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Research Paper

BIC based on Modified Droop Control of Hybrid AC/DC Microgrid with PV/Wind/ESS under Variable Generation and Load Conditions

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Abstract: The idea of a microgrid is created by utilizing more diverse ac or dc distributed generation (DG) sources along with an energy storage system (ESS) and loads. The most efficient and reliable selection of ac and dc microgrids is a hybrid ac/dc microgrid. The hybrid microgrid largely overcomes the shortcomings of standalone ac or dc microgrids. A bidirectional interlinking converter (BIC) is utilized in the interface for controlling power flow between sub-grids. In order to improve voltage and frequency regulation with effective power sharing, the BIC based on the proposed control scheme is implemented for power flow between ac and dc sub-grid in Islanding mode. The control scheme is modified based on conventional droop control with voltage and frequency variation in order to improve bus voltage and frequency regulation with effective power sharing for intermittent sources. The operation of the islanded hybrid ac/dc microgrid is performed with solar, wind, and energy storage system under variable generation and load conditions. In order to make robustness of the system, there are considered different cases for generation and load scenarios. In the transient state, the overshoot and settling time of frequency and voltage are improved, as well as the frequency and voltage regulations are found within the permissible limit in the steady state. Furthermore, the corresponding variations are shown in tabular form in the simulation result. The actual data of solar irradiance and wind speed have been taken from the National Renewable Energy Laboratory. The performance of the system is verified in MATLAB/Simulink environment.

Keywords: Hybrid AC/DC microgrid, Droop control, power sharing, voltage regulation, frequency regulation.

1 Introduction

RECENTLY, renewable energy sources (RES) have gained more attention due to the deterioration of the environment and depletion of traditional resources.

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Integration of renewable energy with microgrids is becoming very important and making the energy system more reliable and efficient. A small group of distributed generators (DGs), energy storage systems, loads with the controller, and communication subsystem is referred to as a microgrid. [1]. Solar, wind, and ESS are utilized for integration into the microgrid. The microgrid can be ac microgrid, dc microgrid, or hybrid ac/dc microgrid [2], [3]. It can either operate in grid-connected or islanded operation.

The most important control aims for an islanded hybrid ac/dc microgrid are to precisely distribute the load current across all DGs under their rated powers and to regulate bus voltages and frequency into the required range. Traditionally the control architecture categorization of the abovementioned is based on centralized, decentralized, and distributed control [4]. Hierarchical architecture, on the other hand, consists of primary, secondary, and tertiary levels. These levels can be centralized, decentralized, or distributed. To calculate the control signals in a centralized controller, each DG must connect to the microgrid central controller (MGCC). A significant communication overhead and single-point failure issue also plague the centralized control approach. Therefore, decentralized [5]-[8] and distributed control [9], [10] strategies have grown in popularity because a node doesn't have to communicate with all the other nodes within the network. Distributed secondary control scheme is proposed in [11]-[16] to provide precise active power sharing and to offset frequency and voltage variation brought on by main control. It is suggested to use an energy management system for resource allocation and use in [17]-[21].

Droop-based control is a popular method to achieve proper power flow [22] because decentralized control does not require communication between DGs. Additionally, the bus frequency and voltage quality are compromised, and only the balanced current component may be transferred. Various articles are proposed for improving power flow and voltage and frequency regulation [23]-[26]. The design methodology of the triple-droop control scheme for low voltage microgrids in a decentralized way is presented [23]. A novel adaptive droop control algorithm that dynamically changes the droop coefficients of the VSCs to ensure maximum utilization of available resources in each microgrid under different operating modes is presented [26] as part of a unified power management strategy for Intra and inter-microgrid power sharing in a hybrid ac/dc microgrid system. In [27], Power balancing under resistive-inductive and resistive-capacitive loads is proposed to be achieved autonomously via f-P/Q droop control. A droop-controlled interlinking converter is studied in order to regulate power sharing in hybrid ac/dc microgrids and to simplify delivering efficient load power during the islanded mode of operations [28]. Moreover, droop control is utilized for a parallel converter to share equal power among converters and lower the circulation current [29]-[33]. A universal droop control scheme has been proposed in [34] for converters with variable output impedance to achieve parallel operation. A comparison of the approaches of virtual oscillator control, modified droop control, and droop control for parallel inverter operation in the standalone microgrid in [35].

The conventional droop method is suitable for maintaining the desired behavior of the active and reactive power. However, the variation of frequency and voltage is a serious concern with intermittent sources. In the conventional method, it is observed that the variation in frequency and voltage are found significant variation and it should be limited for the effective operation of the system. These objectives are significantly improved by the proposed control scheme.

The contributions are covered in this paper as follows:

i. In order to improve voltage, frequency regulation, and effective power sharing, the islanded hybrid microgrid is performed based on the proposed control scheme.
ii. The performance of the system is analyzed and compared with the conventional control scheme under constant power generation with step load changes. Frequency and voltage in transient cases are improved such as overshoot and settling time as well as regulations in the steady state.
iii. The control scheme is analyzed under different generation conditions with the constant and variable load as well as generation. The performance analysis of the system under variable loading and the generation with the integration of DGs. Solar irradiation and wind speed data are considered from National Renewable Energy Laboratory (NREL). It is verified for comparative performance in MATLAB/Simulink environment.

The rest of the paper is divided into subsections: In section 2, a simplified hybrid microgrid structure and the control structure of solar & wind generators have been discussed. In section 3, the conventional and proposed control schemes for BIC based on droop control are explained. In section 4, the simulation results of different cases corresponding to the proposed control scheme have been discussed. Finally, the conclusion is drawn in section 5.

2 Hybrid Microgrid Structure

A hybrid microgrid has the most effective and reliable solution to use the advantages of both dc [36] and ac sub-grids [37]. A simplified islanded hybrid ac/dc microgrid is shown in Fig. 1. The dc and ac subgrids are linked with the help of BIC.

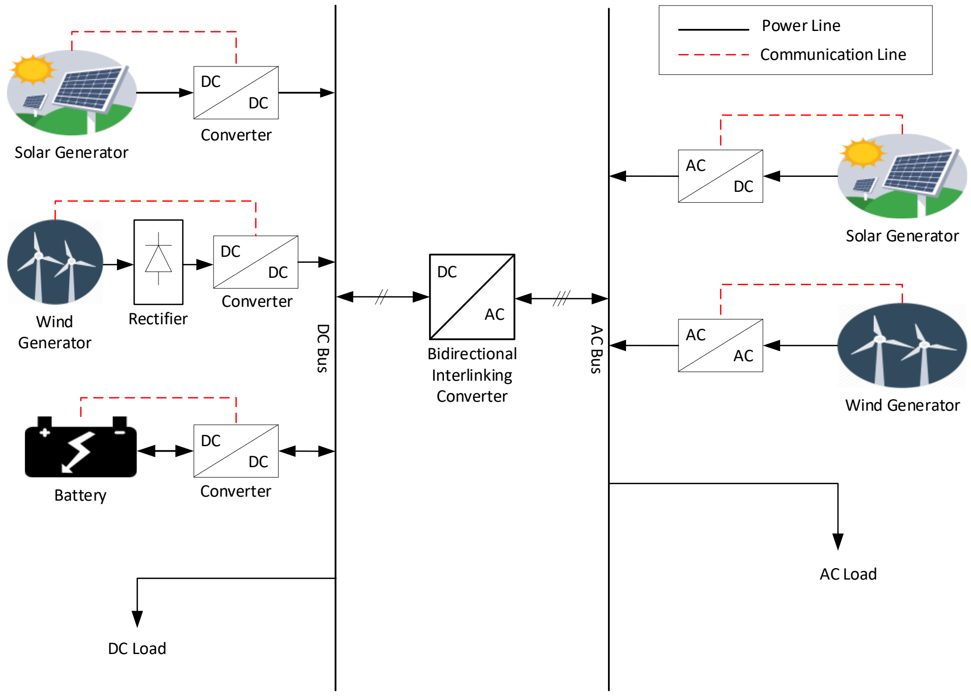

Fig. 1 Islanded hybrid ac/dc microgrid.

