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Power Management in Hybrid Microgrid

Hitesh M. Karkar, Indrajit N. Trivedi, Prasanta K. Ghosh

Abstract*: This paper is representing power management in a hybrid microgrid. The hybrid microgrid consists of PV, wind, battery, and grid. The power management strategy is mentioned in islanding and grid-connected mode. In a grid-connected system, the grid converter has to monitor and manage the power to flow between microgrid and grid. The voltage shifting based droop control technique is used in DG for proper load sharing when two sources are connected in parallel. DG units in hybrid microgrid have two switching modes including droop control and maximum power tracking (MPPT). The operation of a hybrid microgrid is operated in different thee mode. The bus voltage is the main carrier to switching the mode of a hybrid microgrid. The power management algorithm for hybrid microgrid described here. This renewable-based hybrid microgrid model can be used for different aspects like small residential and commercial buildings. The feasibility and effectiveness of this strategy for hybrid microgrid running in various modes verified by simulation result.

Keywords*: Hybrid Microgrid, Power Management, Droop Control, DG.

I. INTRODUCTION

Distributed Generation (DG) has an importance role in large power grid. It has various advantages like high efficiency, low pollution, low T&D losses, easy to install. Now a day it is popular for a key features of power system [1,2]. A microgrid is sub grid and consists of various DG like PV and wind, energy storage system and load [3,4]. Microgrid improves stability, efficiency and reliability of the power system. It reduces co_2 emission and provides high power quality supply to the consumer. The Microgrid is connected to low or medium voltage, depending upon location and a total capacity of DG. The function of the DG unit is to generate power and support microgrid system [5].

Development of the hybrid microgrid is due to restarting the conversation cum challenges between *Thomas Edison* and *George Westinghouse*, which is the merits of DC and AC distribution systems [6]. Hybrid Microgrid is an idea of mixing both AC Grid and DC microgrid. So, hybrid microgrid has a benefit for both the sources [7]. The design of hybrid microgrid is classified into AC connected and DC connected hybrid microgrid. In AC connected hybrid microgrid, DGs and ES are connected to the AC bus by a converter. But in DC connected hybrid microgrid various ES and DG are connected to AC bus through a converter. The power will flow from the AC bus to the DC bus during overload in microgrid and the grid converter will run as a rectifier. The grid converter is run as an inverter when power flows from the microgrid to the AC grid during surplus power generation of a microgrid. The main purpose of the grid voltage source converter is power flow between DC and AC bus as per the load requirement [8].

The DC coupled hybrid microgrid has several advantages like simple structure, need not any synchronization. When power management and control for parallel interfacing converter (IFC), their output voltage synchronization is big challenges. The DG is connected directly to DC bus without any conversion in some specific DC coupled hybrid microgrid.[9].

The power management strategy (PMS) is needed for the sound operation of DG unit when multiple numbers of DG (more than one) are connected in particularly islanding mode operation. In each mode of operation, available power must be fulfilled the total load demand. Too flexible and fast control strategy of a microgrid is needed to minimizing the dynamic e.g. damped out system transient and due to islanding. The main goal of droop-based PMS in islanding mode are load sharing among DG, maintaining the voltage profile, improving the dynamic response, voltage restoration during system transient.

II. SYSTEM ARCHITECTURE

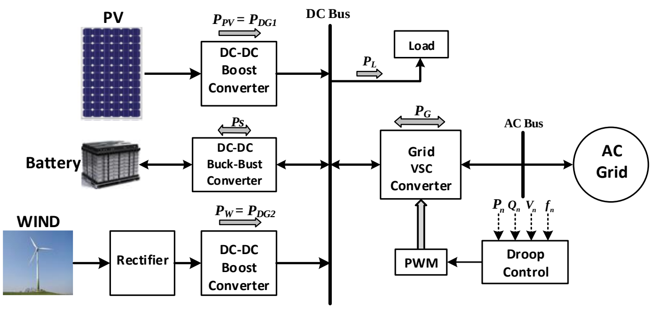

Figure 1. Architecture of proposed hybrid microgrid

The proposed Hybrid microgrid structure is shown in Fig. 1. PV generating unit is linked to a DC bus through the DC to DC boost converter. A PMSG type wind turbine has an AC output voltage. An uncontrolled rectifier is sent DC power to boost converter.

