrid structure.

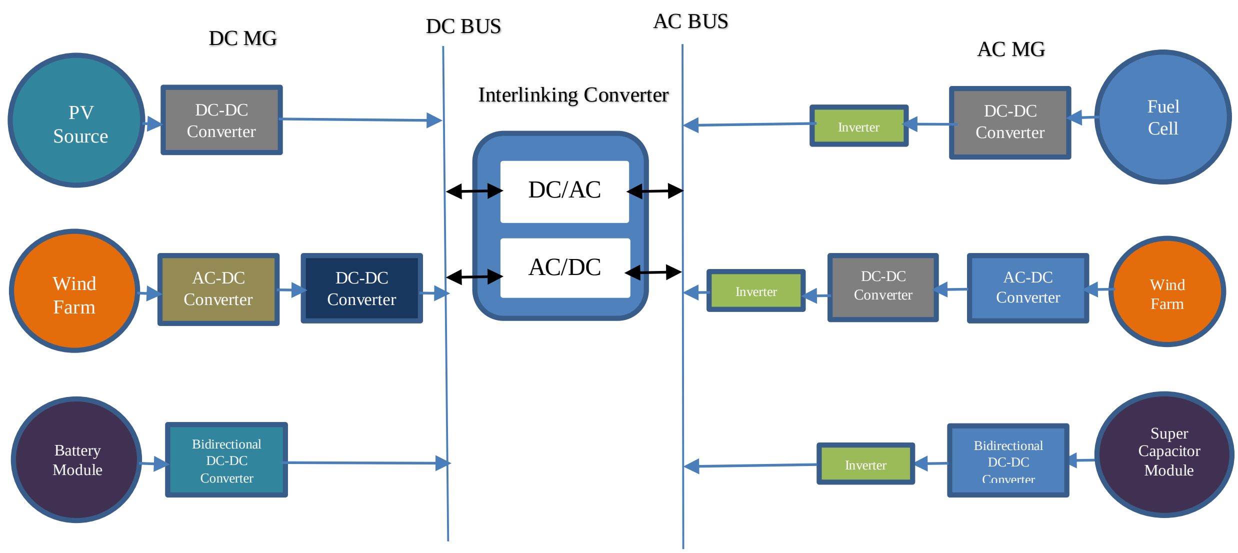

Fig. 1 Hybrid AC/DC microgrid

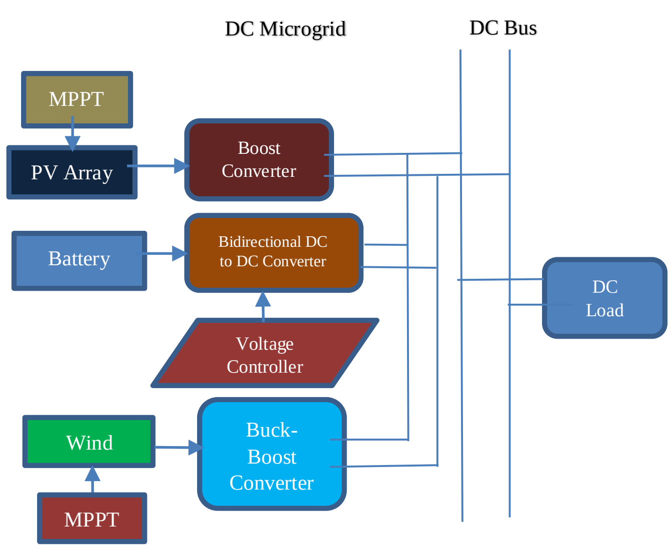

Fig. 2 DC microgrid architecture

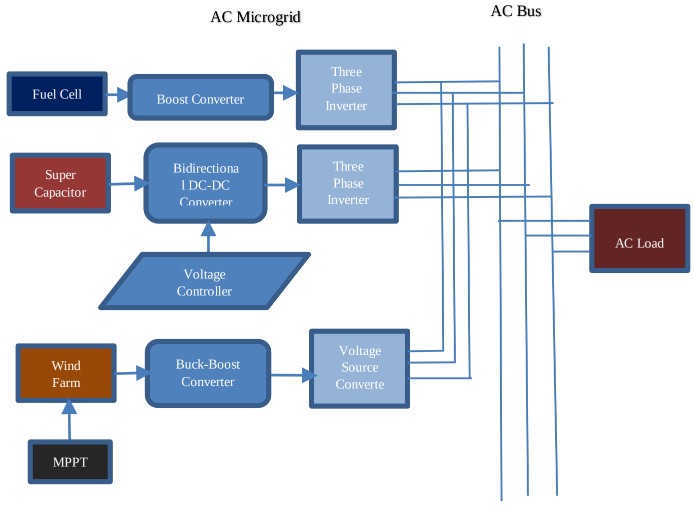

Fig. 3 AC microgrid architecture

4. Hybrid Microgrid Configuration

Each source is linked to a different inverter on the AC MG to share power at the AC bus. Only DC-DC converters, which switch power at the DC bus, are present in the DC MG [13].

The two MGs have selected distinct renewable energy sources to improve the system's flexibility. The DC Microgrid consists of a solar renewable energy system named a PV module, and it is coupled to a boost converter managed by an MPPT control [14]. The MPPT control system governs the DC MG, which consists of a photovoltaic source coupled to a boost converter using photovoltaic panels. The hybrid AC/DC Microgrid block diagram for the proposed system is shown in Figure 4.

In addition to the PV, a wind farm includes a Photovoltaic (PV) source, a diode bridge rectifier, and a Buck-Boost (BB) converter. A battery backup module is linked for energy storage and support through a Bidirectional DC-DC Converter (BDC) [15].

One fuel cell plant on the AC MG is believed to have a boost converter powered by Constant Voltage (CV) control and coupled to a 3-ph VSC [16]. A 3-ph VSC connected to a BB converter is added to the same wind farm construction used in DC MG for AC MG. A 3-phase VSC is also connected to a SC module for energy storage via BDC [17]. A 6-switch IGBT VSC circuit topology known as ILC connects the two MGs. Each module in the provided hybrid MG has its circuit architecture and is managed by a separate controller [18].

