POWER MANAGEMENT IN HYBRID MICROGRID USING RENEWABLE SOURCES

Ph.D. Synopsis

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in

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by

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CONTENTS

1. Abstract

In this research, the control strategy is used for power management in renewable sources connected to hybrid microgrid for both islanding and grid-connected modes. The power management between sources and load is required to achieve voltage regulation during variable load. Parallel connected sources in microgrid create bus voltage maintenance issues, power quality, and load sharing among sources. So, the conventional droop control strategy is implemented for power-sharing among sources. But it has the drawback of poor voltage regulation. So, to fulfill this requirement, a voltage shifting based droop control strategy is implemented at the primary level. In this method, the voltage deviation of a bus is compensated by shifting the sources' droop characteristic. For the operation of a hybrid microgrid, the power management and control strategy is most important. The power management strategy manages the generation power from DG, Grid, and ES and same time control the voltage and frequency of the microgrid. Renewable sources-based DG (PV and Wind) is operated in droop mode if DG's power is sufficient. If DG power is not enough to supply a load, DG units switch to MPPT mode. By changing in voltage detection, hybrid microgrid switches in a different mode. In an islanding microgrid, the secondary control is also implemented to achieve accurate voltage regulation and current sharing compared to primary droop control by using voltage shifting and slope adjusting. In this secondary control method, the average value of current, voltage, and droop resistance of two neighboring converters is calculated. It is controlled by an additional layer of distributed secondary control over both primary controls. By adjusting the converter's droop coefficient to make the same value of output impedance of the converter, current sharing and voltage regulation are achieved. Also, in a transient state, current sharing is achieved by using this secondary control technique. These control strategies are verified in MATLAB simulation in a hybrid microgrid with renewable DG (PV and Wind), Energy Storage battery, and AC Grid.

The output power of the PV system is always changing with the weather conditions. Thus, the experimental analysis is presented for the I-V and P-V characteristics with varying temperature and irradiation levels by using a real-time plotter for two series and parallels connected standalone PV Module. A different power management mode is then observed between PV, Energy Storage battery, and AC-DC load by using MPPT algorithm through PIC microcontroller for Islanding System. Power management mode is also observed between PV, grid, and AC load for active and reactive power flow in the grid-connected system by using grid tied inverter.

2. State of the Art of the Research Topic

Today, non-renewable energy sources like coal, oil, gas, etc., are used worldwide to produce electrical energy. But these non-renewable energy sources are producing environmental pollution [1-3]. So, the Distributed Generation (DG) system's importance increases to utilizing renewable energy sources to produce electricity [4-5]. There are various types of renewable energy sources (REs) like solar photovoltaic (PV), wind generator, etc., available [6-7]. It is challenging for renewable energy sources to connect with AC main grid directly. So, a microgrid's role is very important to interface between DG and grid to connect REs. This microgrid is a small distribution system with a combination of DG units, energy storage devices like battery and load. The hybrid microgrid can be operated in islanding and grid-connected mode [8-10].

In a hybrid microgrid, various sources are connected in parallel with the bus via a power electronics converter (PEC). So, it creates issues of bus voltage maintenance, power quality, and load sharing among sources. Hierarchical control is used to solve these issues. It has primary and secondary control level. The primary control level is used to solve power-sharing among sources. The secondary control layer is used for voltage compensation and enhancement of current sharing [11-12]

There are two methods for power sharing among DG in the primary control level: Active load sharing and Passive load sharing. Active load sharing is further classified into master-slave control, centralized control, and circular chain current (3C) [13]. The drawback of these methods is that it requires high bandwidth communication.

A decentralized based passive load sharing method is mostly used to avoid communication links. It is also called the droop concept. The droop concept's principle is that the synchronous rotating generator allows changing their power output during the change in load without a communication link [14-16]. Droop control is widely used in a hybrid microgrid for the current sharing purpose [17-24]. Due to its reliability, its application in a microgrid is higher [25-29].

The multiple sources are connected in parallel with a bus, which creates a circulating current among converter in a hybrid microgrid. For these, there are two solutions. In the first solution, a resistor is put in series with DG. But it is not possible practically in a real hybrid microgrid system because it produces high power losses [30]. The second solution is better applicable in a hybrid microgrid. It is known as a virtual resistance method. This method is widely used because there is no communication line. Virtual resistance is the ideal value and not affected by temperature. It will not produce real power losses. This virtual resistance is also called the droop coefficient, droop gain, or droop constant. It is used to suppress circulating current among converter [31, 32].

In the conventional droop control method, there is a trade-off between load sharing and voltage regulation. Voltage regulation performance is superior in the case of a small droop coefficient as compared to the selection of a large droop coefficient. If we select a larger droop coefficient, current sharing among the converter is fair, but voltage regulation is inferior. It is a drawback of conventional droop control [33-35].

The main key point is power management in the hybrid microgrid. It means power must be balanced between renewable energy sources (REs), energy storage devices, grid, and load in any condition. So, bus voltage also must be maintained at any load. Microgrid should be operated in a different mode for power management. If power generation is not sufficient by DG, then extra power will be provided by the islanding mode's storage device. In grid-connected mode, the grid exchange power to the microgrid as per load requirement [36-39].

The secondary power management strategy is divided into centralized, decentralized, and hybrid in the islanding mode. The centralized secondary control is also called supervisory control [40]. Its application in which a centralized layer is suggested to achieve power balance in a microgrid. The decentralized secondary control is further divided into two methods.: (i) with communication and (ii) without communication. Communication is required between DG in decentralized secondary control with communication. In [41] low bandwidth signal is used for voltage and current information between DG Average current sharing (ACS) communication-based control is presented in [42]. The drawback of ACS is that load sharing bus has to be distributed across with power lines inside the microgrid. It can be interjected by the external noise in the bus. In [43] decentralized communication-based power line singling [PLS] is given. The drawback of this method is that it has very slow communication. Multi agent-based control system (MAS) is presented in [44-45]. These are applied using a conjunction of intelligent agent and real-time control that communicate with each other. In this process, each agent is answerable for finding the portion of trouble, such as voltage balancing, load priority, and battery charging. Without communication, mostly the DC bus singling (DBS) method is used [46-49]. When multiple numbers of sources are used. It is complicated to divide the voltage level of each source. Hybrid secondary power control gives an accurate result at both levels [50].

Secondary droop control is the proposed solution for voltage regulation and current sharing accuracy to solve the islanded microgrid problem [51- 58]. The summary of the existing method of secondary control is in [51-55]. The issue of single-point failure is given in [51]. There is no problem with single-point failure, but current sharing accuracy is only achieved by selecting a large droop coefficient in [52]. The current sharing and voltage regulation are good in [53], but its performance is very poor in dynamic condition. In [54-55], performance is good in dynamic condition, but it has more complexity for implementation.

Power management is also required in grid-connected microgrid [59-60]. There is surplus power generation in the microgrid; extra power will be transfer to the grid [61-62]. Power shall be transferred back to the microgrid due to overload [63]. So, the droop control strategy is used in the grid converter for power-sharing with the AC grid. There are various control techniques for power-sharing for power management and voltage regulation in grid-connected mode [64-68]. In [64] the frequency deviation is very high. The communication channel is required in [65]. In [66] separated controller is needed. Accurate power-sharing is difficult at a high gain in [67]. The system becomes more costly in [68].

3. Definition of The Problem

With this background, this research is focused on the power management strategy of a hybrid microgrid. In power management of hybrid microgrid for standalone and grid-connected mode, generation power must be equal to load power by controlling renewable energy sources and converter. For this purpose, the voltage regulation of the bus is also required. Proportional current sharing is a significant issue due to the number of sources that are connected by a bus. A conventional droop control method is implemented in primary control by most of the researchers. So, in this method, the selection of a droop coefficient is essential. But by selecting a higher droop coefficient, there is a problem of poor voltage regulation. It is a limitation of conventional primary droop control. To solve this limitation of conventional primary droop control, another control strategy to be found to improve the voltage regulation of the hybrid microgrid. Some researchers have also implemented secondary control, but its performance is inferior in dynamic conditions during a fast change in load. So, some other control strategy is to be implemented at the primary and secondary level for proper load sharing among sources, improve the voltage regulation and current sharing accuracy in the hybrid microgrid.