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* Correspondence Author
Hitesh M. Karkar*, Research Scholar, Gujrat Technological University, Ahmedabad, India. Email: hmkarkar@gmail.com
Indrajit N. Trivedi, Professor, Department of Power Electronics, Vishwakarma Government Engineering College, Ahmedabad, India.
Prasanta K. Ghosh, Professor, Department of Electrical Engineering & Computer Science Syracuse University, Syracuse, New York, USA.

PV and wind both have a MPPT and droop control. Grid is connected to the microgrid through the grid voltage source converter. Battery unit is linked to the DC bus by bidirectional DC-DC converter. The PV and wind turbine units can work together.

III. POWER MANAGEMENT STRATEGY

A. *Islanding and Grid connected Mode*

The power management strategy is most important for the function of the hybrid microgrid. The power management strategy means manages the generation power from DG and ES and at the same time controls the voltage of microgrid. The hybrid microgrid is operated in islanding and grid mode.

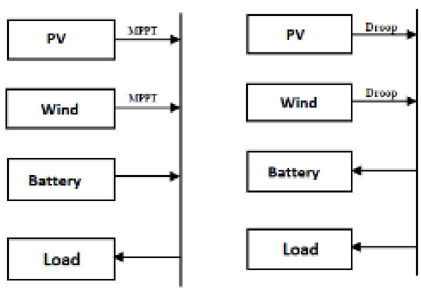

Figure 2. Power management strategy in Islanding mode

The power management strategy in islanding mode is presented in Fig. 2. The microgrid bus voltage is maintained by PV, wind or battery in this mode. The PV and wind are operated in droop mode if its power is sufficient. If its power is not sufficient enough to provide to a load, these DG units change to MPPT mode. When the PV & wind units run at droop mode and battery requires charging then the power management among PV, wind, battery, and load should be observed. When PV and wind power generation is sufficient, the charging current can be placed to the maximum. On the other hand, if DC bus voltage falls, then the rest of the power provided by a battery. So, the battery's charging current reduced by the current limiter to maintain the stability of the microgrid system.

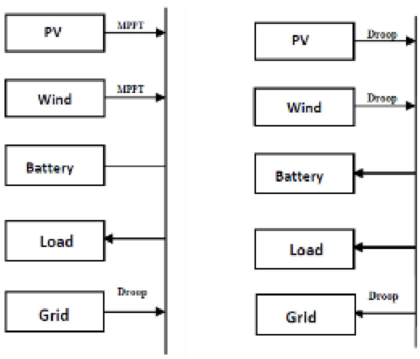

Figure 3. Power management strategy in Grid Mode

Fig. 3 is shown the power management strategy for grid mode. In this mode, the grid bidirectional converter is operated in droop mode and bus voltage of the microgrid controlled. The PV and wind are operated in MPPT mode. If DGs power is sufficient and the battery is not completely charged then the remaining power will be supplied to the grid. If DGs power is not enough to provide the load then the grid converter operated in rectifier mode and sent power to load. If a battery is fully charged then it will be disconnected from the grid.

B. *MPPT Control of DG*

The PV and Wind exists an MPP as per characteristics when converter and PV/Wind's impedance are matched. As shown in Fig. 2, V_{DG} and i_{DG} are sent in MPPT module. Boosts type converter regulated by V^*_{DG} and voltage control loop. Perturb and observe (P&O) method is accepted to track the PV/Wind MPP. MPPT mode of DG units can be a concept as current produce to DC microgrid, but droop mode is needed in other conditions.

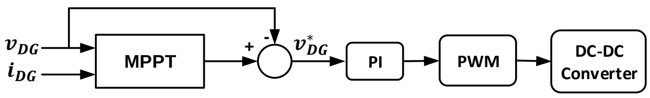

Figure 3. MPPT Strategy of PV & Wind converter

C. *Droop Control of DG*

The multiple numbers of sources are connected in parallel with a bus which creates circulating current among converter in a hybrid microgrid. Droop control is widely used in a hybrid microgrid for the proper current sharing purpose. It is also avoided the communication links. The droop control is known by adding virtual resistance in an existing system. Virtual resistance is the ideal value and not affected by temperature. It will not produce real power losses. Virtual resistance is also called the droop coefficient, droop gain, or droop constant.