The dc sub-grid is the same as the dc microgrid, which consists of DGs, loads, and ESS connected to the dc bus with a dc/dc converter. DG is connected with the help of a dc/dc boost converter, which is controlled by either MPPT control or voltage control mode based on the operation. Solar and wind generator are used as DGs, and the battery is used as ESS in this island ac/dc hybrid microgrid system.

Solar generators consist of a combined series-parallel combination of solar arrays. The power generated from the solar cell is the function of solar irradiation and temperature. A solar generator is connected to the dc bus with the help of a dc/dc boost converter. The PWM fed to the converter is generated according to the duty cycle (D). However, the duty cycle is fixed for the open loop. Moreover, it is generated by the controller in the closed loop. The control techniques are the MPPT technique and Constant voltage control [38]. For the grid-connected mode, MPPT is used to extract maximum power. Moreover, in island mode, MPTT is used whenever ESS is available. Otherwise, constant voltage control is used. In the hybrid microgrid system, a battery is used as ESS. Hence, the MPPT control technique is used for solar power extraction.

A wind generator is made when a permanent magnet synchronous generator (PMSG) is properly connected to a wind turbine [39]. A wind turbine produces torque, which is the function of wind speed, pitch angle, and generator speed. The wind turbine is coupled with PMSG, which converts mechanical input to electrical output. PMSG is directly connected to the three-phase ac supply with the help of a capacitor bank in the ac subgrid. However, in the case of the dc subgrid, the three-phase supply is further connected to the uncontrolled rectifier with dc/dc converter. MPPT control is used to extract the maximum power and feed it to the dc subgrid, similarly to solar energy.

The battery is considered an ESS and plays a vital role in island mode. The dc bus voltage and power balance are regulated with the help of a battery, and it acts as both source and load. The power balance diagram of isolated microgrid is shown in Fig. 2. The battery is connected with the help of a bidirectional dc/dc converter. Constant voltage control is used in the bidirectional dc/dc converter. The combined solar, wind, and ESS connection with dc load makes a dc subgrid. The dc and ac subgrid operate individually, making the dc and ac microgrid. For a hybrid microgrid, ac and dc subgrid are connected with the help of a power electronic interface called BIC. The controller is used to power flow between the subgrids.

3 Control Structure

3.1 Conventional BIC Control structure

A power electronic interface named BIC is used to power flow between ac and dc buses [40].

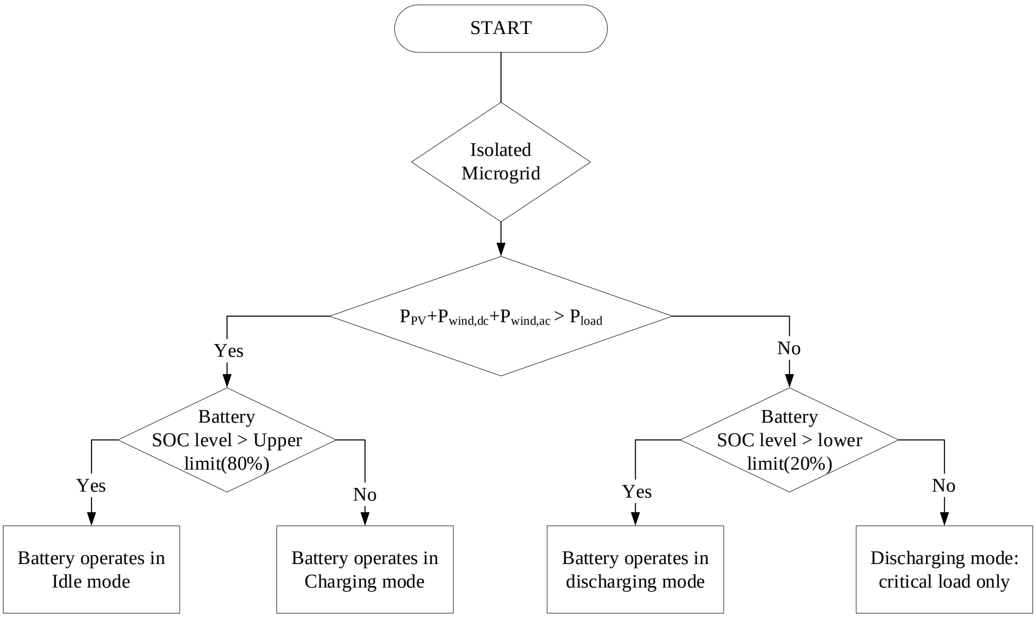

Fig. 2 Power balance diagram of isolated microgrid.

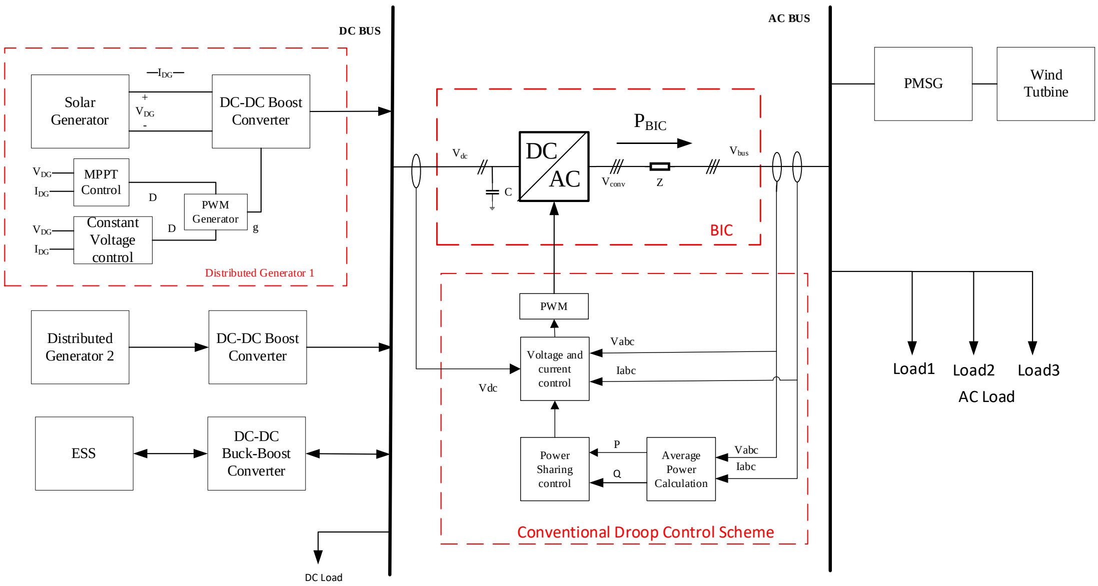

Fig. 3 Overall Structure of the islanded hybrid ac dc microgrid.

BIC is considered a generating source in which power can be positive, negative, and zero. Positive power shows that the power flows from dc to ac subgrid, negative power shows that power flows from the ac to the dc subgrid, and zero power shows no power exchange between the subgrids. PBIC is the power flow from dc to the ac subgrid, calculated from the average output power of the three-phase ac bus side of BIC.

The BIC average power calculation is done from the ac bus voltage and current signals. A low pass filter is required to eliminate the harmonics of the calculated average power, which is then fed to the power sharing control. Power sharing control is discussed in the below subsection. P-f and Q-V droop control is used to generate the Voltage and frequency signals [22]. This droop-controlled voltage and frequency output is the reference voltage for the inner control loops. The inner control loop is also discussed in the next subsection [41]. The output of the inner control loop is fed to the PWM generator to generate the gate signals of the BIC. The overall structure of the islanded hybrid ac dc microgrid with the conventional droop control scheme of the BIC is shown in Fig. 3.