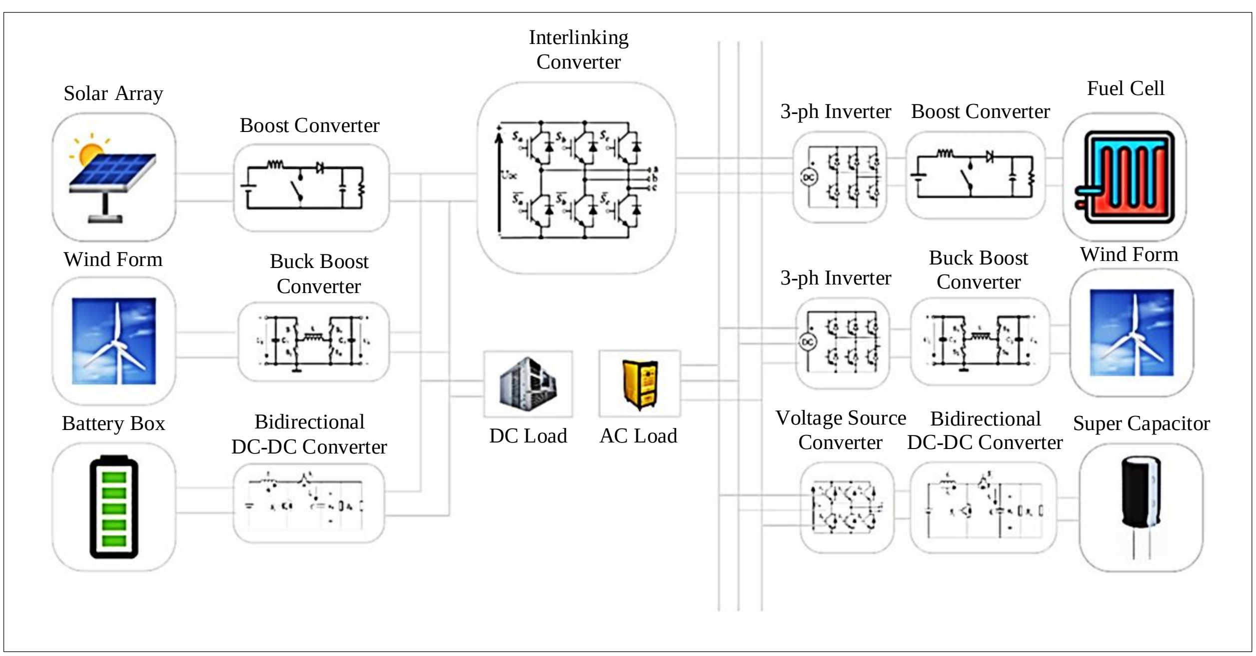

Fig. 4 Hybrid AC/DC microgrid block diagram

5. Hybrid AC/DC Microgrid Control Process

The controllers installed within each grid determine how independently the AC and DC microgrids run [19]. The smooth management of power flow in a hybrid AC/DC microgrid using droop control or V-f control applied to VSC between the AC microgrid and DC microgrid can be achieved by maintaining the power flow within each grid using independent controls in each grid. A hybrid AC/DC microgrid structure can be operated in two modes, such as grid connected mode or islanding mode [20].

In grid-connected mode, as the main grid is present, the main grid will take care of AC grid frequency [21]. But in standalone mode, the utility does not assist the hybrid AC/DC microgrid. In the standalone mode of operation, power management between AC and DC microgrids according to the load demand can be the responsibility of the interlinking converter.

There are two main types of control operations for interlinking converters: droop-based control and communication-based control. The suggested control approach makes the hybrid AC/DC microgrid operate independently, i.e. in an islanded mode of operation, and it uses a droop-based interlinking converter control strategy. Using different droop controls inside separate microgrids and then letting the ILC run independently is known as droop-based control.