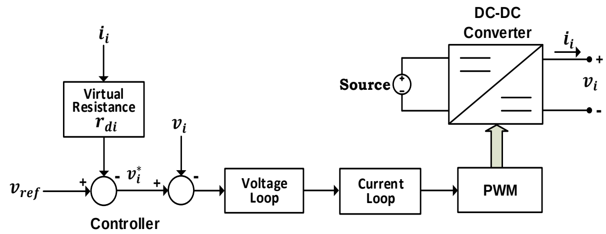

Figure 4. Control diagram of droop control technique

There are three loops in the droop control strategy for the DC-DC converter as per Fig. 4. The virtual resistance loop in which a droop resistant r_d multiply with converter current i. The other inner current control loop and outer voltage control loop are in these units.

- **Conventional droop control technique**

The conventional droop control can be presented by equation (1).

$$v^* = v_{ref} - ir_d \qquad (1)$$

Where v_{ref} = Reference value of DG units output voltage, $v*$ =New reference voltage after droop control implemented, r_d = Droop gain, i = converter output current

The conventional droop control strategy is easy to implement. When droop gain rises, the voltage regulation increased. So, the larger voltage regulation is not allowable to loads. So, the poor voltage regulation is the drawback of conventional droop control.

- **Voltage shifting based droop control technique**

In a hybrid microgrid, a conventional droop control strategy is easy to implement but poor voltage regulation.

So, in voltage shifting based droop control, Δv is added to them with a converter reference voltage to regulate the bus voltage. In Fig. 5, droop characteristic is represented by a solid line for conventional droop control. When load current increases from *i* to *i'* the voltage is reduced in conventional droop control. So, the droop curve is shifting from point *b* to *b'*. Thus, the voltage at current at *i'* to be the same after shifting droop characteristic.

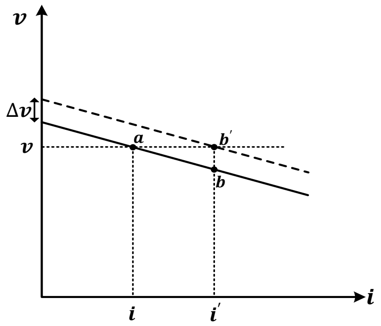

Figure 5. Voltage shifting based droop control

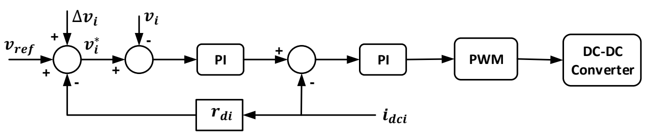

Figure 6. Control diagram of voltage shifting droop control

In voltage shifting based droop control loop, Δv is added. It can be expressed in equation (2). The control diagram of voltage shifting based droop control is shown in Fig. 6.

$$v^* = v_{ref} - ir_d + \Delta v \quad (2)$$

D. Operation Mode of Power Management

The total distributed generation power (P_{DG}) is the sum of solar PV generation output power (P_{PV}) and wind generator output power (P_W). The P_{DG} is the main source of power and supply unidirectional power in the microgrid system. The energy storage battery power (P_S) is managing the power in microgrid by a bidirectional flow of power through charging and discharging of the battery. The operation mode of power management in a hybrid microgrid is shown in Table I.

E. Operation Mode Switching for Power Management

The power balance mode of a hybrid microgrid is decided by bus voltage changing. The output characteristic of PV and wind were not taken in observation in droop control without MPPT mode. So, system utilization efficiency is decreased. For this problem, the energy storage battery is used to overcome this fluctuation of PV and Wind. Which is also reduces the continuous fluctuation of bus voltage and improves stability.

Table-I: 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	$P_{G(max)}$	$P_S = P_{G(max)} - P_{DG} + P_L$

- **DG Unit:**

The DG units are a combination of PV generation unit and wind generation unit which are connected through the converter with dc bus. The Fig. 7 is shown the switching process in a different mode of this DG unit. The DG unit is normally working in MPPT mode to capture the maximum possible solar and wind energy, increasing energy efficiency. When solar and wind output is sufficient then DG power output becomes large, so the bus voltage of microgrid increases. Thus, the operating mode of DG will shift into droop mode to maintain a stable voltage. If the ac grid and load are not connected and the battery is fully charged then the DG unit will cut off from microgrid.

