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Reliability Enhanced Autonomous Hybrid Micro Grid Based Distribution System With Renewable Resources

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Abstract: Renewable resources have attracted the attention due to depletion of conventional energy sources and increased public awareness in reduction of carbon emissions. Microgrid facilitates interconnection of various distributed generation resources (DER) such as the distributed generation (DGs) and battery energy storage systems (BESSs) into the distribution system and hence removes the need for expansion of distribution system. DGs can be non-inertial or inertial, non-dispatchable or dispatchable especially when the microgrid operates in an autonomous (islanded) mode. For stable operation of microgrid, the response rates of non-inertial DG units (DGs interfaced using converters) should be matched with response rates of inertial DG units using virtual inertia concept. This paper studies real power flows among autonomous hybrid micro grid test systems developed using different combinations of DG units such as hybrid microgrid system using two inertial DG units, hybrid microgrid system using two non- inertial DG units, hybrid microgrid system using one inertial and one non-inertial DG units. This paper also focuses on impact of integration of non-dispatchable DG units on power flows of hybrid micro grids. To enhance the reliability of proposed autonomous hybrid microgrid, methods like synchronization of other micro grids along with BESS units have been discussed in this work, which are validated through computer aided simulation using MATLAB.

Keywords: Autonomous microgrid, Hybrid microgrid, Inertial DG units, Microgrid cluster, Virtual inertia.

1 Introduction

A microgrid can be synchronized to power grid or can be isolated from the grid, similar to physical islands [3-5]. A microgrid can be formed by integrating small scale, cheaper and efficient renewable generation technologies to distribution networks.

Table 1 Benefits of Microgrid [6]

Value Proposition	Description
Clean & Green Power	Environmentally friendly technologies and helping to manage the intermittency of renewable and promoting the deployment and integration of energy-efficient
Security	By promoting the dispersal of power resources and increasing the resiliency and security of the power delivery system

Reduced Cost	Reducing the cost of energy and managing price volatility
Reliability	Improving reliability and power quality
Service Differentiation	Providing different levels of service quality and value to customer segments at different price points
Power System	Assisting in optimizing the power delivery system, including the provision of services

1.1 Distributed Generation Resources (DER's)

A typical hybrid microgrid system comprises different power generating sources including PV panels (PVs), wind turbine generators (WTGs), and storage batteries (SBs). These power generating sources have different impacts on reliability, cost and environment. In a hybrid microgrid system, these are integrated together and complement one another in order to meet the load while satisfying certain environmental, economic and reliability criteria. The hybrid microgrid system can be operated autonomously or connected to the utility grid whose power is from the conventional fossil-fuel-fired generators (FFGs).

Table 2 Typical interfaces for various DERs

Type Of Primary Energy Source		Typical Interface
DG	Combined Heat And Power (CHP)	Synchronous Generator
	Internal Combustion Engine (ICE)	Synchronous or Induction Generator
	Fixed Speed Wind Turbine	Synchronous or Induction Generator
	Variable Speed Wind Turbine	Power electronics converter (AC–DC–AC)
	Micro Turbine	Power electronics converter (AC–DC–AC)
	Photo Voltaic (PV)	Power electronics converter (DC–DC–AC)
	Fuel Cell (FC)	Power electronics converter (DC–DC–AC)
Energy Storage	Battery	Power electronics converter (DC–DC–AC)
	Fly Wheel	Power electronics converter (AC–DC–AC)
	Super Capacitor	Power electronics converter (DC–DC–AC)

1.2 Structure of proposed autonomous hybrid microgrid

In a hybrid microgrid system, the dynamic responses of non-inertial and inertial DGs are different. The inertial DGs exhibits a slower response, while non-inertial (converter interfaced) DGs can respond very quickly [11]. The behavior of autonomous hybrid microgrid is a challenge due to mismatch of response rate in different types of DGs which creates transient oscillations in an autonomous microgrid where no strong source is present to control the system frequency and voltage. These DGs can also be either dispatchable or non-dispatchable. In order to understand the behavior of autonomous hybrid microgrid, the following test systems are considered.

Test system-A: Autonomous hybrid microgrid with two Inertial DG units

Test system-B: Autonomous hybrid microgrid with one Inertial & One Non-inertial DG units

Test system-C: Autonomous hybrid microgrid with two Non-inertial DG units

Type of DG units considered for study of test system behavior

A. Inertial DG unit: Diesel Generator set (DGEN)

The diesel generator set consists of a 4-stroke internal combustion (IC) engine coupled to a synchronous generator. The schematic arrangement of DGEN set is shown in Figure 1.