Figure 5 shows the normalization method of the droop control technique. On the DC side, the control parameter is voltage; on the AC side, the control parameter is frequency. Controlling the power flow between the two microgrids to adjust frequency and voltage comes next after each microgrid has put its droop methods into practice. ILC is employed for this reason, i.e., for each grid's power management. The smooth functioning of ILC is essential to the stability of a hybrid microgrid. In order to control the hybrid grid's voltage at the DC microgrid side and frequency and manage power flow, droop control is frequently employed in ILCs [22].

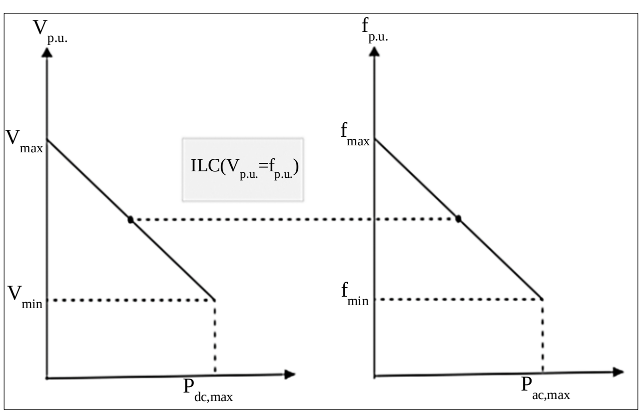

Fig. 5 Normalized droop control

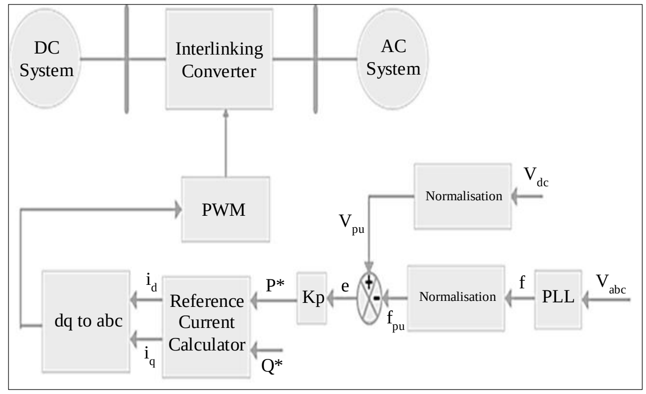

Fig. 6 Normalized droop control block diagram

Power management in a hybrid AC/DC microgrid can be managed by a Normalized droop control based Interlinking converter. An interlinking converter can not handle reactive power control, so the AC microgrid must handle this issue. An Interlinking converter should control the active power flow in either direction between the two grids. Depending on load demand, the ILC's job is to switch power between two grids. Droop control uses an interlinking converter to transfer electricity from an underloaded microgrid to an overloaded microgrid.