- **Battery Unit:**

The battery is connected parallel with DG to a hybrid microgrid. The bidirectional dc to dc converter is jointed between microgrid dc bus and battery. The battery is operated in charging mode during normal microgrid operation. When the battery is completely charged, it would be cut out. The microgrid is isolated from the main grid during fault takes place in the grid. So, in this islanding mode, the battery would be balancing the voltage and stabilized the microgrid operation.

The power balance in hybrid microgrid means to keep the constant voltage of the bus. This hybrid microgrid 400 V is considered for the rated voltage for the reliability and safety of microgrid. By following the operation mode of hybrid, the microgrid is classified into three types of bus voltage range. It is shown in Table II.

Mode I:

In this mode I, the grid converter maintains the stability of microgrid. The operation of DG units is under MPPT to capture the maximum possible energy from solar and wind.

The battery unit operates in constant current charging mode by the battery management system and when fully charge then it will be cut off from microgrid. In this mode voltage between 390 V to 410 V is maintained.

Mode II:

The energy storage battery supports the DC bus voltage stability in this mode. The operation of DG units is under MPPT. The grid converter will switch into the current limiting mode in case of fault arises or power transfer from the main grid to microgrid makes the grid converter limitation. Under this mode, 360V-370V of a bus is maintained in the range.