3.1.1 Power sharing control

The BIC is used for power exchange between ac and dc subgrid. The Power flow equation of the BIC converter is given as Eq. (1). It shows the power flows from the dc to ac subsystem.

$$S = V_{conv} I_{conv}^{*} = \frac{V_{Conv} V_{bus} \angle(\theta - \delta)}{Z} - \frac{V_{conv}^{2} \angle\theta}{Z} \quad (1)$$

Where, V_{conv} is the BIC output voltage, I_{conv} is the current fed to the ac bus by BIC, V_{bus} is the three-phase bus voltage, $Z = R + jX$ is the interconnection line impedance, θ is the impedance angle, and δ is the load angle. Total power extracted from BIC is given by eq. (1). This is further converted into active and reactive power in Eq. (2) and Eq. (3).

$$P = \frac{V_{conv} V_{bus}}{Z} cos(\theta - \delta) - \frac{V_{conv}^{2}}{Z} cos(\theta) \quad (2)$$

$$Q = \frac{V_{conv} V_{bus}}{Z} sin(\theta - \delta) - \frac{V_{bus}^{2}}{Z} sin(\theta) \quad (3)$$

In a transmission line, an inductive component of the line impedance is typically much higher than the resistive one as $X \gg R$. This is approximated as $Z \approx X$ and $\theta \approx 90°$. After rearranging and approximation, the equation becomes:

$$P \approx \frac{V_{bus} V_{conv} Sin(\delta)}{X} \quad (4)$$

$$Q \approx \frac{V_{bus}\left(V_{bus} - V_{conv} cos(\delta)\right)}{X} \quad (5)$$

The following droop control expressions can be written for the inductive microgrid in Eq. (6) and Eq. (7). From this equation, the conventional P-f and Q-V droop characteristic is obtained, as shown in Fig. 4. According to the P-f droop characteristic, the frequency decreases as active power demand increases, and similarly in the Q-V characteristic [42].

$$f - f_0 = m_p(P - P_0) \quad (6)$$

$$V - V_0 = n_q(Q - Q_0) \quad (7)$$

3.1.2 Voltage and current control

The outer voltage control loop and the inner current control loop are the primary components that make up these control loops [41]. The output voltage may be regulated with the help of a voltage controller, and the maximum amount of current can be limited with the help of a current controller. There are many different controllers that may be created for use with inner control loops. Cascaded PI control, on the other hand, is employed here because it is both reliable and simple in its design. Fig. 5 provides a representation of the control block diagram for the cascaded PI controller.

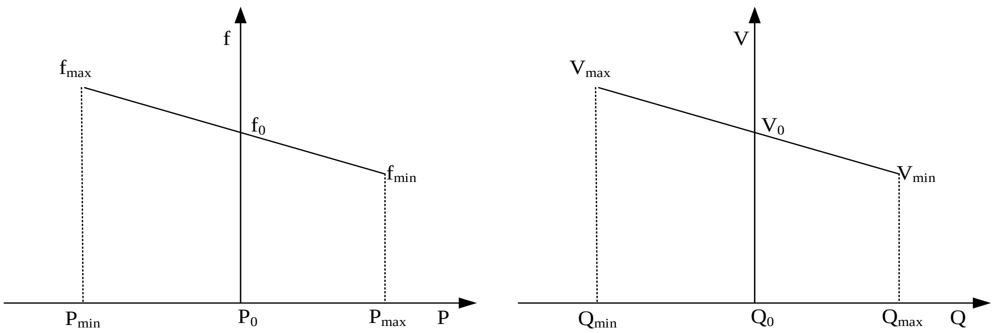

Fig. 4 Conventional frequency and voltage droop characteristics.

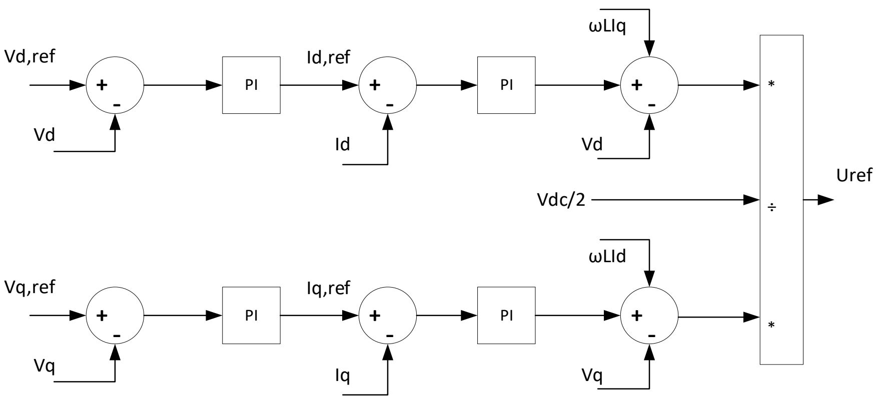

Fig. 5 Voltage and current control loops.

The abc to dq0 Clarke transformation theory is used to derive the dq0 components of the voltage and current. The phase shift may be calculated using the derivative of the frequency of the power sharing P-f droop control while the system is operating in islanded mode. On the other hand, the phase is directly taken in grid-connected systems by employing PLL blocks.

3.2 Proposed BIC Control Structure

Voltage and frequency are restored with a PI controller, as shown in Fig. 6. It improves the voltage and frequency regulation caused by conventional droop control. Hence, the conventional droop equation is modified as Eq. (10) and Eq. (11).

$$f - f_0 = m_p(P - P_0) + \delta f \quad (10)$$
$$V - V_0 = n_q(Q - Q_0) + \delta V \quad (11)$$

The P-f droop characteristic in Fig. 7 indicates that the rated power P0 operates at frequency f0. As the power demand increases, frequency shifts from f0 to f0′, which causes degradation in frequency regulation. The deviation in frequency (δf) and voltage (δV) is summed with the dropped frequency (f0′) and voltage (V0′). This shift the droop-line upwards and it gives the new operating frequency (f0′′) and voltage (V0′′), as shown in Fig. 7. The new droop-line operates at the rated frequency (f0) and rated voltage (V0) with increased power. The same occurs in the case of power deficiency.

The proposed control is utilized in the BIC to power flow from the dc subgrid to ac subgrid and vice versa. The block diagram of the proposed controller is shown in Fig. 8.

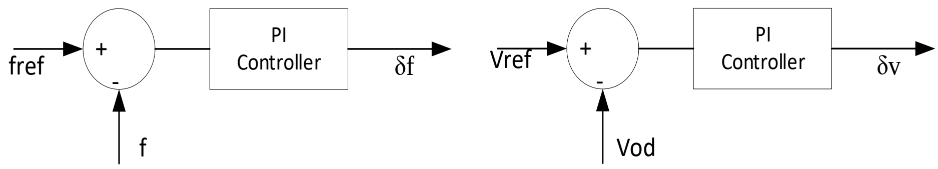

Fig. 6 Proposed voltage and frequency controller

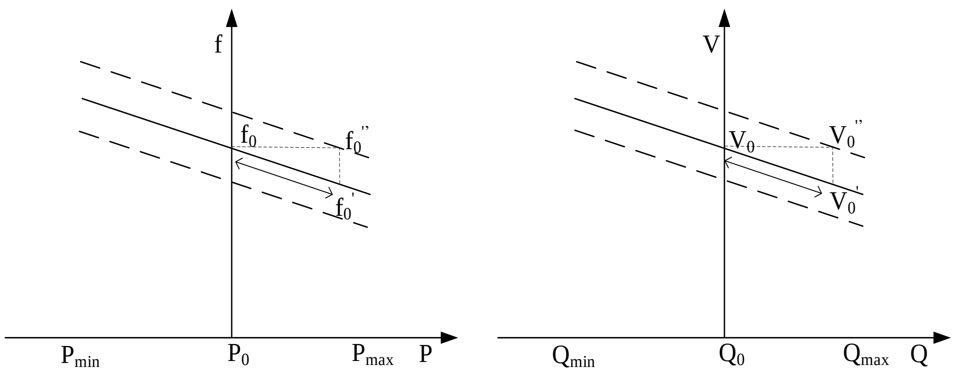

Fig. 7 Proposed frequency voltage and droop characteristics.