The AC microgrid's active power will fluctuate in response to changes in the AC demand, and the frequency of the microgrid will oscillate between two limitations, known as the lower and higher limits, or fmin and fmax. Similarly, V_{dc} is the parameter on the DC microgrid side affected by fluctuating load demand. By measuring the voltage terminal value at the DC side and the frequency terminal value at the AC side, an interlinking converter may calculate the power flow. Power exchange across the grids might happen based on the request that the DC or AC microgrid makes to the interlinking converter. ILC will accept the request to switch to AC power if the DC microgrid's Vdc value is lower than Vmin. If the AC microgrid frequency is detected as less than $f_{min,}$ then ILC will take the request of exchanging the power from the DC side. Maintaining a consistent scale is essential for appropriate power management establishment. Therefore, "Vdc" on the DC side and "f" on the AC side are transformed to P.U. values. Voltage and frequency are normalized in the following equation [23].

$$fpu = \frac{f-0.5(fmax+fmin)}{0.5(fmax-fmin)} \quad (1)$$

$$Vpu = \frac{V-0.5(Vmax+Vmin)}{0.5(Vmax-Vmin)} \quad (2)$$

Equations (1) and (2) will show the formula to convert 'f' on the AC side to the P.U. value and 'V_{dc}' on the DC side to the P.U. value. Figure 5 shows the normalized droop control method block diagram. V_{dc}, f are normalized using Equations (1) and (2), then V_{dcpu} and f_{pu} are given to the actuator, and the error signal will be generated if the error value is given to the P-Controller.

The output of the P-controller is P*, which will give the reference active power [24].

$$P^* = k_p(V_{dcpu} - f_{pu}) \tag{3}$$

When there is no reactive power exchange, the reactive power reference Q* can be zero or any finite number. To generate the current signals in a dq frame, the reference current generator is fed the P* and Q* values. Applying the ABC transformation technique to the dq frame current values generates Pulse-Width Modulation (PWM) for ILC. Recall that choosing a reference direction is necessary for power flow. When transferring DC to AC, the active power flow (P) is negative [25]. Figure 6 will show the control block diagram of the proposed droop control technique. The load demand on each side of the hybrid microgrid is determined using this method. This droop will function when an AC or DC microgrid has to have a separate control mechanism. In the DC microgrid, by applying a voltage controller at the battery module, load demand on the DC side can be managed, and on the AC side, we use droop control at every point of source and ESS to identify the load demand.

This technique can decide which source can supply the load to the DC and AC sides accordingly. The main aim of the proposed system is to exchange the power between two microgrids depending on the load demand. The power exchange between microgrids can be possible with the help of the control technique we apply at VSC. Suppose we use the control technique rather than the Droop control technique, such as Synchronous Reference Frame (SRF) control for controlling the VSC operation. In that case, it can only exchange the power from the DC Microgrid for the AC Microgrid, but vice versa is not possible. But, the VSC with the proposed droop control can exchange the power on either side of the Hybrid AC/DC Microgrid.

6. Result Analysis

Modelling and analysis of the given Hybrid AC/DC microgrid is modelled and analyzed as shown in Figure 4 using MATLAB Simulink software. Each module is defined with specific parametric ratings for simulating the Hybrid AC/DC microgrid operating in different conditions. Table 1 will show all the system parameters used for simulation.