4. Objective and Scope of Work

The objective of the research is as per following.

To develop a control strategy for power management to maintain the power balance and stable operation of hybrid microgrid under variable load conditions by combining renewable sources, energy storage devices, and utility in islanding (standalone) and grid-connected mode. Further, this control scheme will also be useful for proper load sharing among the bus's source and voltage restoration.

To achieve above the objective, the scope of work includes:

- To investigate the drawback of a conventional control strategy as per the literature survey and improve the performance at the primary and secondary level for proper load sharing.
- To simulate the microgrid with two DG for primary and secondary droop control for accurate current sharing and voltage regulation.
- To simulate a hybrid microgrid with MPPT and AC droop control and evaluate its operation to propose a power management mode then implement a proposed power management algorithm in renewable-based DG (PV & Wind), Battery, and Grid for power balance between source and load in a hybrid microgrid.
- To compare real-time parameter in single, series, and parallel-connected PV module at a different temperature, irradiation, and partially shaded using MPPT control.
- To evaluate experimental performance for the different modes of power management in a standalone and grid-connected system.

5. Original Contribution by the Thesis

- Power management's control strategy is implemented to maintain a power balance in a hybrid microgrid under different operating conditions. Furthermore, the balanced power state of a hybrid microgrid can be decided by bus voltage changing.
- For power management in a hybrid microgrid, both MPPT and droop modules are implemented in DG (PV and Wind). A droop control strategy is implemented to achieve proper load sharing. DG is operated in droop mode if its power is sufficient. If DG power is not enough for load, PV and wind units switch to maximum power tracking mode. During switching between MPPT and droop module, it produces unfavorable transient. So seamless control strategy is implemented in the DG unit to avoid transient.
- Q-V and P-Q droop control are also implemented in VSC based interlinking bidirectional converter to balance the power between grid and microgrid.
- For proportional power-sharing, the selection of the virtual droop coefficient is essential. But by selecting a higher droop coefficient, there is a problem of poor voltage regulation. During higher load, the voltage of the bus is reduced. There is a limitation of the conventional droop control method in primary control. For that purpose, the first voltage deviation (Δv) produces by conventional droop control is sensed. Then Δv is adding in the conventional primary loop.

So, the droop curve position is shifted after adding Δv. This proposed voltage shifting based droop control is implemented at the primary level.

- There is three PI controller used in the secondary control technique. In secondary control, its performance is right in the dynamic condition under fast-changing in load. The secondary control first controller is used to restore voltage deviation in each converter produced proposed primary control, and another both controllers work together and regulate droop coefficients separately. So, the output impedance of each converter would be the same.
- By experimental analysis, prototype series and parallel PV modules are tested under different temperatures and radiation. Then, by observing the different real-time parameters, maintaining a power balance between PV, Battery, DC and AC load in various modes using the MPPT algorithm in the PIC microcontroller. Also, by control of grid-tied solar inverter, the active and reactive power balance is maintained between PV, Grid, and load.

6. Methodology of Research, Results / Comparisons

6.1 System Configuration

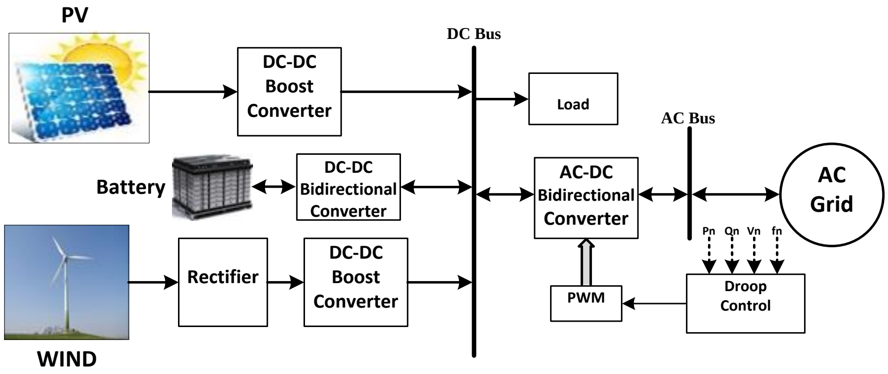


Fig. 1 Block Diagram of Hybrid Microgrid

The proposed Hybrid microgrid structure is shown in Fig. 1. PV generating unit is connected to a DC bus through the DC-DC boost converter. Permanent magnet synchronous generator type wind turbine has an AC output voltage. An uncontrolled rectifier is sent DC power to boost converter. PV and wind both have a maximum power point tracking (MPPT) and droop function. The grid is connected to the AC and DC bus through the AC-DC bidirectional converter. Through a bidirectional DC-DC converter Battery storage unit is connected to the DC bus. PV and wind turbine units can work together. When PV has no power at night time, the wind turbine can continue to supply power. The battery storage unit is installed to improve system stability.

This microgrid is connected to the AC main grid through a bidirectional DC-AC converter. The power flow in both directions. It is a VSC based bidirectional converter. The droop control strategy is used to control the bidirectional power flow. This system is allowed for voltage regulation and power-sharing using droop control. The parameter of the proposed hybrid microgrid is as per below.

Power output of Photovoltaic array (PV) generation system (DG 1) – 10 KW.

Power output of Wind generation system (DG 2) – 8.5 KW

Power output of ES System – 5 KW, Maximum output power of AC Grid – 10 KW.

Load – 20 KW Rated DC bus Voltage – 400 V

6.2 Operation Mode of Power Management

Table 1: Operation Mode of Power Management in Hybrid Microgrid

Mode	Power Generated by PV	Power Generated by Wind	Battery Power (P_S) Delivered (+) /Absorb (-)	Load Power	Grid Power	Power Characteristic
I	P_{PV}	P_W	$-P_S$	P_L	P_G	$P_G = P_S - P_{DG} + P_L$
	P_{PV}	P_W	0	P_L	P_G	$P_G = P_L - P_{DG}$
II	P_{PV}	P_W	$-P_S$	P_L	0	$P_{DG} = P_L - P_S$
	P_{PV}	P_W	0	P_L	0	$P_{DG} = P_L$
III	P_{PV}	P_W	P_S	P_L	0	$P_S = P_L - P_{DG}$
	P_{PV}	P_W	P_S	P_L	$P_{G(max)}$	$P_S = P_{G(max)} - P_{DG} + P_L$

Table 2: Operation Mode Switching Power Management in Hybrid Microgrid

Mode	Bus Voltage Range	Bus Voltage Regulation	Operation of DG Unit	Operation of Battery	Operation of Grid
I	$390 < V_{Bus} < 410$	Grid	MPPT	Charging	Droop
			MPPT	Off	Droop
II	$V_{Bus} > 410$	DG Unit	Droop	Charging	Const. Power
			Droop	Off	Const. Power
III	$V_{Bus} < 390$	Battery	MPPT	Discharge	Off
			MPPT	Discharge	Const. Power

A hybrid microgrid is operated in three different modes, as shown in Table 1 & 2. As per changes in bus voltage range, mode switching from one to other. The grid is maintaining the stability of the hybrid microgrid in mode I. During mode I, the DG unit operate in MPPT, and the grid operates in droop mode. DG unit works in MPPT mode normally to capture maximum possible energy by solar and wind. When solar and wind energy are sufficient, DG output power is large. So, the bus voltage of the hybrid microgrid is increase. Hence DG unit will be switched to mode II to maintain stable bus voltage in a hybrid microgrid. In mode III, the energy storage battery is maintaining the stability of the hybrid microgrid. It operating in droop mode under discharging condition.

6.3 Droop Control Strategy

In a microgrid, the sources are connected in parallel. So, the droop control strategy is used to avoid circulating current and proportional current sharing among source. The droop control is put to each source. It is a decentralized method, so there is no need for communication between sources.

6.3.1 Conventional Primary Droop Control Strategy

There are two loops in the conventional droop control strategy for the DC-DC converter. There is the droop control, inner current control loop and outer control loop in these units. The current inner loop can improve the response speed. The basic equation of conventional primary droop control is expressed by equation (i).

$$v_i = v_{ref} - i_i r_{di} \ldots\ldots\ldots \text{(i)}$$

Where v_{ref} = Reference voltage of converter, v_i= Local output voltage of i^{th} converter after applied droop loop, r_{di} = Droop Resistance, i_i = Output current of the converter.