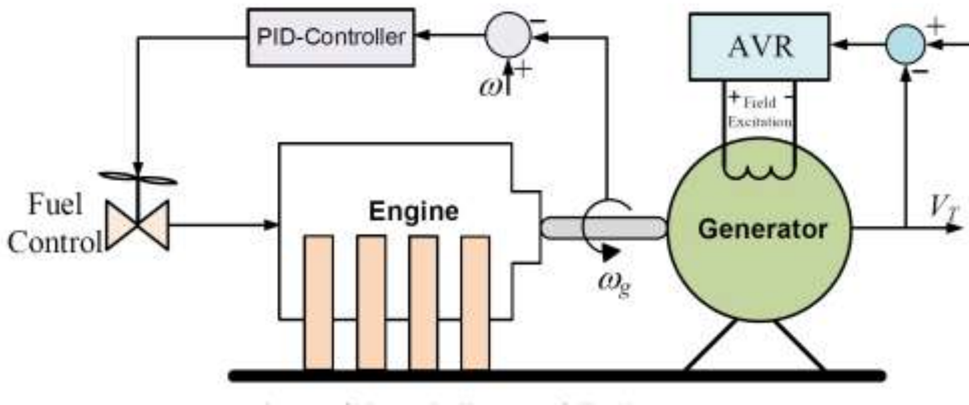

Figure 1 Schematic diagram of DGEN set- Inertial type DG unit

B. Non-inertial DG unit: Micro Turbine (Converter interfaced)

The schematic arrangement of the micro turbine with converter interfacing system is shown in Figure 2.

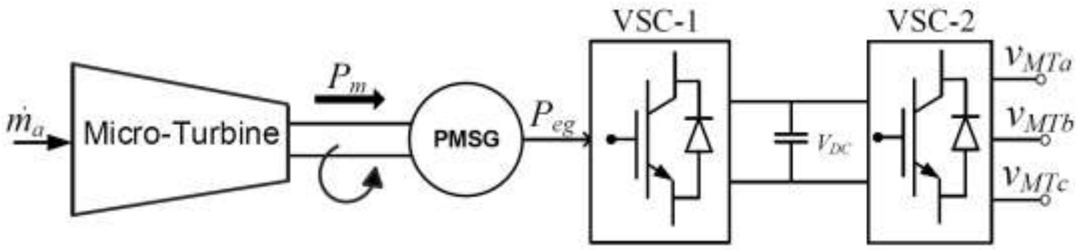

Figure 2 Schematic diagram of micro turbine with converter – Non-inertial type DG unit

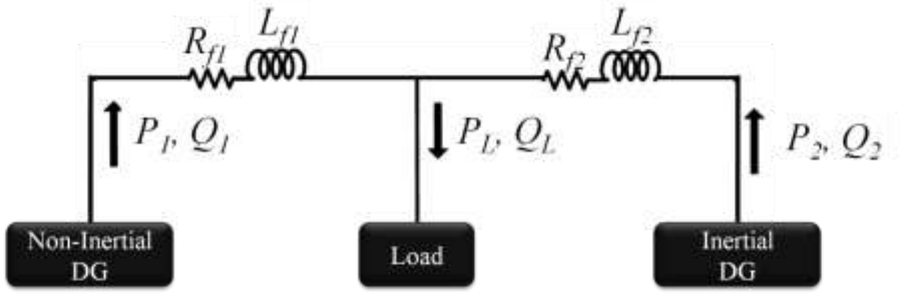

Figure 3 Block diagram of Test system-B: Autonomous hybrid microgrid with one Inertial & one Non-inertial DG units

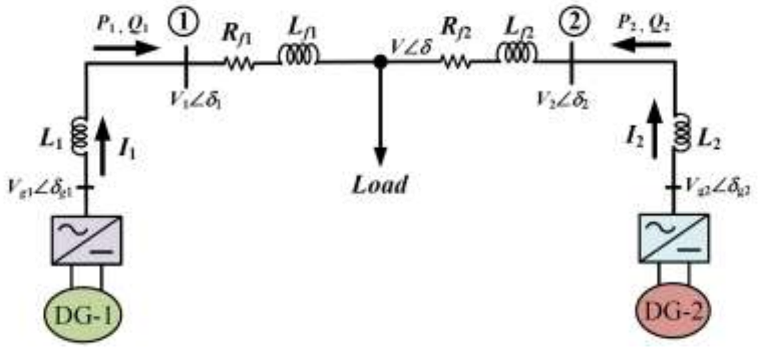

Figure 4 Block diagram of Test system-C: Autonomous hybrid microgrid with two Non-inertial DG units