6.1. Case 1: DC Microgrid Power Generation is Equal to DC Load Demand, and AC Microgrid Power Generation is Equal to AC Load Demand

In this case, the power generated at DC side sources such as PV is 21.3kW, the wind energy system is 33.7kW, and the battery is in stable mode as neither charging nor discharging. The total power generated on the DC microgrid is 55 kW. On the DC side, the load demand is also 55 kW. So, the DC load is supplied by the DC source. In this case, the power generated on the AC microgrid side by RES, such as Wind form, is 5kW, the fuel cell is 2kW, and the energy storage element, i.e., supercapacitor, delivers 1Kw power. The total power generated on the AC microgrid side is 8kW. The load demand on the AC side is 8kW. As both grids can supply the loads accordingly, ILC will not exchange the power. So, the power exchange at ILC is zero watts. Table 2 will show the results of case 1.

Table 1. System parameters used for simulation

Name of the Parameter	Values
PV Source	V_m=55.1 V, I_{mp}=6.10A, V_{oc}=64 V, I_{sc}=6 A, N_s=10, N_p=10, P_{pv}=30.5 kW MPPT= Incremental Conductance, Dint=0.5, f_s=5KHz.
Wind farm DC MG	P=35kW, T_m=125N-m, V_{dc}=570V, N=3000 rpm, p=4, J=0.011kg.m^2. MPPT= Power signal feedback.
Wind farm AC MG	P_n=6 kW, T_m=41.4 Nm, V_{dc}= 300V, N=2200rpm, J=0.003945kg.m^2. MPPT= Power signal feedback.
Battery Module	V_{bat}=500V, Capacity=200Ah, SOC_{int}=90% K_p=1, K_i=0.0023, V_{dcref}=750V, f_s=5kHz.
Fuel Cell Plant	PEM-FC - V_{in}=400V, I_{in}=50A, V_{end}=250V, I_{end}=150A. V_{dcref}=750V, K_p=1, K_i=0.0023, f_s=5kHz, m=0.89
SC Module	V_{rated}=500V, N_p=N_s=1, V_{int}=500V, T=25^{0}C. L_{bdc}=161uH, C_{out}=220uF. K_p=1, K_i=0.0023, V_{dcref}=750V, f_s=5kHz
ILC	V_{dcref}=740V, K_p=1, k_1=k_2=1.

Table 2. Results of case 1

S.No.	Parameter Name	Value
1	Ppv	21.3kW
2	Pwf	33.7kW
3	Pbat	0
4	Pdc Total = Ppv+Pwf+Pbat	55kw
5	Pdcload	55kW
6	Pfc	2kW
7	Psc	1kW
8	Pwf	5kW
9	Pac Total= Pwf+Psc+Pfc	8kw
10	Pacload	8kW
11	PILC	0

6.2. Case 2: DC Microgrid Power Generation is Less than DC Microgrid Load Demand, and AC Microgrid Power Generation is > AC Load Demand

In this case, DC Microgrid power generation is less than the DC microgrid load demand. The power generated at DC side sources such as PV is 10.6 kW, the wind energy system is 3 kW, and the battery delivers the power of 28 kW. The total power generated on the DC microgrid is 41.6 kW, and the DC side load demands 55 kW. In this case, the DC microgrid power generation is less than the DC load. In this case, the power generated on the AC microgrid side by RES, such as Wind form, is 6.7kW, the fuel cell is 7.7kW, and the energy storage element, i.e., supercapacitor, delivers 5.6 kW power. The total power generated on the AC microgrid side is 20kW. The load on the AC side is 8kW. The AC Microgrid has excess power and low AC load demand in this case. Now, the interlinking converter will exchange the power of 11.5 kW. Table 3 shows the results of case 2.

Table 3. Results of case 2

S.No.	Parameter Name	Value
1	Ppv	10.6kW
2	Pwf	3kW
3	Pbat	28kW
4	Pdc Total = Ppv+Pwf+Pbat	41.6 kW
5	Pdcload	55kW
6	Pfc	7.7 kW
7	Psc	5.6 kW
8	Pwf	6.7 kW
9	Pac Total= Pwf+Psc+Pfc	20 kW
10	Pacload	8 kW
11	PILC	-11.5 kW