The conventional droop control is used in a hybrid microgrid for proper current sharing among converter. But there is a trade-off between current sharing and voltage regulation in conventional primary droop control. This is the drawback of the conventional primary droop control strategy.

6.3.2 Voltage Shifting Based Primary Droop Control Strategy

In a hybrid microgrid, a conventional droop control strategy is easy to implement but poor voltage regulation. So voltage shifting based proposed primary droop control, in which Δv is added to them with a reference voltage of the converter to regulate the bus voltage.

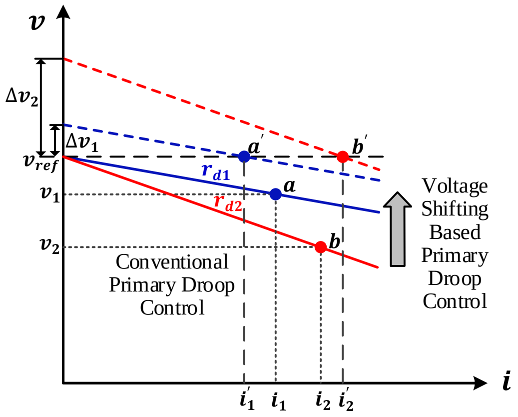


Fig 2. Voltage-shifting based droop characteristics

Fig. 2 describes that voltage is balanced by adding the value of Δv. Due to increases in load, the voltage reduces from v_{ref} to v_1 and v_2 in conventional primary droop control. But after adding Δv_1 and Δv_2 , shifting the droop curve line from a to a' and b to b' respectively. So, voltage shifting based proposed primary droop control generates a new voltage reference value (v_i^*) of the local converter unit by shifting the drooping line, regulating the voltage of the converter at normal value. The voltage shifting based primary droop control is expressed by equation (ii).

$$v_i^* = v_{ref} - i_i r_{di} + \Delta v_i \ldots\ldots\ldots \text{(ii)}$$

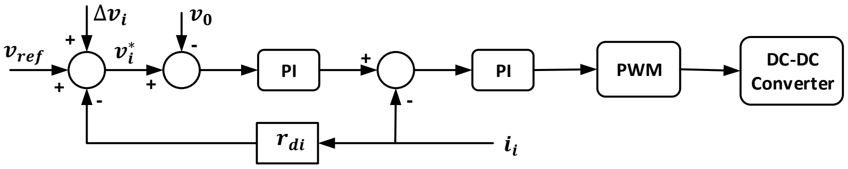


Fig. 3 Control diagram of Conventional primary droop control technique

The voltage shifting based primary droop control strategy of the DC-DC converter unit is shown in Fig 3. It consists of a droop control loop, inner voltage loop, and inner current loop and Δv. The new reference value of voltage v^* is generated by adding Δv in a conventional droop control loop. v^* is compared with v_0. Its result is sent to the PI regulator and generates PWM signals to the boost converter unit.

Here fixes the value of droop resistance is used in each converter. So, the total impedance of the converter would be unequal. So dynamic performance under a fast change in load current is poor. It is a limitation of voltage shifting based on the proposed primary droop control**.**

6.3.3 Secondary Droop Control Strategy

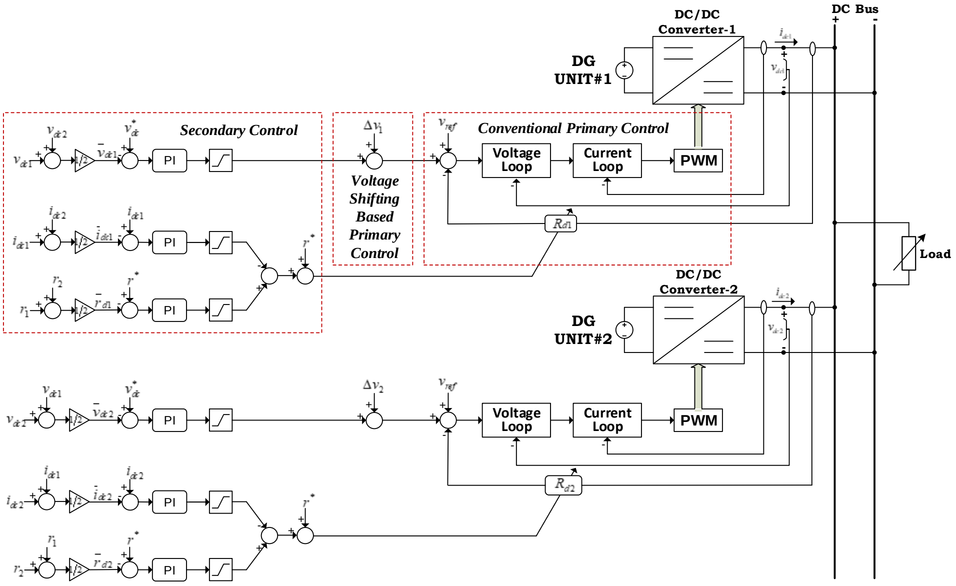


Fig. 4 Control Diagram of Microgrid with Primary & Secondary Control Technique

Fig. 4 is shown a control circuit diagram of a microgrid with a primary, voltage shifting based primary and secondary control scheme. There are two boost converters (dc to dc) connected in parallel with a common load bus. In the primary control scheme voltage loop, the current loop and droop coefficient loop are used. In voltage shifting based primary control scheme, Δv_1 and Δv_2 are added in each converter over conventional primary control.

In this secondary control strategy, the average value calculation of voltage, current, and droop coefficients of the neighboring converter by three PI controllers. The average voltage controller compensates the voltage deviation over-voltage shifting based primary control by producing the voltage shifting value. So, it regulated the output voltage of the converter. Average current and droop coefficient controllers are used for droop curve adjusting by adaptively controlling each converter's local droop coefficient. Using both current compensating and droop coefficient controller control, two converters' output impedance is the same. So, its performance is good in the dynamic condition under fast-changing in load.

In secondary control, voltage regulation and current sharing is achieved accurately. This secondary control has enhanced dynamic behavior under variable load conditions.

6.3.3 Droop Control Scheme for Grid Converter

Fig. 5 shows the implementation of the P-f and Q-V droop control in the grid converter. It generates pulse through PWM and controls the power flow of the interlinking bidirectional converter. It includes active and reactive power measurement from the available voltages and currents, P-f and Q- V Droop control, voltage combination, dual-loop control, and Pulse Width Modulation (PWM) pulses generation. Droop control regulates the power flow by the interlinking converter between AC and DC bus.

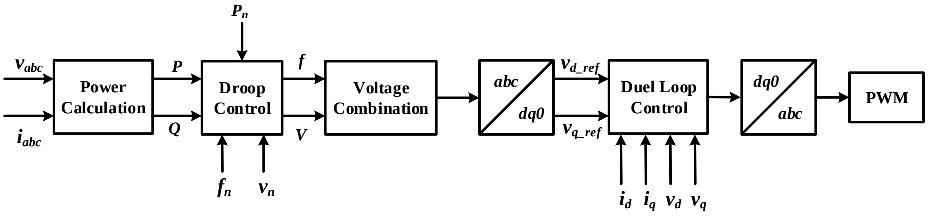


Fig. 5 Droop Control Scheme for Grid Converter

6.4 Result and Discussion

Fig. 6 shows the waveform of the total load current of a microgrid. The load current is increasing at 0.3 s & 0.7 s due to step up a load. Fig. 7 is shown the load voltage of the microgrid in conventional primary droop control. In conventional primary droop control, the voltage is drooped at 0.3 s & 0.7 s due to increased load. So, in the conventional primary droop control method, there is increasing in current caused by higher voltage droop. Fig. 8 shows the waveform voltage for voltage shifting based primary droop control method. In this method, less voltage droop as compare to the conventional method. The waveform of voltage for secondary droop control is shown in Fig 9. After applying the secondary control voltage of microgrid is regulated within 4V, even load increasing at 0.3 s & 0.7 s.