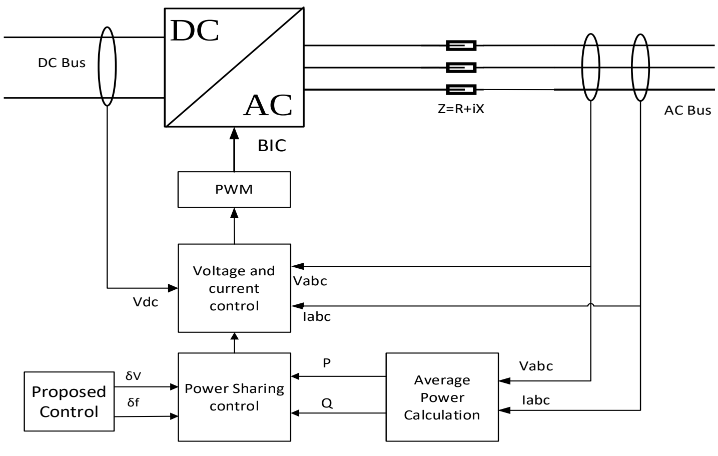

Fig. 8 proposed controller with the droop control.

4 Simulation Results

The islanded hybrid microgrid is designed and performed in the MATLAB Simulink, as shown in Fig. 1. The rating of DGs, ESS, and loads is given in Table 1, and the control system parameter is given in Table 2. Moreover, realistic 12-hour solar irradiation and wind speed data are taken from National Renewable Energy Laboratory (NREL). The 12-hour data are scaled for 12 seconds, as shown in Fig. 9, and this is done due to MATLAB run time constraints. Based on the proposed control scheme, the following cases have been verified. Case I: Comparison with the conventional droop control scheme under constant solar radiance and wind speed. Case II: Comparison with the conventional droop control scheme under variable solar radiance and wind speed. Case III: Primary operation in step load change. Case IV: Integration of new DGs during operation. Case V: ESS integration on each subsystem of dc bus.

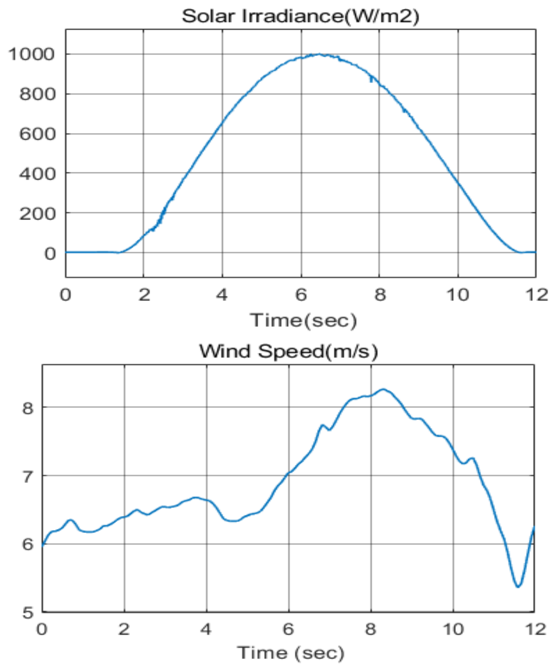

Fig. 9 Solar Irradiance and Wind speed of 12 hr. data scaled into 12 second.

Case I: Comparison with the conventional droop control scheme under constant solar radiance and wind speed.

In this study, a comparison is made between the standard droop control and the proposed control method that is devised and presented. As can be seen in Fig. 1, a solar generator with a capacity of 100 kW and a wind generator with a capacity of 200 kW are both linked to the alternating current and direct current subgrids of the hybrid microgrid. Solar irradiance and wind speed for this study are taken as constant of 1000 W/m2 and 8 m/s, respectively. The solar irradiance is decreases to 100 W/m2 at time t=3s and again increases to 1000 W/m2 at time t=4s due to intermittent in nature.

Table 1 AC/DC hybrid microgrid system parameter

Parameter	Symbol	Value
PV Parameters		
Total Solar max Power	P_{PV}	100 kW
No. of Cells in Parallel	n_p	47
No. of cells in series	n_{se}	10
Solar irradiance	S	0-1000 w/m^2
Cell temperature	T	25 ºC
Wind Parameters		
Wind speed	V_w	5-9 m/sec
Total Wind Power	P_w	200 kW
Energy Storage Parameters		
Nominal Voltage	V_b	800 V
Rated Capacity		400 Ah
Initial SOC	SOC	70 %
Bus voltages and Loads		
DC Bus Voltage	V_{dc}	1200 V
AC Bus Voltage	V_{ac}	311 Vrms
Rated Frequency	f_0	50 Hz
DC Load	P_{dc}	100 kW
AC Load 1	P_{ac}	100+j10kVA
AC Load 2	P_{ac}	100+j10kVA
AC Load 3	P_{ac}	100+j10kVA

Table 2 Control parameter of hybrid AC/DC microgrid

Parameter	Symbol	Value
Droop control Parameter		
Droop Coefficient	m, n	6e-6, 4e-4
Restored voltage and	K_p	0.1
frequency parameter	K_i	8
Current Control Parameter		
Proportional gain	K_{pc}	4
Integral gain	K_{ic}	40
Voltage Control Parameter		
Proportional gain	K_{pv}	8
Integral gain	K_{iv}	20

Solar and wind generator are extracting maximum power of 100 kW and 160 kW, as shown in Fig. 10. Battery is used for the constant voltage regulation on the dc subgrid. Depending on the power balance, it will either function in the charging mode or the discharging mode. BIC power is the power flow from dc to ac subgrid. A constant load of 200+j10 kVA on ac side and 100 kW on the dc side is connected, and by the time we reach time t=2s, the ac load is increased by 100+j10kVA. At t=6s, the load is again raised by 100+j10kVA, and finally, a reduction in ac load of 200+j20kVA is made at t=10s as shown in Fig.10. The system in which it runs uses conventional and proposed scheme, which is then followed by voltage and current control loops. The regulation of the voltage, as well as the frequency of the ac subgrid, is within the purview of this controller. The DGs and the battery are being drawn upon to provide power for the dc and ac load. The result is shown in Fig. 10 shows that the power-sharing by the DGs and power exchange between the subgrids are satisfactory. The frequency and voltage on the ac subgrid depend on the BIC power.

The conventional P-f droop shows as the active power increases, the frequency decreases, and similarly, in Q-V droop, as reactive power increases, the voltage decreases, as shown in Fig. 11. However, as the proposed scheme consists of the restoration of voltage and frequency due to droop control with the help of an extra PI controller. Hence, the proposed scheme shows better voltage and frequency regulation.

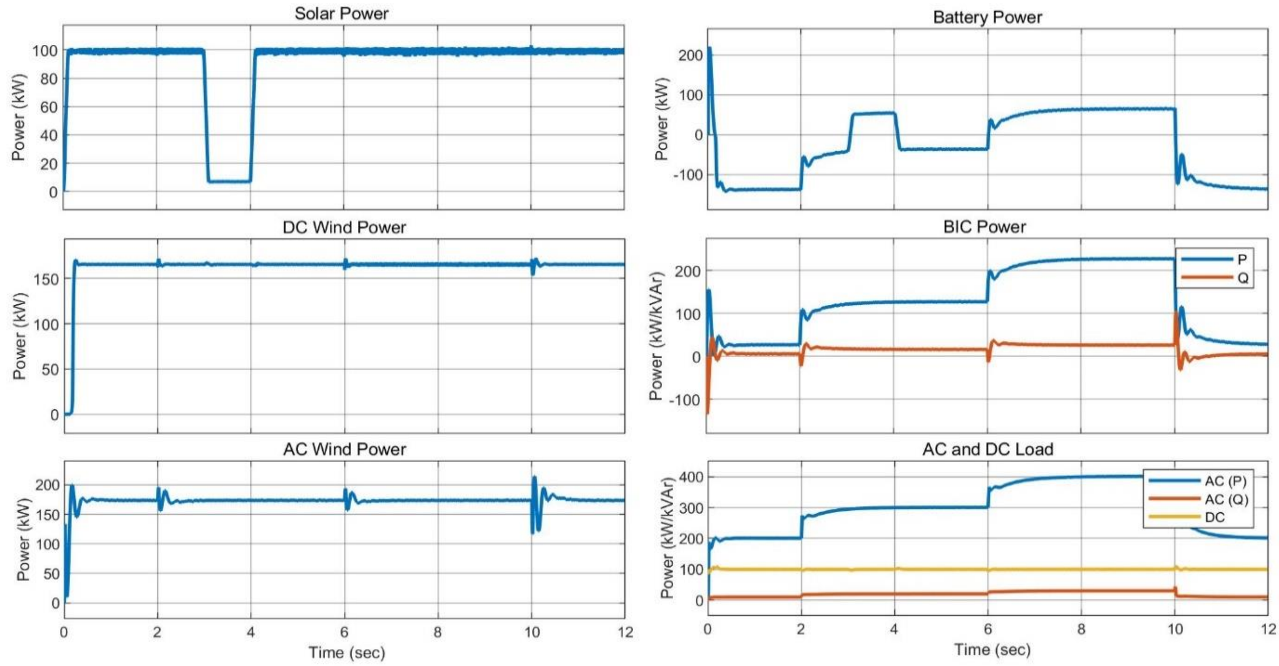

Fig. 10 Power sharing of each source during constant generation and step load change.