Table-II: Voltage range for operation mode switching

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

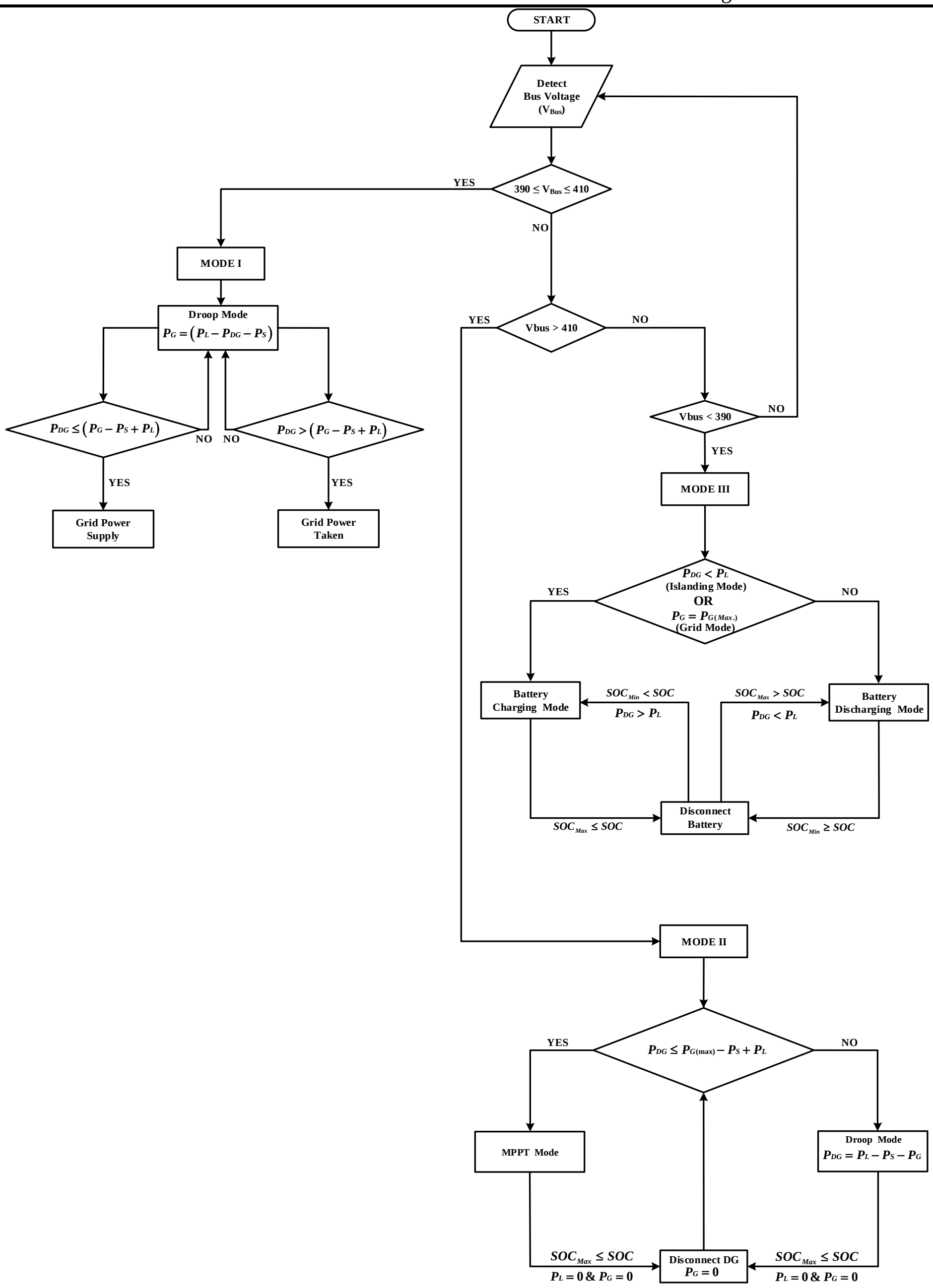

Figure 7. Flowchart for the operation mode of power management in hybrid microgrid

Mode III:

The DG unit maintains the DC bus voltage stability in this mode. By battery management system, the battery would be charged during light loads and bus voltage increases V. The gird converter transmits power to the grid in its maximum power from microgrid or cut out from microgrid.

IV. RESULT AND DISCUSSION

In the sequence of proving the fruitfulness of the control strategy for power management, the MATLAB/Simulink simulation model is presented in Fig. 8 to Fig. 10. The simulation result waveform is conducted in three mode as per the above analysis. The constant irradiation and wind speed model are considered for PV and wind generation respectively. We assume the wind speed and irradiation level are under step change during switching mode.

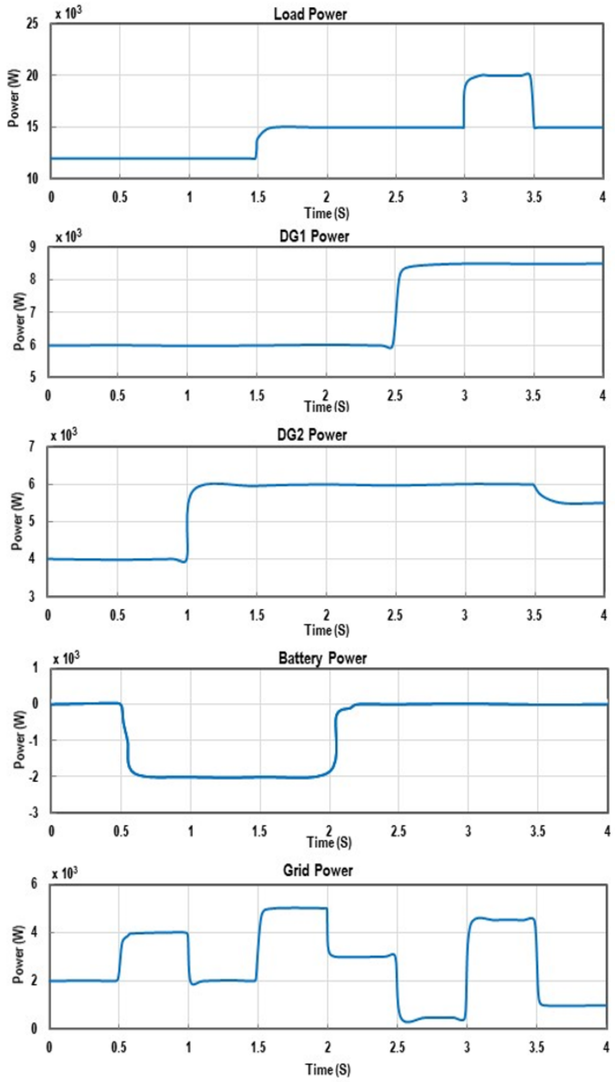

Figure 8. Simulation waveform result for a case I

The simulation result for a case I is shown in Fig. 8. In this case, a hybrid microgrid is worked in mode I. In this mode I, the grid converter maintains the stability of microgrid. When the load changes, the grid converter exchange the power between the AC network and the DC grid as per grid characteristics. At 0.5 s, battery start charging so grid power is increased and on 2 s, the battery is fully charged so it cut out from grid and it is becoming in standby.