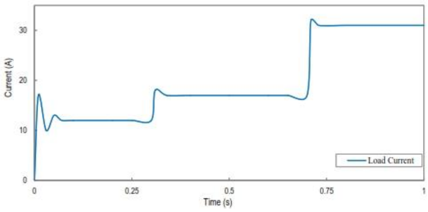
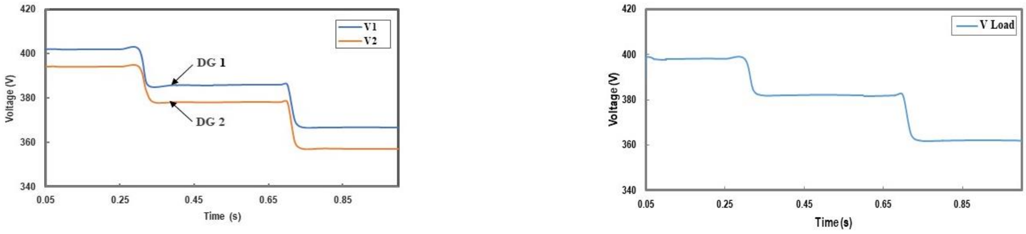
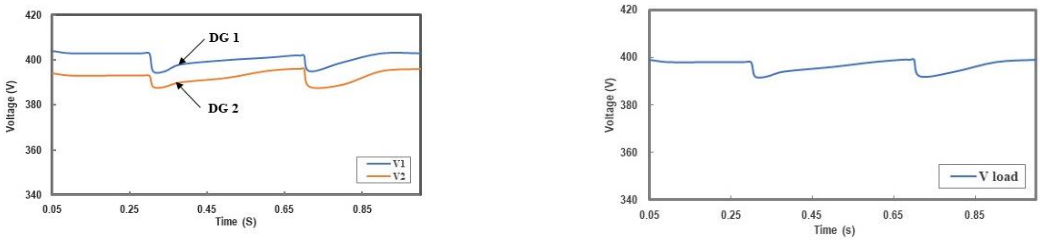


Fig. 6 Load Current Waveform



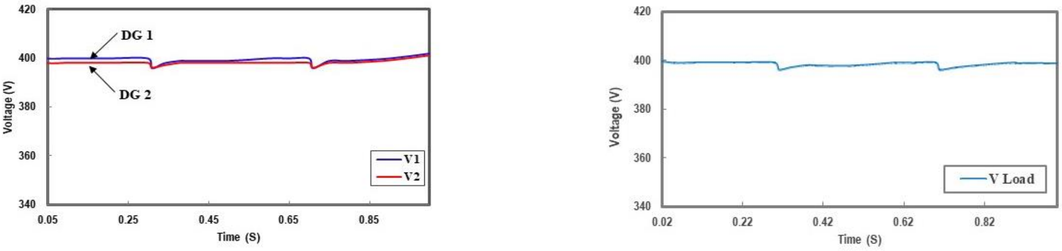
Converter Voltage of DG. *Load Voltage*

Fig. 7 Conventional Primary Droop Control Method



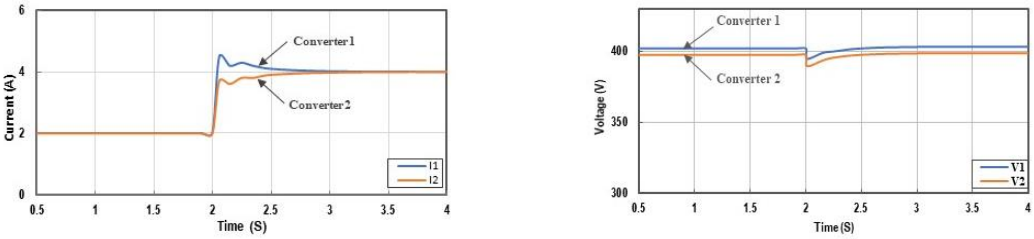
Converter Voltage of DG. *Load Voltage*

Fig. 8 Voltage Shifting Based Primary Droop Control



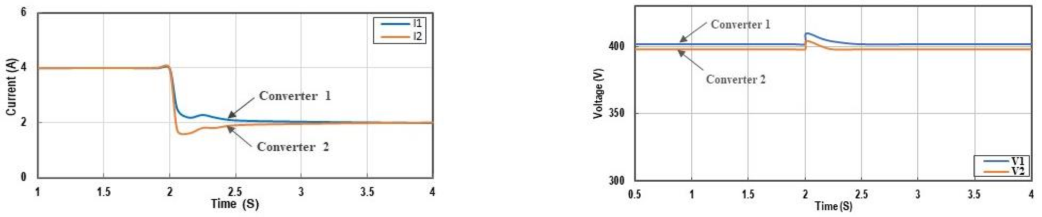
Converter Voltage of DG. *Load Voltage*

Fig. 9 Secondary Droop Control Method



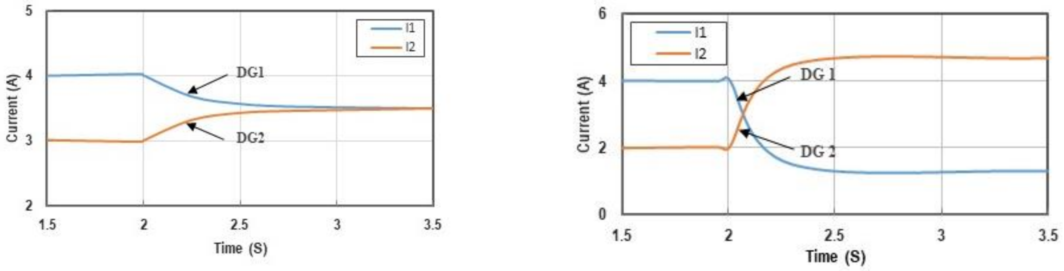
(a) Current Sharing *(b) Voltage Response*

Fig. 10 Performance of Secondary Control for Transient Response during Step Up Load



(a) Current Sharing *(b) Voltage Response*

Fig. 11 Performance of Secondary Control for Transient Response during Step Down Load



(a) *(b)*

Fig. 12 Performance of Secondary Control Method for Proportional Current Sharing

The transient response during secondary control is shown in Fig. 10 and 11. In Fig. 10 (a) at 2 s suddenly step up a load, no current sharing error of converter current. And at the same time, the voltage response of the converter is also good. The voltage of each converter is maintained by nearly 400V of dc microgrid voltage. In Fig. 11, the same transient resource performance is achieved for current sharing and voltage restoration in secondary control during suddenly step down load.

Current sharing during primary and secondary is shown in Fig. 12. In Fig. 12, before 2 s primary control is used. During this period, an error in current sharing appears in the converter's current waveform. Different line resistance is selected for current waveform error, and equal current sharing proportion is taken in Fig 12(a). At 2 s, secondary control is activated, the current of each converter will be the same as per Fig 12(a). The current sharing error is also becoming zero. In Fig. 12(b), unequal current sharing proportion is selected for the control objective. So, two converters' current is becoming the expected value after applying secondary control at 2 s.