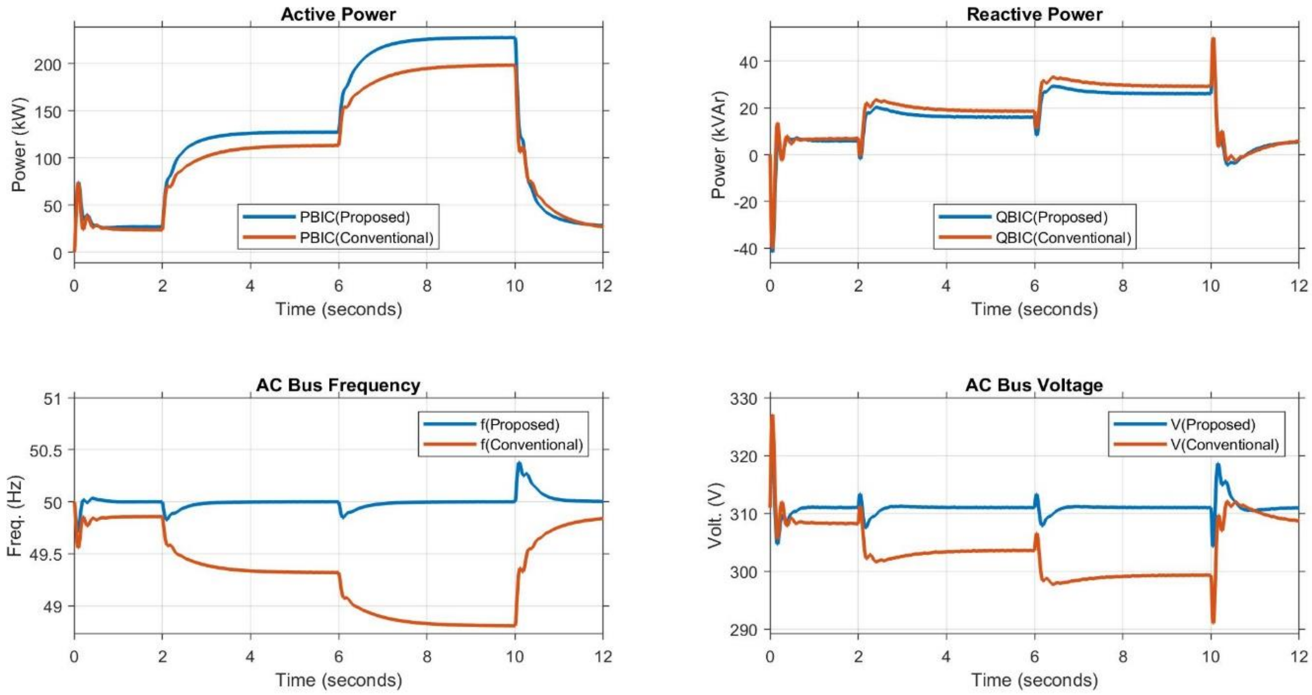

Fig. 11 P-f and Q-V droop control of conventional and proposed control.

The Transient behavior in terms of percentage peak overshoot and settling time (with 0.1% error band) of frequency and voltage are shown in Tables 3 and 4, respectively. From Fig. 12 and Fig. 13, it is observed that the proposed scheme has lesser peak undershoot/overshoot and settling time than the conventional.

From Fig. 11, it shows that the voltage and frequency decrease with the increase in load in a steady state of the conventional control method. But, these variations are restored in proposed control scheme, which is shown in Table 3 and Table 4.

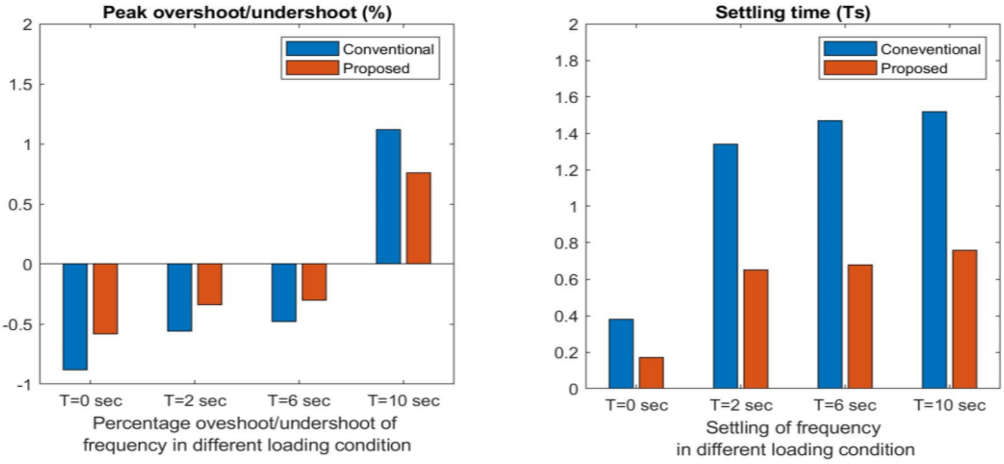

Fig. 12 Transient behavior of frequency in terms of overshoot and settling time.

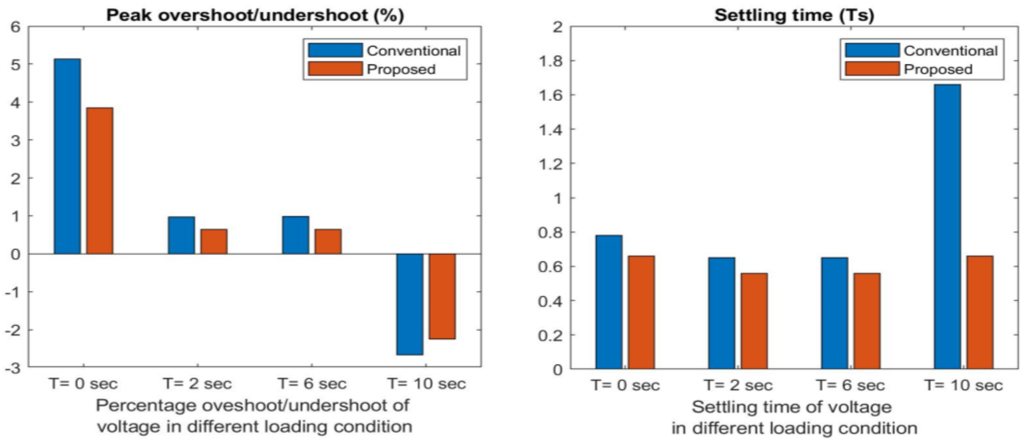

Fig. 13 Transient behavior of voltage in terms of overshoot and settling time.

Table 3 Steady state and transient behavior of frequency at different loading conditions.

	Maximum overshoot/undershoot								Settling Time (0.1% of steady state f)			
	Conventional				Proposed				Conventional		Proposed	
	Steady state frequency	1st over-shoot	error	% over-shoot	Steady state frequency	1st over-shoot	error	% over-shoot	T+Ts	Settling Time	T+Ts	Settling Time
T=0 sec (initial)	50	49.56	-0.44	-0.88	50	49.71	-0.29	-0.58	0.38	0.38	0.17	0.17
T=2 sec	49.86	49.58	-0.28	-0.56	50	49.83	-0.17	-0.34	3.34	1.34	2.65	0.65
T=6 sec	49.32	49.08	-0.24	-0.48	50	49.85	-0.15	-0.3	7.47	1.47	6.68	0.68
T=10 sec	48.81	49.36	0.55	1.12	50	50.38	0.38	0.76	11.52	1.52	10.76	0.76

Table 4 Steady state and transient behavior of voltage at different loading conditions.