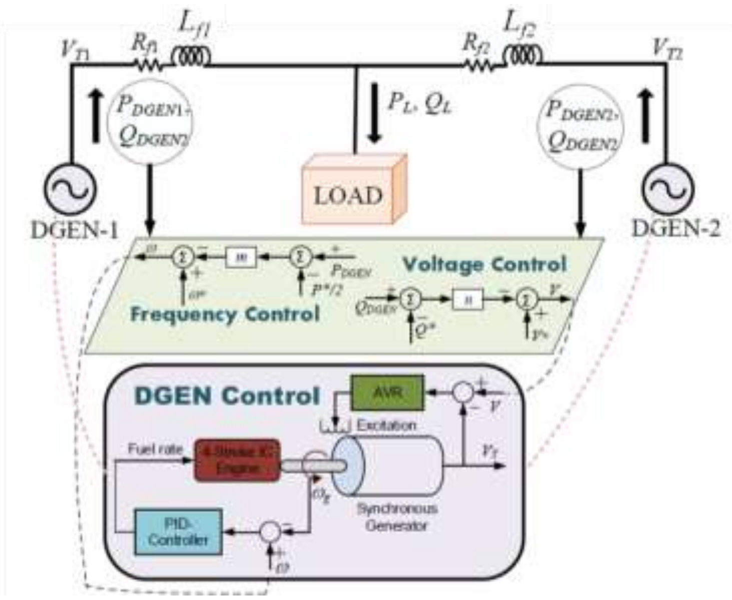

Figure 5 Block diagram of Test system-A: Autonomous hybrid microgrid with two inertial DG units

1.3 Control strategies for autonomous hybrid microgrid

Proper control strategy is a prerequisite for stable, economical and efficient operation of a microgrid, in both grid connected and islanded modes [15]. The same control strategy cannot

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be employed in both modes. For grid connected mode, the system frequency and voltage of the microgrid are mainly controlled by the grid. In autonomous mode of operation, DGs in the microgrid need to be controlled such that the voltage and frequency in the islanded microgrid are maintained within acceptable limits. Therefore, droop control is employed for islanded microgrid. Various methods can be adopted for controlling autonomous microgrid are: Frequency and voltage droop are the most commonly adopted control strategies for Inertial DGs in islanded microgrid to achieve desired frequency and voltage limits and for load power sharing among different DGs. Angle droop control strategy is applied for an isolated microgrid which consists of only Non-inertial DGs [12].

The Virtual inertia concept: When a retrofitted microgrid contains of both inertial and non-inertial DGs, there may be large power and frequency excursions during transients. The Non-inertial DG starts drawing power and the inertial DG balances this out by delivering a large amount of power. Also the system takes a long time to reach steady state, while the frequencies of the two DGs never coincide. Note that the inertial DG may never be able to supply the transient power resulting in a system collapse. To match the response rates of change in power output of inertial and non-inertial DGs, a derivative term is added in power output of the Non-inertial DG angle droop control strategy.

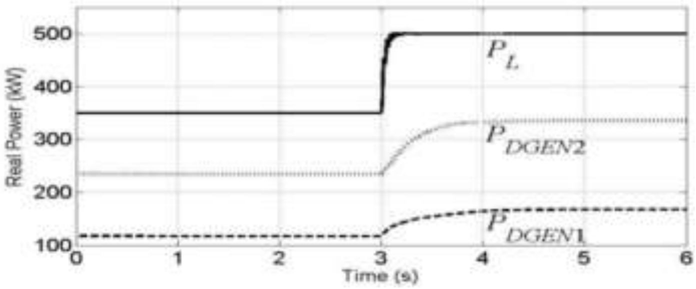

Figure 6 Load sharing among Inertial DGs using Frequency droop control in Test system-A