In Fig. 9, the hybrid microgrid operates in mode II and the battery maintains the stability of microgrid. The microgrid operates in mode I at first. At 1 s, the AC grid converter is disconnected from microgrid due to fault. So, the system switched into mode II from mode I at 1 s. At this time, the battery works in discharging mode and provides power to a microgrid. At 1.5 s fault is cleared, so system again switched into a mode I. At 2 s and 2.5 s, the load is increased in a hybrid microgrid, so the grid converter reached up to its maximum power limit. Due to this reason, a grid converter operates in current limit mode and the system switched to mode II. At 3.5 s, power output can't meet the load demand so some load is cut off. After load cutting, power output can match the load requirement and the system can securely run in mode.

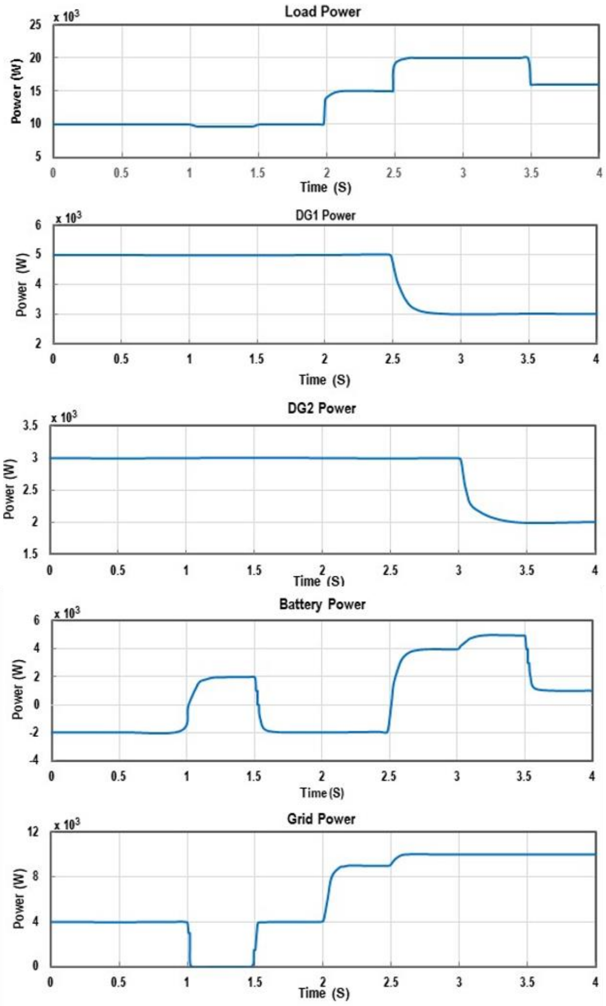

Figure 9. Simulation waveform result for case II

In Fig. 10, the DG unit maintains the stability of hybrid microgrid and microgrid works in islanding mode. The microgrid is disconnected from the main grid and run islanded mode at 1.5 s. So, the system switched into mode II and the battery provides the stability of microgrid. At 2.5 s, an output power of the DG unit is increased, so microgrid switched into mode III. Thus, the DG units are operated in droop control mode to sustain the power balance and bus voltage stability. The battery fully charges at 1.5 s and cut out from the grid.