6.5 Experimental Analysis

6.5.1 Comparison of Two Series and Parallel connected PV module with different radiation and temperature effect

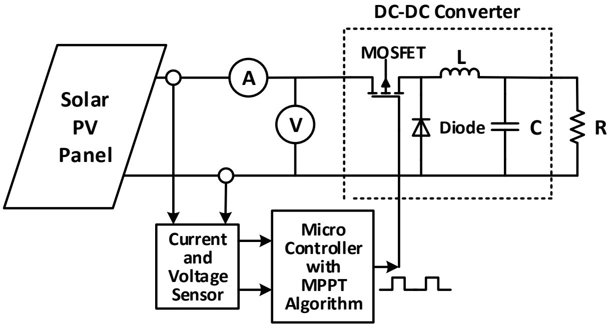
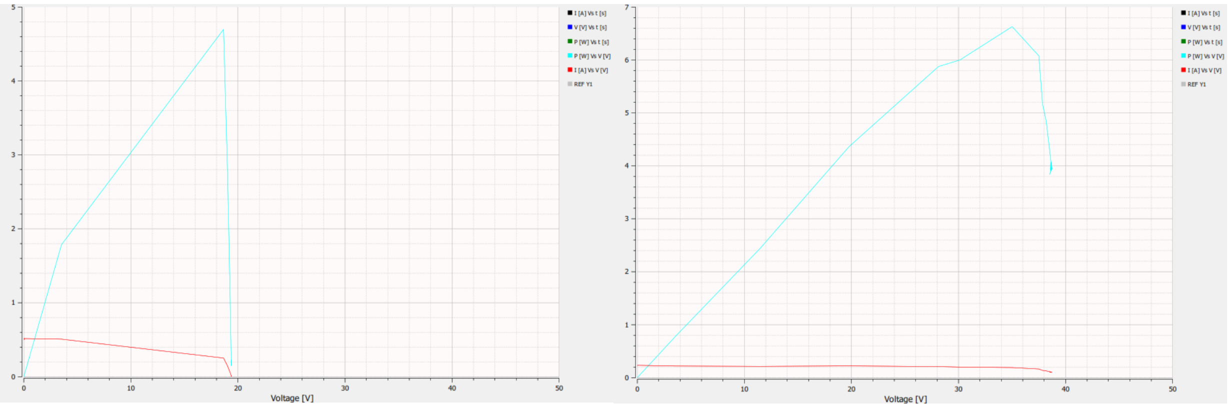
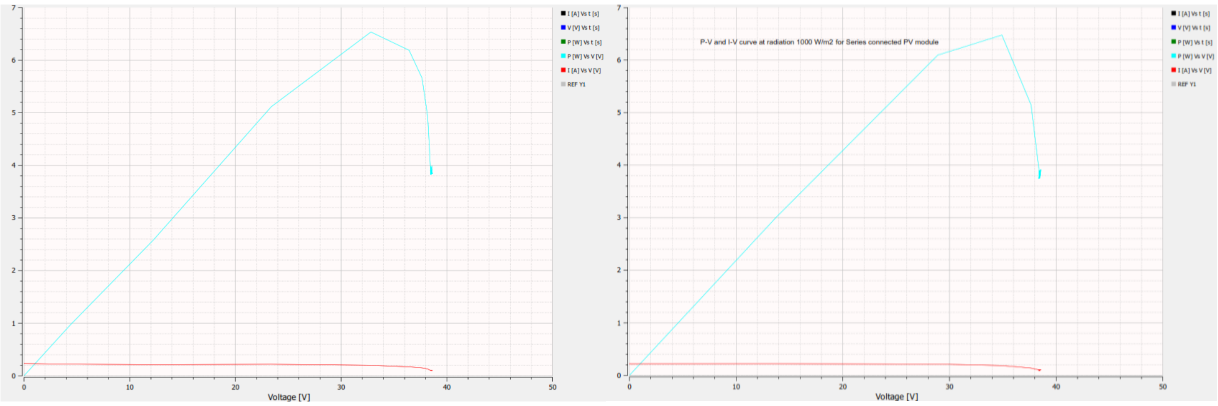


Fig. 13 Block Diagram of PV with MPPT

A Solar PV panel is connected to the DC-DC converter, and PIC microcontroller with MPPT is shown in figure 13. Perturb and observe (P&O) algorithm is applied in the PIC microcontroller. The digital meters and data logger/plotter by connecting the Logger Plotter Box with module output are used for taking readings. The values of current and voltages can be taken from the data logger, and then the I-V curve can be plotted at different radiation and temperature levels. The Real-time plotter, which will plot the curve of I-V and P-V.

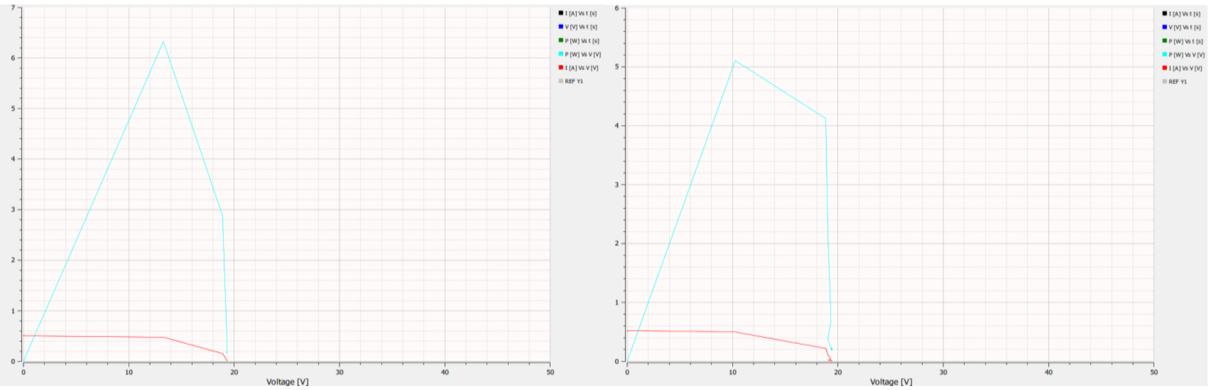


(a) 200 W/m² *(b) 600 W/m²*



(c) 800 W/m² *(d) 1000 W/m²*

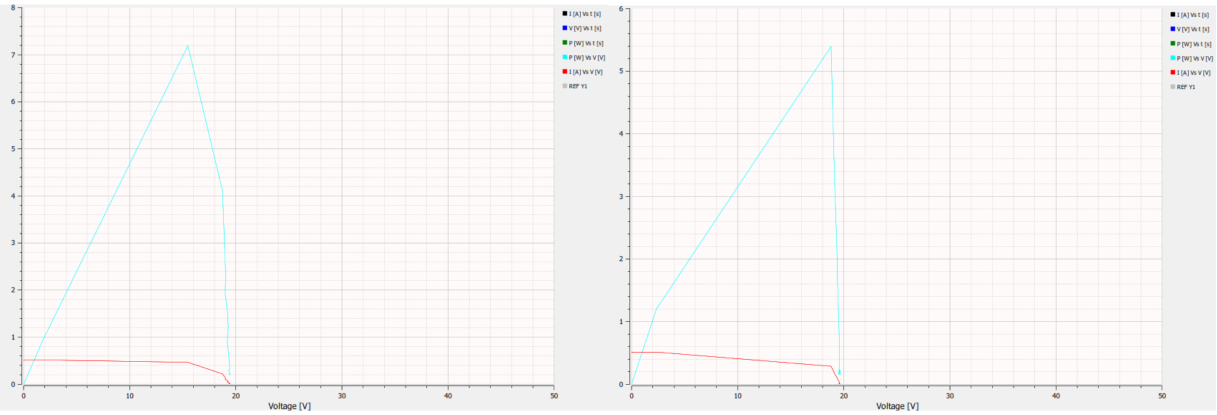
Fig. 14 P-V& I-V curve for Two series connected PV module



(a) 200 W/m² *(b) 600 W/m²*

In I-V characteristic maximum current at zero voltage is the short circuit current (I_{sc}) which can be measured by shorting the PV module and maximum voltage at zero current is the open-circuit voltage (V_{oc}). It is shown in Fig. 14 & 15. In the P-V curve, the maximum power is achieved only at a single point, which is called MPP (maximum power point), and the voltage and current corresponding to this point are referred to as V_{mp} and I_{mp}.

The Fill Factor (FF) is essentially a measure of the quality of the solar cell. The ratio of the actual achievable maximum power to the theoretical maximum power (PT) would be achieved with open-circuit voltage and short circuit current together.