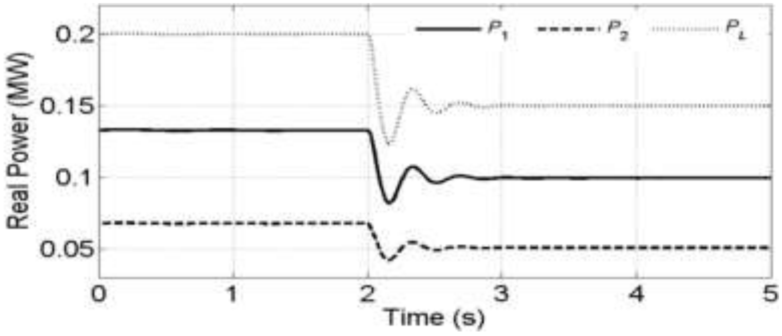

Figure 7 Load sharing among Non-inertial DGs using Angle droop control in Test system-C

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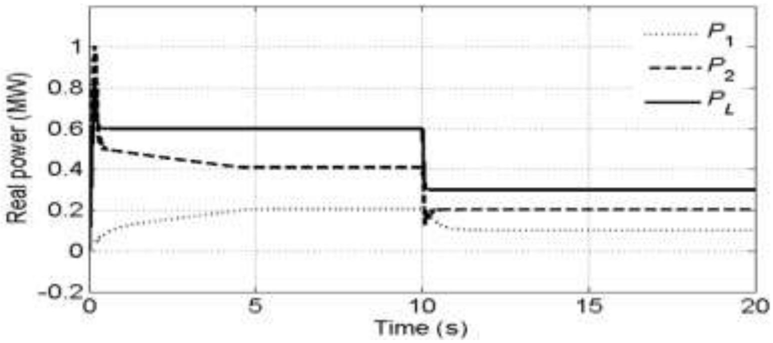

Figure 8 Load sharing among Inertial DG using Frequency droop control and Non-inertial DG using Angle droop control in Test system-B

Table 3 Summary of results of load sharing among DG units in different test systems

	Test system- A			Test system- B			Test system- C		
	P_{DGEN1}	P_{DGEN2}	P_L	P_1	P_2	P_L	P_1	P_2	P_L
Load Sharing (kW) before load variation	125	225	350	130	70	200	200	400	600
Load Sharing (kW) after load variation	170	330	500	100	50	150	100	200	300

2 Synchronization of Non-dispatchable DG units with microgrid

An autonomous hybrid microgrid can contain both inertial/non-inertial and dispatchable/non dispatchable DGs. For the interconnection of a DG unit with microgrid, any one of the following two choices can be selected

A) Synchronization B) Isochronous operation

A non-dispatchable source generates electrical energy but cannot be turned on or off in order to meet fluctuating electricity needs. It is the opposite of dispatchable sources of electricity which are very flexible, being able to change their output fairly quickly in order to meet electricity demands. Non-dispatchable electricity sources are often highly intermittent, which means that they are not continuously available due to factors that cannot be controlled (e.g. weather). There are many different types of non-dispatchable sources such as Tidal power and Wave power [1] but two main types that contribute noticeably to the electrical grid are Solar power and Wind power.

2.1 Interconnection of Wind Energy Conversion System (WECS) with microgrid

The schematic diagram of wind energy conversion system (WECS) connected with a grid is shown in Figure 9.

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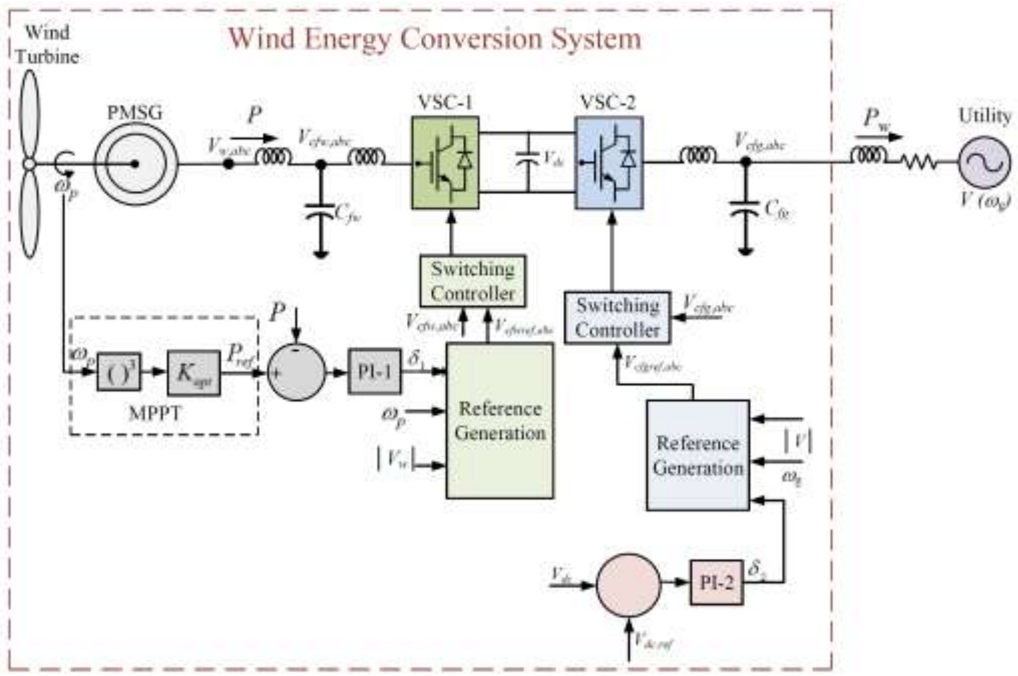