	Maximum overshoot/undershoot								Settling Time (0.1% of steady state V)			
	Conventional				Proposed				Conventional		Proposed	
	Steady state voltage	1st over-shoot	error	% over-shoot	Steady state voltage	1st over-shoot	error	% over-shoot	T+Ts	Settling Time	T+Ts	Settling Time
T=0 sec (initial)	311	327	16	5.14	311	323	13	3.85	0.78	0.78	0.66	0.66
T=2 sec	308	311	3	0.97	311	313	2	0.64	2.65	0.65	2.56	0.56
T=6 sec	303	306	3	0.99	311	313	2	0.64	6.65	0.65	6.56	0.56
T=10 sec	299	291	-8	-2.67	311	304	-7	-2.25	11.66	1.66	10.66	0.66

Case II: Comparison with the conventional droop control scheme under variable solar radiance and wind speed.

In this study, a comparison is made between the standard droop control and the new control method that was devised and presented. As can be seen in Fig. 1, a solar generator with a capacity of 100 kW and a wind generator with a capacity of 200 kW are both linked to the alternating current and direct current subgrids of the hybrid microgrid. A constant load of 200+j10 kVA on ac side and 100 kW on the dc side. Solar power is extracting maximum power, and it varies according to the irradiance, as shown in Fig 14. Initially, the irradiance is zero, so the power is, and it increases gradually and then decreases. Similarly, the wind power varies according to the wind speed, and wind power extracted on the dc subgrid or ac subgrid is the same. The battery is used for the constant voltage regulation on the dc subgrid. Depending on the amount of electricity that is required, it will either function in the charging mode or the discharging mode. BIC power is the overall power flow from dc to ac, and the subgrid in which it runs uses a droop control technique, which is then followed by voltage and current control loops. The regulation of the voltage, as well as the frequency of the ac subgrid, is within the purview of this controller. The DGs and the battery are being drawn upon to provide power for the dc and ac load. The result is shown in Fig. 14 that the power-sharing by the DGs and power exchange between the subgrids are satisfactory. The frequency and voltage on the ac subgrid depend on the power demand of BIC. P-f droop shows as the BIC power increases, the frequency decreases, and similarly in Q-V droop as shown in Fig 15. The proposed scheme consists of the restoration of voltage and frequency due to the droop control method with the help of an extra PI controller. Hence, the proposed scheme shows better voltage and frequency regulation.

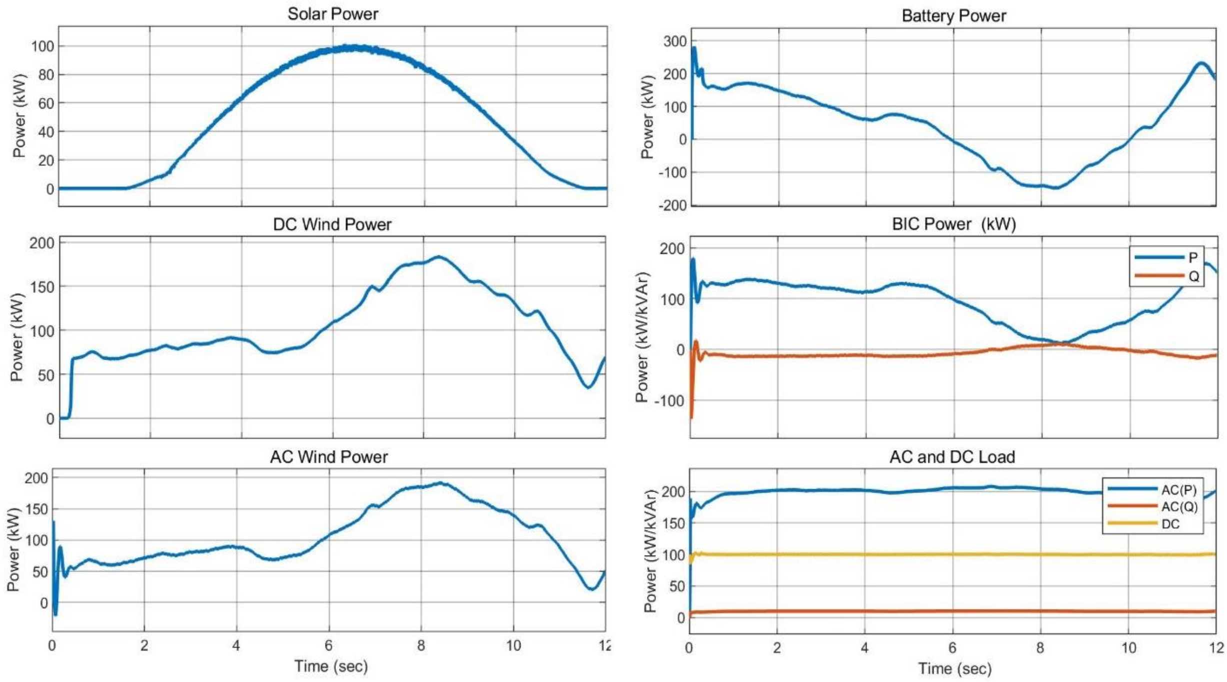

Fig. 14 Power sharing of each sources during constant load operation.

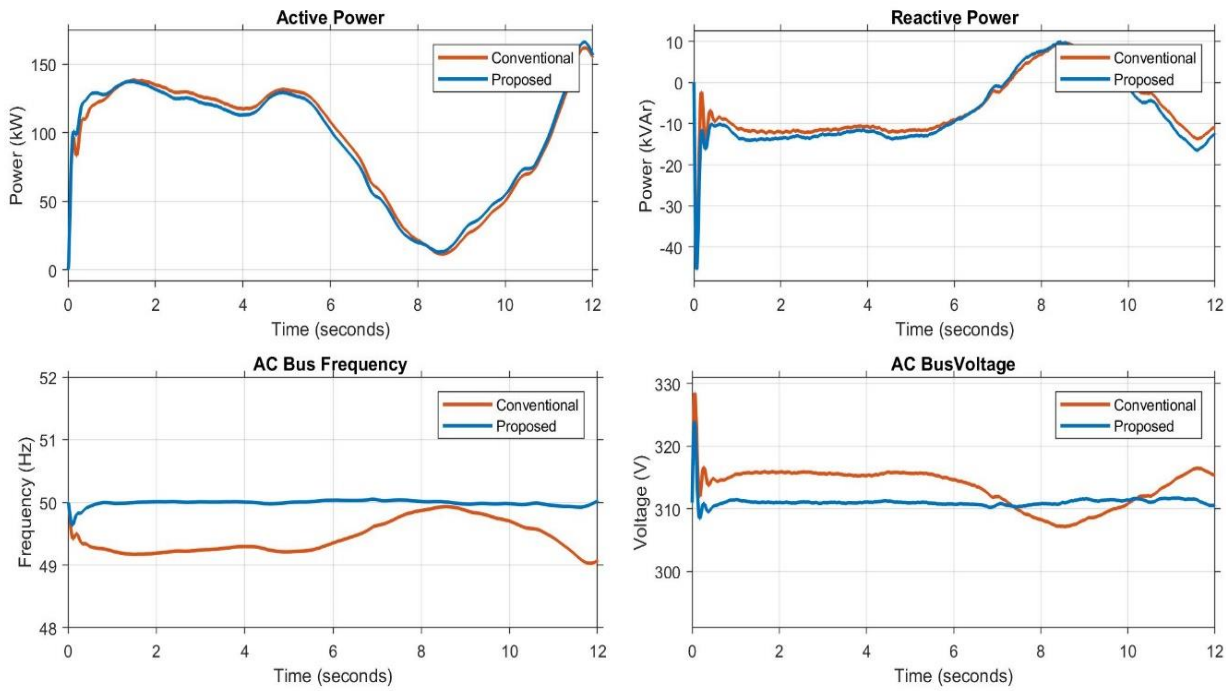

Fig. 15 P-f and Q-V droop control of conventional and proposed control.