(c) 800 W/m² *(d)1000 W/m²*

Fig. 15 P-V& I-V curve for Two Parallel connected PV module

Table 3: Comparison of the real-time parameter at different irradiance for series module

Parameter	**200 W/m²**	**400 W/m²**	**600 W/m²**	**800 W/m²**	**1000 W/m²**
V_{oc} [V]	36.7676	36.9629	38.7207	38.623	38.4766
I_{sc} [A]	0.179688	0.177734	0.232422	0.232422	0.228516
V_m [V]	36.7188	36.9141	35.0098	32.8125	27.7832
I_m [A]	0.0996094	0.0996094	0.189453	0.199219	0.208984
P_m [W]	3.65753	3.67699	6.63271	6.53687	5.80626
Fill Factor	0.553612	0.559699	0.737006	0.728192	0.660365
Efficiency [%]	4.14383	6.59623	8.52726	12.08554	16.90313

Table 4: Comparison of real time parameter at different irradiance for parallel module

Parameter	**200 W/m²**	**400 W/m²**	**600 W/m²**	**800 W/m²**	**1000 W/m²**
V_{oc} [V]	19.3359	19.3848	19.4824	19.4824	19.5312
I_{sc} [A]	0.0117188	0.525391	0.523438	0.0117188	0.0117188
V_m [V]	19.3359	19.1406	18.1641	19.4336	19.4336
I_m [A]	0.0117188	0.103516	0.304688	0.0117188	0.0117188
P_m [W]	0.226593	1.98135	5.53436	0.227737	0.227737
Fill Factor	0.1637	0.194545	0.5427	0.997494	0.995
Efficiency [%]	4.566483	6.47669	8.61197	12.142336	16.113869

Table 5: Results at varying Irradiance and fixed 35˚C Temp. of Series & Parallel PV Modules

Temp. (Deg.)	**Series Module**			**Parallel Module**		
	Voltage (V)	**Current (A)**	**Power (W)**	**Voltage (V)**	**Current (A)**	**Power (W)**
32.	39.60	0.109	4.331	19.78	0.0117	0.2314
34	39.40	0.109	4.233	19.48	0.0097	0.1889
36	39.06	0.105	4.121	19.38	0.0078	0.1511
37	38.92	0.105	4.104	19.28	0.0066	0.1272
38	38.22	0.102	3.913	19.13	0.0059	0.1128

On increasing the temperature, V_{oc} of modules decreases while I_{sc} remains the same, which in turn reduces the power. Therefore, if modules are connected in series, then power reduction is twice when connected in parallel. On changing the solar insolation, I_{sc} of the module increases more while the V_{oc} increases very slightly. Therefore, power is increased. In a series connection, power increment is more than when connected in parallel.

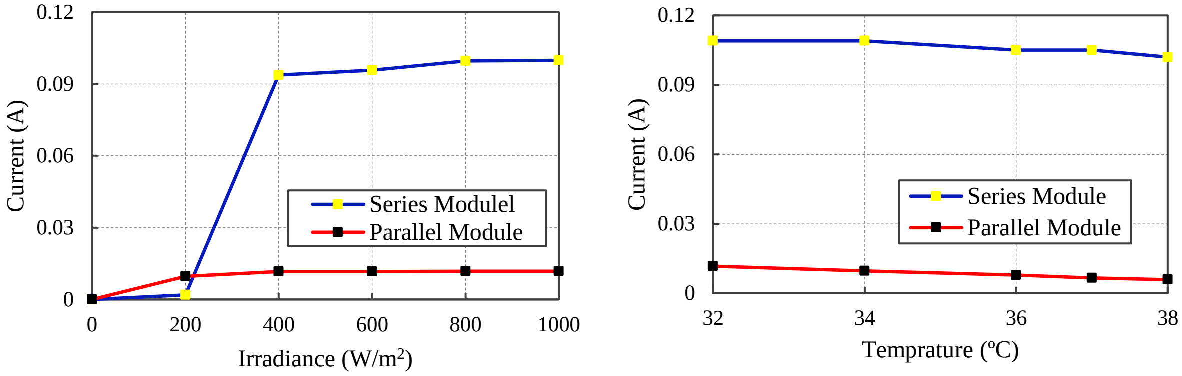


Fig. 16 Comparision of Current at Different Irradiance and Temperature

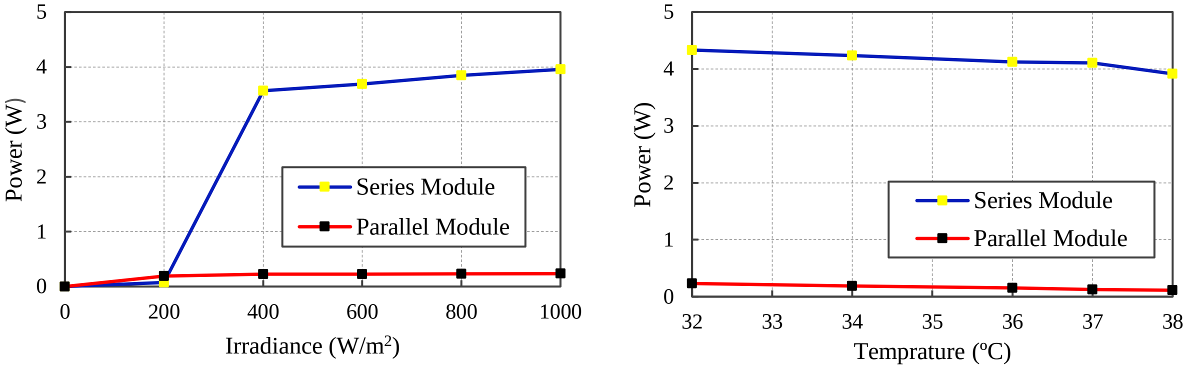


Fig. 17 Comparision of Power at Different Irradiance and Temperature

Different parament of PV is found per experimental analysis on a standalone series and parallel connected module. Fig. 16 & 17 show the graphical representation for comparing current and power at different temperature and irradiance. The current and power are more increases during in series connected module at higher irradiance. At the same time, current and power are slightly reducing at a higher temperature in both series and parallel connected panel.

6.5.2 Power Management in Standalone PV System

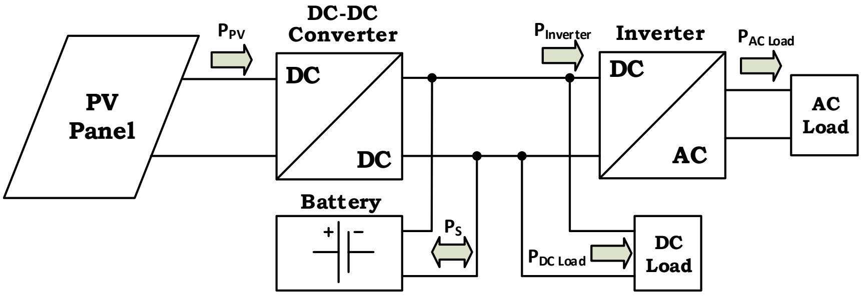


Fig. 18 Block Diagram of Standalone System

A standalone PV system is the one that be used for the locations where grid connectivity is not present, and these systems fulfil the requirements of these locations. As per fig. 18, this system consists of PV module, controller with MPPT algorithm, Energy storage battery system, DC load, inverter, and AC load. The controller regulates the module voltage required by the battery bank or load and then powered the load. The different operation mode of power management is given in table 6.

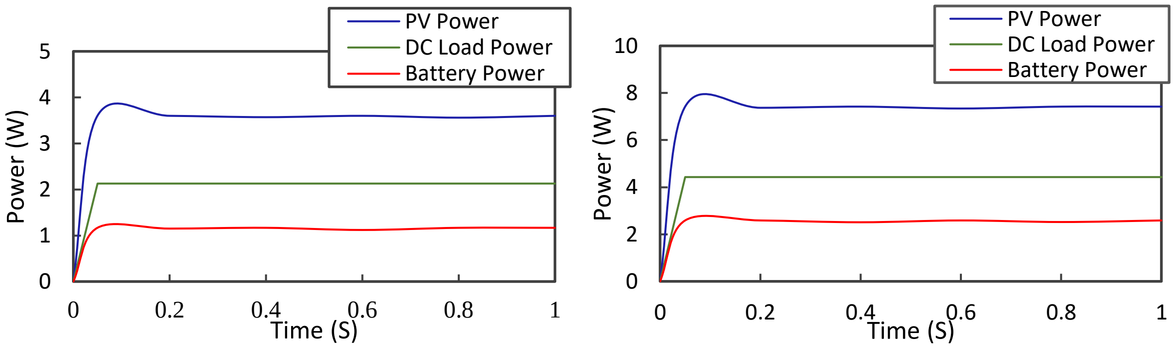
Table 6: Operation Mode of Power Management in Standalone PV System