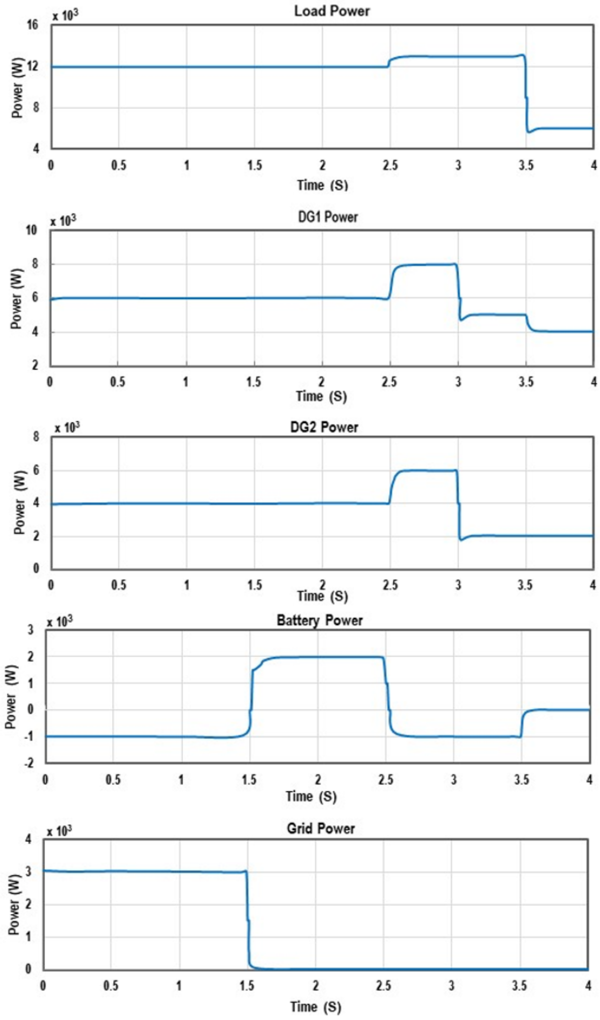

Figure 10. Simulation waveform result for case III

V. CONCLUSION

The operation of a hybrid microgrid for DG (PV, wind), energy storage battery and the grid is in different thee mode. For variable load conditions, the hybrid microgrid is operated in a different three-mode by detecting the change in bus voltage. So, load power is balanced by the AC grid, DG or battery unit. On the basis of detecting the voltage, various modes of operation of DG (PV, wind), Energy storage battery and grid are determined and switch smoothly. So, in each mode, the power balance is possible when the different bus voltage. PV and wind collaborate to supply power, building the microgrid run in the optimal state and working under its maximum efficiency. Thus, the microgrid bus voltage supported the appropriate range. Here there is no communication between various units. So, the system has a plug-in-play is to be realized. The simulation results verify the implemented control strategy for the secure performance of a hybrid microgrid.

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AUTHORS PROFILE

Hitesh M. Karkar, has received his bachelor in Electrical Engineering from L. E. College, Morbi, Gujarat (India) in 2001. He obtained his Postgraduate Degree in Electrical Engineering with a specialization in Automation & control power system from L. D. College of Engineering, Ahmedabad (India) in the year 2013. At present he is working as an Assistant Professor in the Department of Electrical Engineering at L. E. College, Morbi and pursuing his Ph.D. in Gujarat Technological University, Ahmedabad under the supervision of Indrajit N. Trivedi and Prasanta K. Ghosh. His research interests include photovoltaics, microgrid and converter control in renewable energy sources.

Indrajit N. Trivedi, has received his bachelor in Electrical Engineering from L. E. College, Morbi, Gujarat (India) in 1993. He obtained his Postgraduate Degree in Electrical Engineering with specialization in Power System from L. D. College of Engineering, Ahmedabad (India). He has received his Ph.D. Degree from Yokohama National University, Japan in the year 2010. At present, he is working as a Professor in the Department of Power Electronics at Vishwakarma Government Engineering College, Chandkheda, Ahmedabad. He has 25 years of experience in the field of teaching. His research interests include microgrid, energy management, optimization, distributed generation and power system restructuring.

Prasanta K. Ghosh, has received his Ph.D. Degree from Pennsylvania State University. At present, he is working as a Professor in the Department of Electrical Engineering & Computer Science at College of Engineering and Computer Science, Syracuse University, Syracuse, New York, USA. His research interests include smart grid, sensors and measurement, high-speed electronic devices and integrated circuits, power engineering and power electronics. He is actively developing several research projects in the area of microgrid design and analysis, smart grid systems, including distributed resources and EVs. Other projects include the design and analysis of FinFET, as well as the development of thin-film sensors.