Case III: Primary operation in step load change.

According to Case II, a 100-kW solar and a 200-kW wind generator are both linked to the hybrid microgrid's AC and DC subgrids. There are two separate subgrids in the hybrid microgrid: one for dc and one for ac. The dc subgrid of the hybrid ac/dc microgrid connects ESS. By the time we reached t=2s, the ac load had risen by 100+j10kVA. At t=6s, the load is raised by a factor of 100+j10kVA. Fig. 16 shows a reduction in ac load of 200+j20kVA ata=10s. BIC's power consumption affects the ac subgrid frequency and voltage. It is clear from Fig. 17 that when BIC power rises, the frequency falls as well as P-f and Q-V droops.

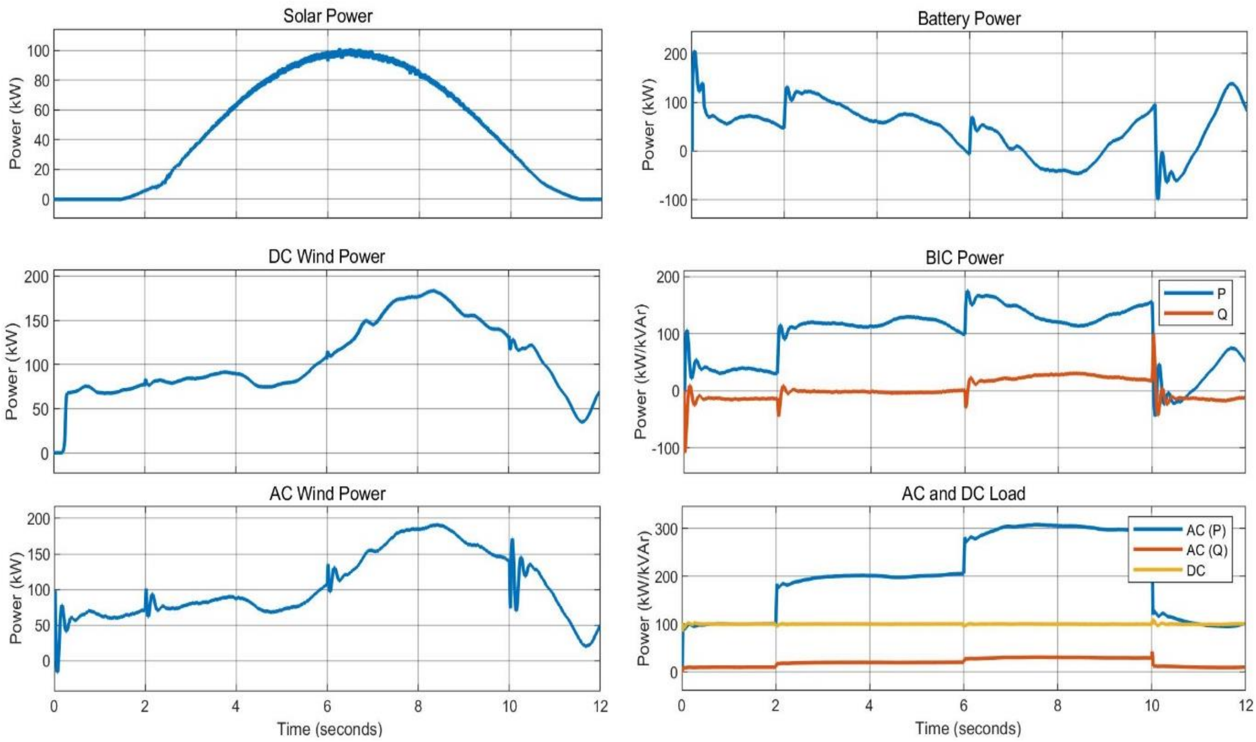

Fig. 16 Power sharing during step load change at time t=2s, 6s and 10s.

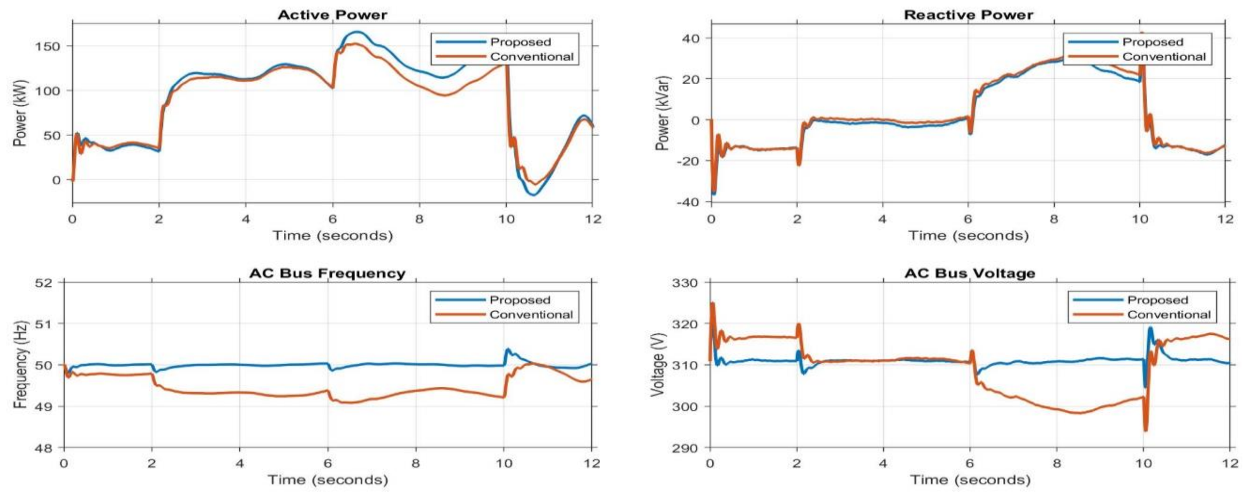

Fig. 17 P-f and Q-V droop control during step load change at time t=2s, 6s and 10s.

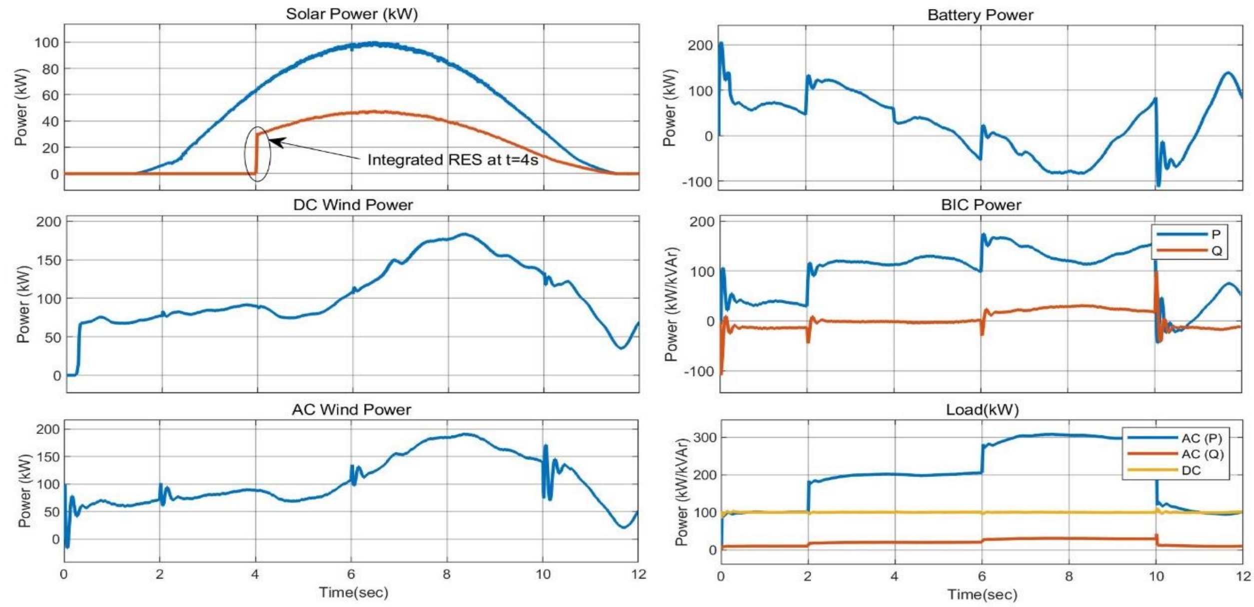

Fig. 18 Power sharing during RES integration at t=4s.