Mode	**Power Generated by PV**	**Battery Power ($P_{s.}$) Released (+) /Absorb (-)**	**Power Delivered to DC Load ($P_{DC\ Load}$)**	**Power Delivered to AC Load ($P_{AC\ Load}$)**	**Power Characteristic**
I	P_{PV}	$- P_s$	$P_{DC\ Load}$	--	$P_{PV} = P_s + P_{DC\ Load}$
	P_{PV}	P_s	$P_{DC\ Load}$	--	$P_{PV} = P_{DC\ Load} - P_s$
II	P_{PV}	$- P_s$	--	$P_{Inverter}$	$P_{PV} = P_s + P_{Inverter}$
	P_{PV}	P_s	--	$P_{Inverter}$	$P_{PV} = P_{Inverter} - P_s$
III	P_{PV}	$-P_s$	$P_{DC\ Load}$	$P_{Inverter}$	$P_{PV} = P_s + P_{DC\ Load} + P_{Inverter}$
	P_{PV}	P_s	$P_{DC\ Load}$	$P_{Inverter}$	$P_{PV} = P_{AC\ Load} - P_{DC\ Load} - P_{Inverter}$

Table 7: Result Table for Power Management in Standalone PV System

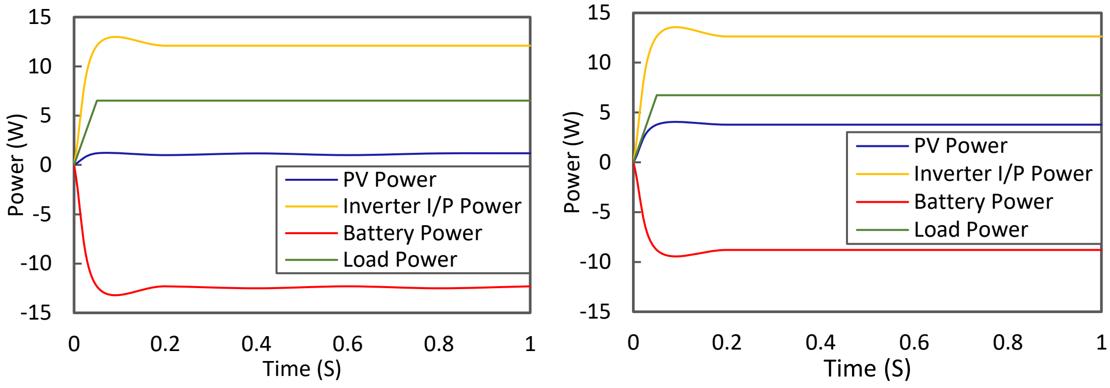
Mode	Module Configuration	P_{PV} (W)	$P_{S.}$ (W)	$P_{DC\ Load}$ (W)	$P_{Inverter}$ (W)	$P_{AC\ Load}$ (W)	D.C. Load Voltage(V)	A.C. Load Voltage (V)
I	Single Module	3.60	1.17	2.13			12.1	
	Series Module	7.20	2.01	4.33			12.1	
	Parallel Module	7.42	2.59	4.43			12.2	
II	Single Module	0.19	-12.31		12.10	6.52		230
	Parallel Module	3.78	-8.80		12.64	6.74		230
III	Single Module	0.19	-16.15	4.11	12.32	6.52	12	230
	Parallel Module	3.72	-12.39	4.16	11.88	6.74	12	230

The parameters to be observed are PV power, Battery power, DC load power, and AC load power with different series and parallel combinations of modules as per table 7. In mode I, the controller regulates the module voltage at 12V or any other voltage value required by the battery bank or load and then powered the load. Its graphical representation is shown in fig. 19.



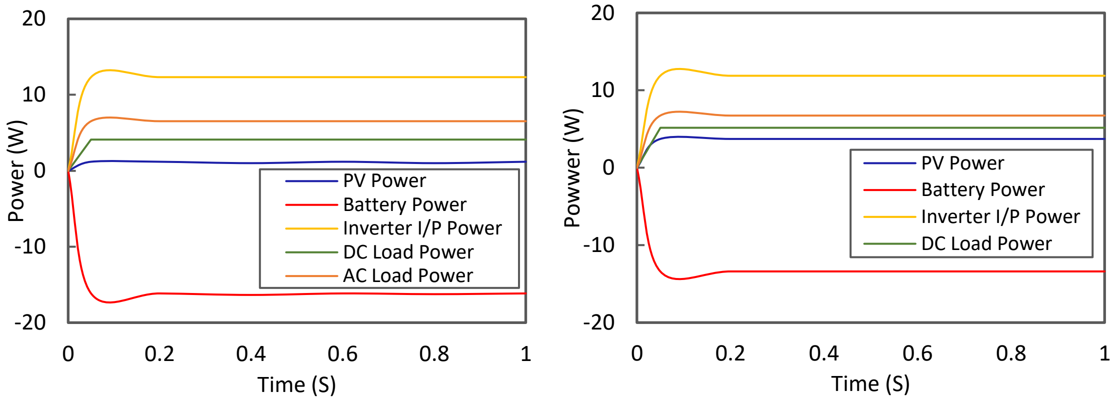
Single Module *Parallel Module*

Fig. 19 Power Management with PV, DC load and Battery (Mode 1)



Single Module *Parallel Module*

Fig. 20 Power Management with PV, AC load and Battery (Mode 2)



Single Module *Parallel Module*

Fig. 21 Power Management with PV, AC load, DC load and Battery (Mode 2)

In mode II, the controller regulates the module voltage to 12-volt DC and charges the battery, and then this regulated DC power is converted to AC through the inverter. The AC voltage is also maintained at 230 V. As per fig. 20; PV and battery power balance load power. In mode III, the system uses DC power to charge the battery and run the DC load but use AC power to run the AC load. This system runs the AC and DC load simultaneously and can fulfill the demand of both types of loads, as shown in fig. 21.

6.5.3 Power Management in Grid-Connected PV System

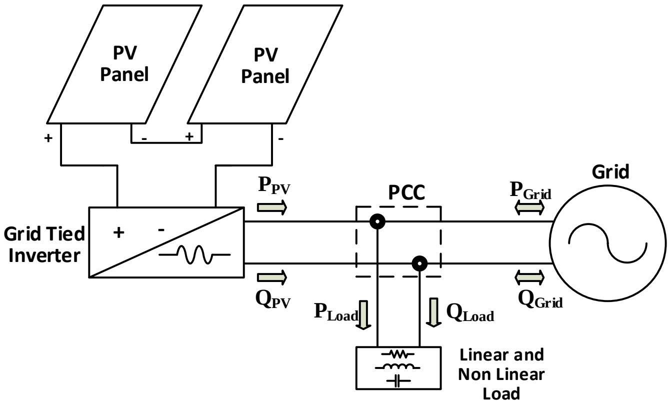


Fig. 22 Block Diagram of Grid-Connected PV System

Fig. 22 shows the block diagram of a grid-connected PV system. It is a grid-connected PV system that links solar power generated by the PV modules to the mains. The grid-connected system consists of a solar PV array connected to a grid-tied inverter. The AC output of the grid-tied inverter is connected to the point of common coupling (PCC). Active & reactive powers are individually balanced at any load. In this experimental system, PCC is an electrical node of three lines. One line is connected to the main grid, the second one to the grid-tied solar PV inverter, and the third one to the local load.