6.3. Output Waveforms for Case1

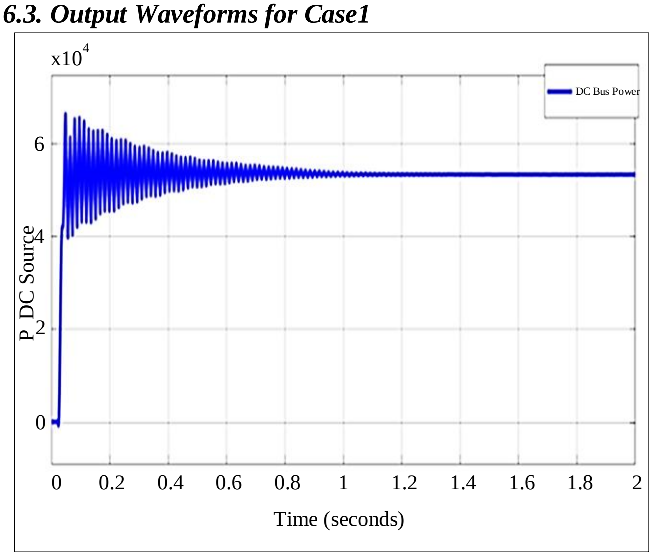

Fig. 7 DC microgrid power in case 1

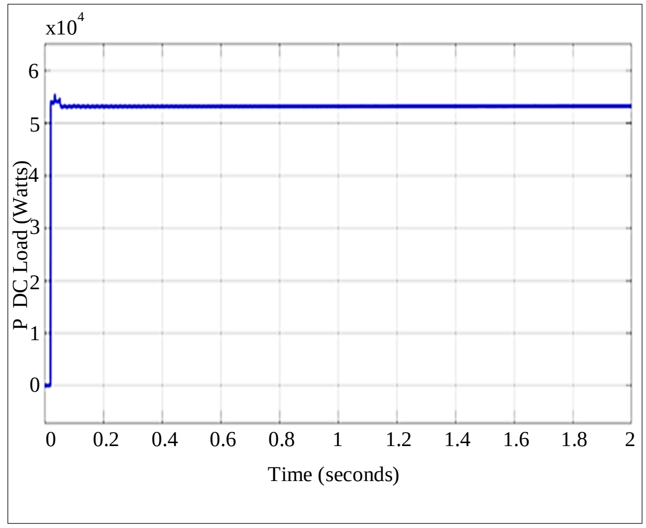

Fig. 8 DC load demand in case 1

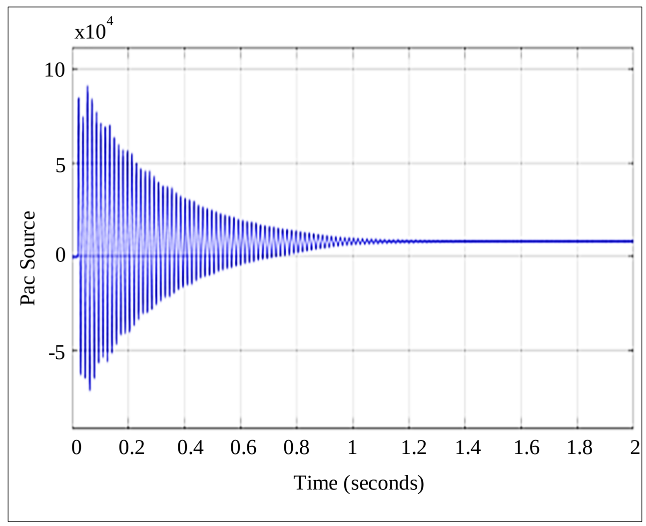

Fig. 9 AC microgrid total power generation in case 1

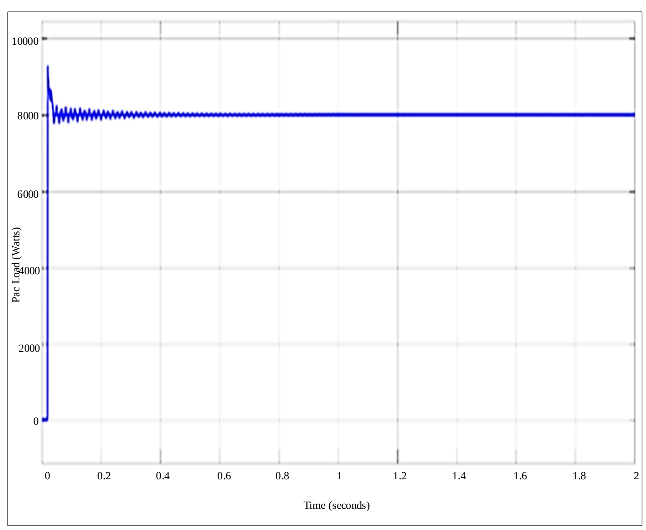

Fig. 10 AC microgrid total load demand in case 1

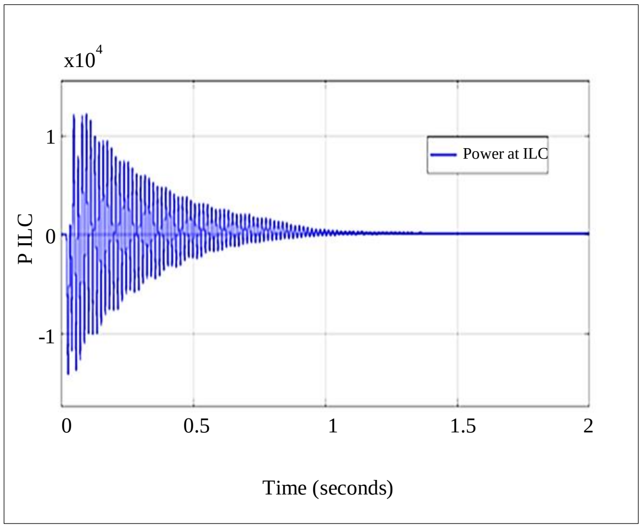

Fig. 11 Power exchange at interlinking converter in case 1