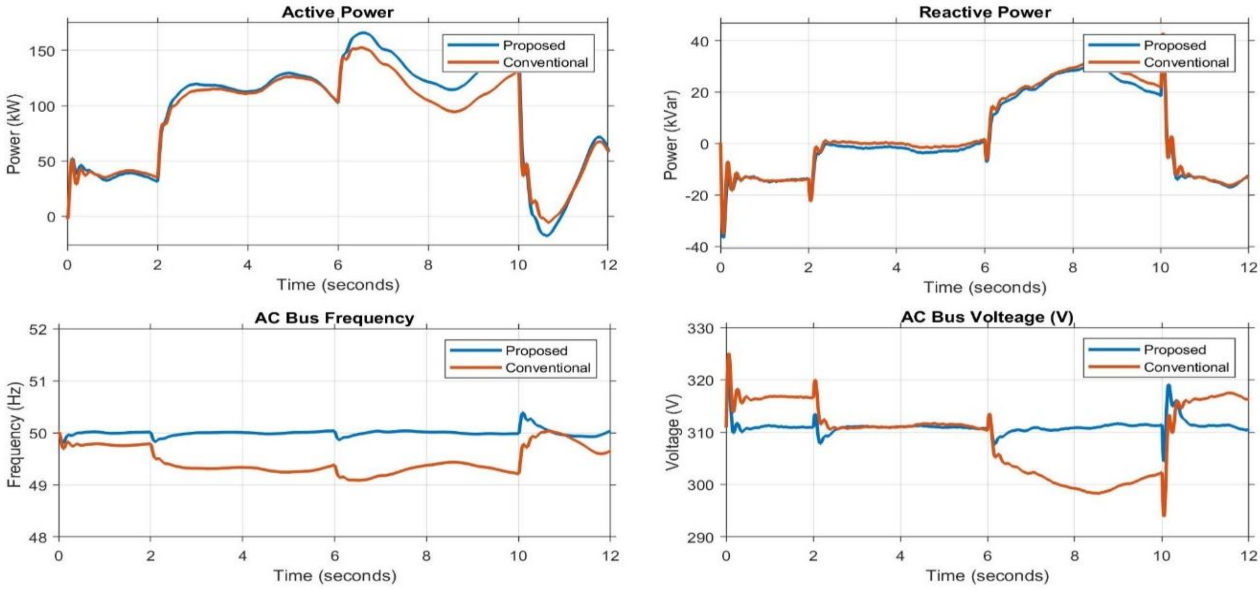

Fig. 19 P-f and Q-V droop control during RES integration at t=4s.

Case IV: Integration of new DGs during operation.

The 50 kW solar generator is used to integrate RES during operation on the dc side. The 50 kW solar generator is integrated into the hybrid microgrid at t=4 sec. The effect of the integration of RES on the hybrid microgrid is shown in Fig.18. The frequency and voltage on the ac subgrid are both established according to the power demand of BIC. As seen in Fig. 19, the frequency decreases in the P-f droop as a result of an increase in BIC power.

Case V: ESS integration on each subsystem of dc bus.

In this case, solar and wind generator consist individual ESS on DC side. Each DC subsystem is connected ESS instead of the common ESS on DC bus is shown in Fig. 20. The rating of each subsystem is given in Table 1 and 2. Integration of ESS on each subsystem increases the reliability and power quality in terms of DC bus voltage.

The comparison of DC bus voltage in different cases is shown in Fig. 21. The transient behavior of the dc bus voltage is improved at time t=0s and t=10s as shown.

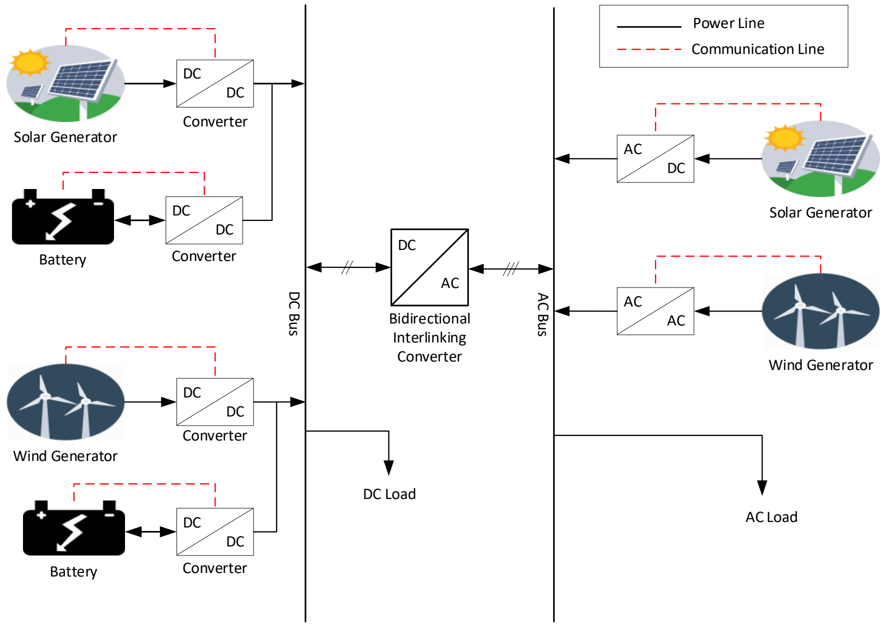

Fig. 20 Islanded hybrid microgrid with ESS integration on each subsystem.

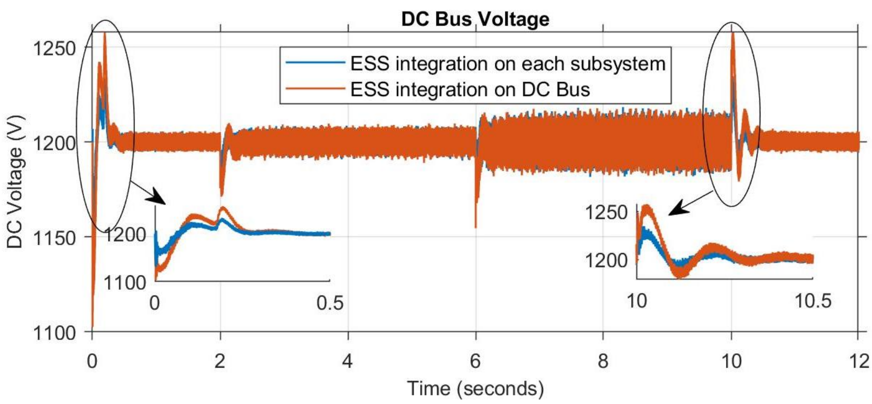

Fig. 21 DC bus voltage

5 Conclusion

In this paper, the bidirectional interlinking converter of a hybrid microgrid based on the modified droop control scheme is performed for variable generation and load conditions in Islanding mode. The bus voltage and frequency regulation and power sharing among subgrids are performed in various cases. The comparative performance analysis is covered in different cases. The performance analysis of the system is done with variable loading and generation, respectively. The accurate solar irradiance and wind speed data have been implemented for analytical purposes. The power-sharing by the DGs and power exchange between the subgrids are satisfactory with the improved voltage and frequency regulation. To verify the aforementioned objectives, the system is performed in MATLAB/Simulink environment.

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing to publication, with respect to intellectual property.

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M. Kumar: Idea & Conceptualization, Research & Investigation, Methodology, Software and Simulation, Revise & Editing, Original Draft Preparation. **Shivam:** Idea & Conceptualization, Research & Investigation, Methodology, Software and Simulation, Revise & Editing, Original Draft Preparation, Supervision.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to "Iranian Journal of Electrical and Electronic Engineering".

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