Table 8: Operation Mode of Power Management in Grid-Connected PV System

Mode	Power Generated by PV.	Power Delivered to Load	Grid Power (P_{Grid})	Power Characteristic
I	P_{PV}	P_L	$P_{PV}- P_L$	$P_{PV} - P_{Grid} = P_L$
II	P_{PV}	P_L	$P_L- P_{PV}$	$P_{PV} + P_{Grid} = P_L$
III	0	P_L	P_L	$P_{Grid} = P_L$

Table 9: Result Table for Grid-Connected PV System

Mode	PV Current I_{PV} (A)	Grid Current I_{Grid} (A)	Load Current I_{Load} (A)	Solar Power P_{PV} (W)	Grid Power P_{Grid} (W)	Load Power P_{Load} (W)
I	0.365	0.428	0.793	56	79	135
	0.582	0.563	1.145	126	116	230
II	0.88	-0.43	0.45	196	-96	100
	0.59	-0.41	0.18	134	-93	41
III	0	0.49	0.49	0	110	110
	0	0.72	0.72	0	160	160

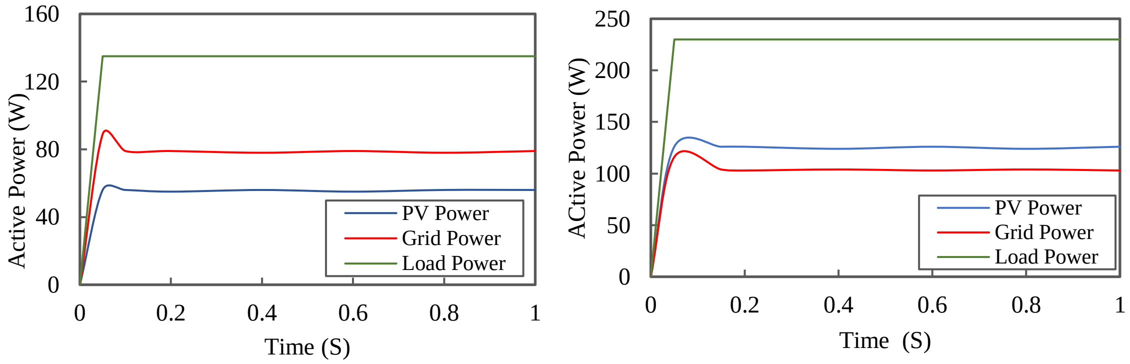


Fig. 23 Power Management with PV, Load, and Grid (Mode 1)

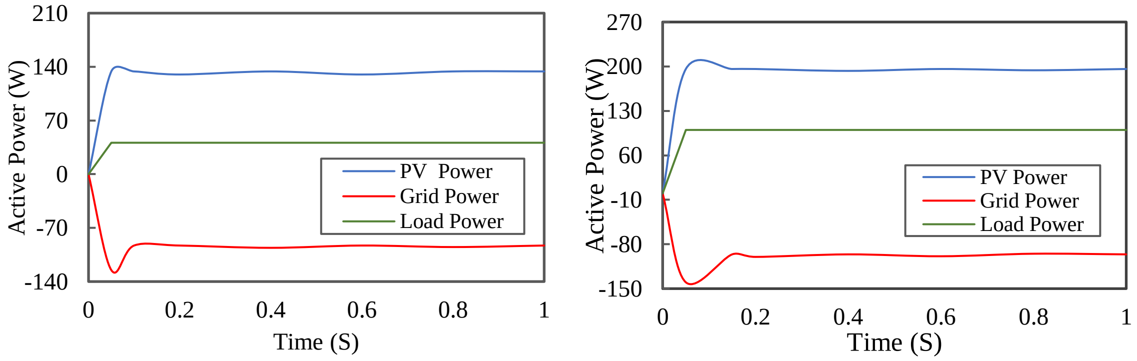


Fig. 24 Power Management with PV, Load and Grid (Mode 2)

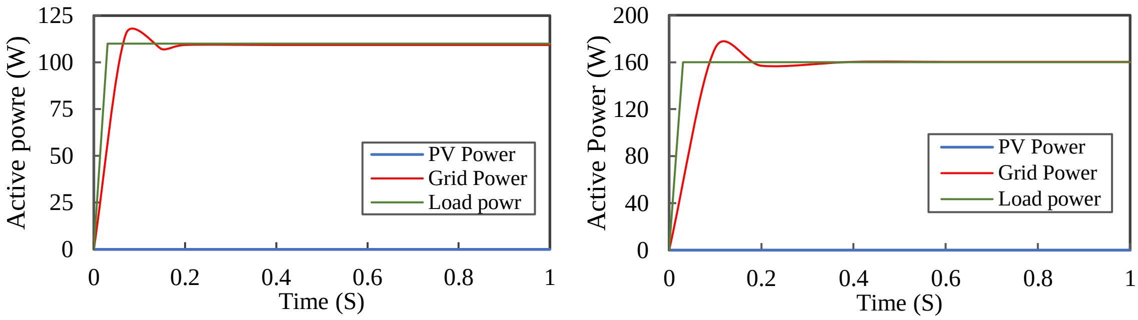


Fig. 25 Power Management with PV, Load, and Grid (Mode 3)

The operation mode of power management in a grid-connected system is shown in table 8. At any instant in time, load power is balanced by grid power. The grid power will be exchanged as per the solar generation and load power requirements. As per mode I, due to low irradiation, solar-generated power (P_{PV}) is less than load power (P_L). So (P_L- P_{PV}) power will be supplied by the grid. The result is shown in table 9 for grid connected system. The graphical representation is shown in fig. 23 as per case I. In the second case, solar-generated power (P_{PV}) is more than load power (P_L). So (P_{PV}- P_L) power will be taken by a grid. The graphical representation is shown in fig. 24 as per case II. There no PV generation during the night, the grid provides power to load as per mode 3. So, in fig. 25, load power and grid power both are the same.

7. Achievements with Respect to Objectives

- Power management strategy for renewable source dominate hybrid microgrid is proposed in this research work. The key point is power management in the hybrid microgrid to keep power balance among Distributed Generation (DG), Energy Storage (ES) battery, utility grid, and load at all times, and maintained bus voltage.
- The power management algorithm is proposed for a hybrid microgrid where bus voltage is the main carrier for a different mode of operation to maintain power balance among source and load.
- Voltage shifting based primary droop control method is introduced to avoid the drawback of poor voltage regulation of conventional primary droop control strategy. This control strategy can achieve power-sharing as well as bus voltage regulation.
- Transient response during suddenly step up a load in secondary control, there is no current sharing error of converter current. And at the same time, the voltage response of the converter is also good. The voltage of each converter is maintained as per the bus voltage. The same transient response performance is also achieved for current sharing and voltage restoration in secondary control during suddenly step down load.
- By combining two average currents and droop coefficient controllers, current sharing and voltage regulation are good under fast-changing load current. As compared to the primary control scheme, both current sharing accuracy and voltage regulation are achieved better by using secondary control schemes.
- As per experiment analysis, various parameters are finding out at different irradiance and temperature in series and parallel connected PV module. The P-V and I-V curve at MPP is observed at different irradiance by using a real-time plotter. From graphical representation, it is analyzed that current and power both are increases at higher irradiance in series connected module compared to a parallel connected module.
- When solar irradiations are enough in standalone systems, electricity generation is usually more than the house's local load requirement. So extra power is used to charge the battery. When PV power is less than load power, the battery is providing the power to load. So, both AC and DC voltage is to be maintained to its rated value.
- However, the grid-tied PV system is beneficial in terms of the excessive power which can be sold to the grid. When solar irradiation is not sufficient, load power is balanced by PV and grid. Likewise, for night-time, the only grid supplies power to load.

8. Conclusion

The hybrid microgrid is presented with renewable sources (PV & wind), battery, and AC grid in islanding and grid-connected mode. It is operated in different modes to sustain power balance by detecting the change in bus voltage. Droop control strategy is applied for proportional load sharing between parallel converter for power management. For variable load condition, the hybrid microgrid is operated in a different mode, and load power is balanced by AC grid, DG, or battery unit**.** In a conventional primary droop control scheme, voltage degrades while increasing the load current. So, voltage shifting based droop control strategy is applied at the primary level to improve voltage regulation.

A further distributed secondary control scheme is also used with compensating controllers. The average voltage controller is compensating the average value of output voltage over the primary controller. By combining the average current controller and droop coefficient compensating controller, adapting the droop resistance can be realized, and the two converter's output impedance would be the same. So, current sharing accuracy is precisely reached. Also, by combining these two average current and droop coefficient controller, current sharing and voltage regulation is good under fast-changing load current in a secondary control scheme. The simulation results verify the implemented control strategy for the stable operation of the hybrid microgrid.

Experimental analysis for Power management is also done for variable load in the islanding and grid-connected PV system. In the islanding PV system, series and parallel connected two PV modules are tested with real-time monitoring for different temperatures and radiation. And at different loads, if irradiation is sufficient, then PV power is given to the battery and load; otherwise, load sinks the power from battery and PV If irradiation is enough in a grid-connected PV system, extra power is fed to the grid; otherwise, load sinks power from grid and PV.

9. Paper Publication

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