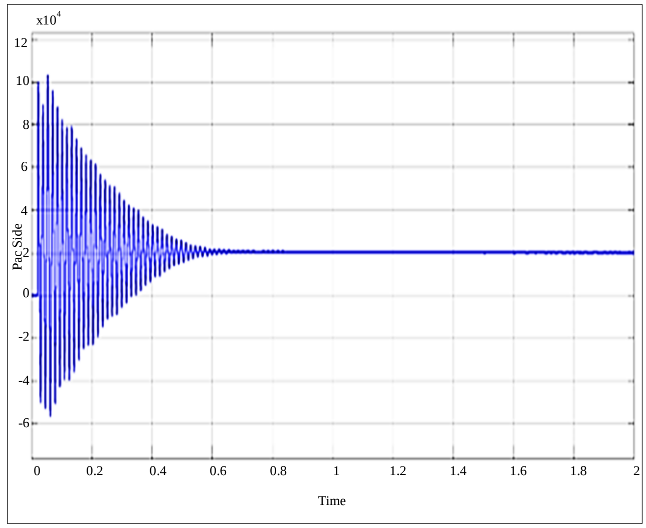

Fig. 14 AC microgrid total power generation in case 2

6.4. Case 2 Results

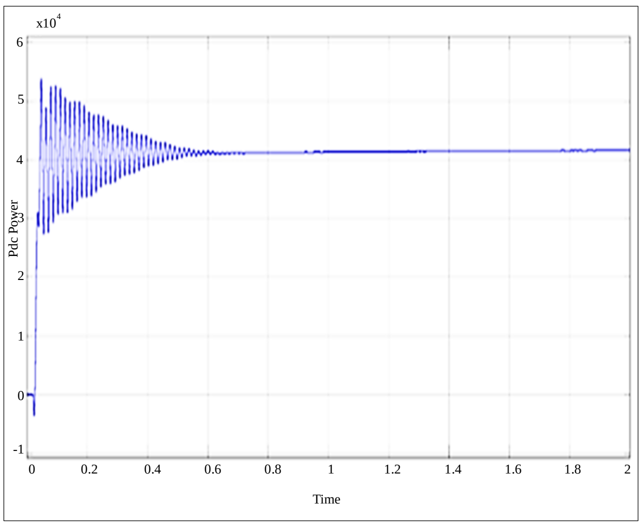

Fig. 12 DC microgrid power in case 2

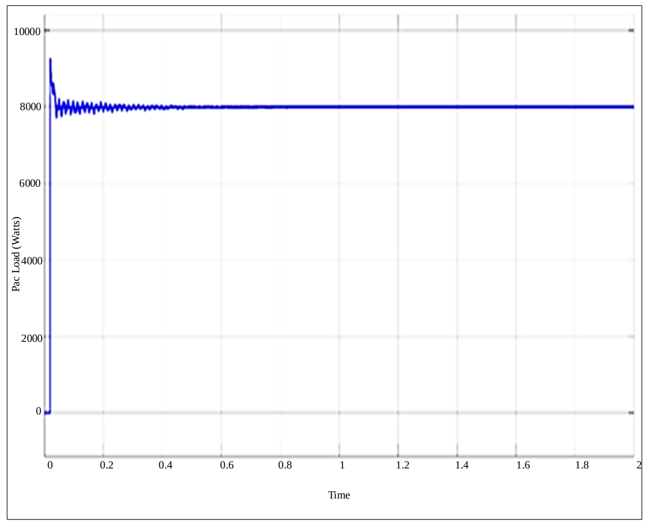

Fig. 15 AC Microgrid total load demand in case 2

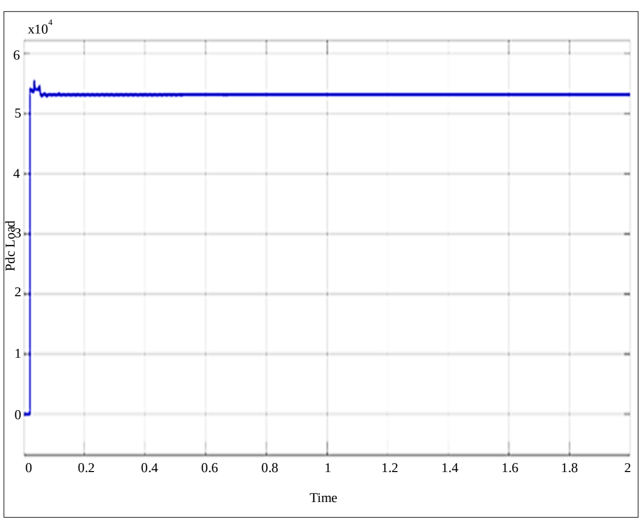

Fig. 13 DC load demand in case 2

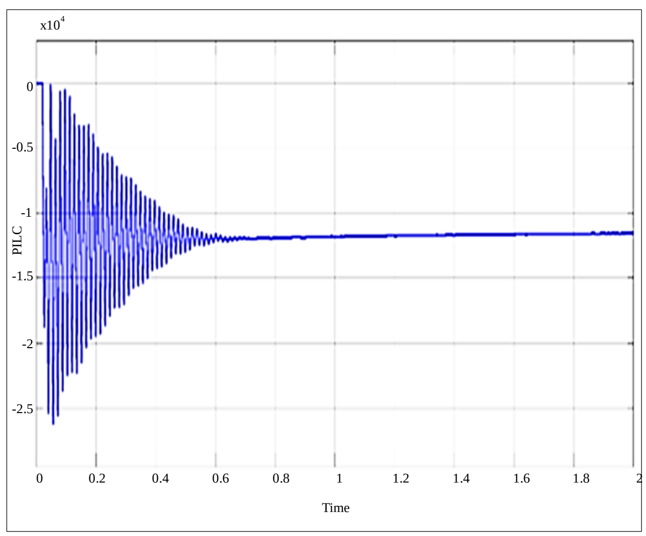

Fig. 16 Power exchange at Interlinking converter in case 2

7. Conclusion

As per the results generated by the simulation of the proposed hybrid AC/DC microgrid system with multiple renewable energy sources and energy storage modules, it is observed that the loads on either side of the Hybrid AC/DC microgrid can be supplied in any given condition. ILC with a normalized droop control method will play a major role in Hybrid AC/DC microgrid power exchange.

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