Figure 9 Schematic of WECS interconnected with utility grid

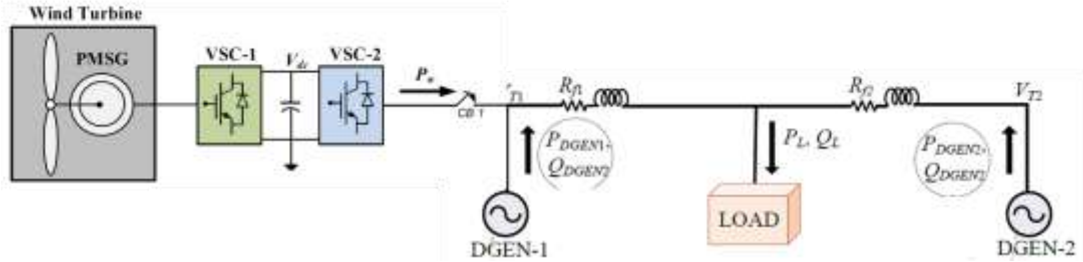

Figure 10 Schematic of WECS integrated with microgrid Test system-A

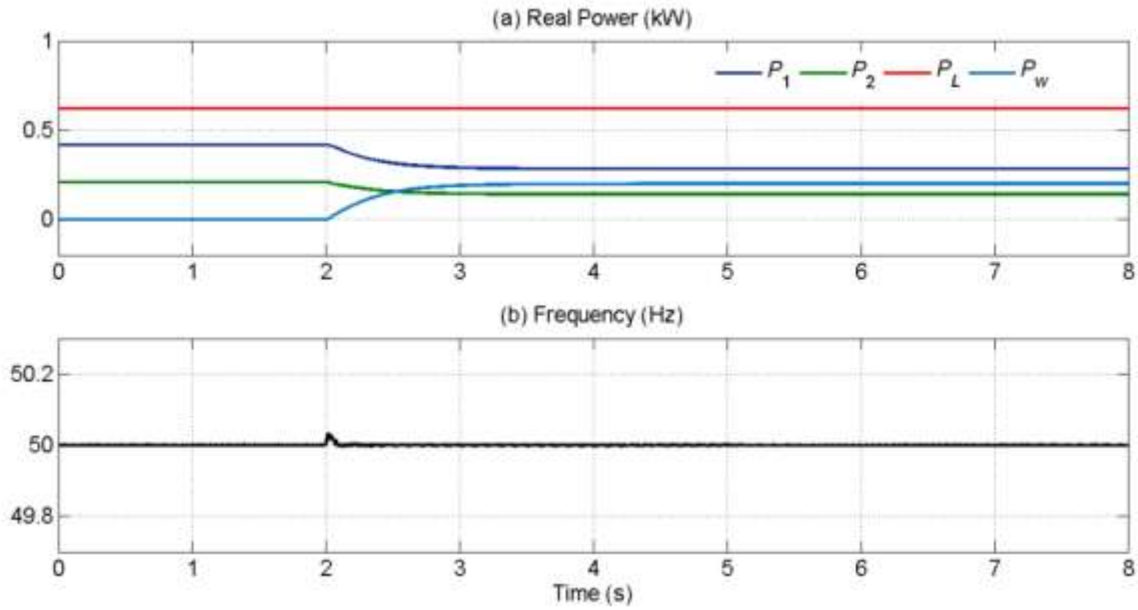

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Figure 11 Real power flows in microgrid with WECS (switched @ 2s) and microgrid frequency without considering load variations

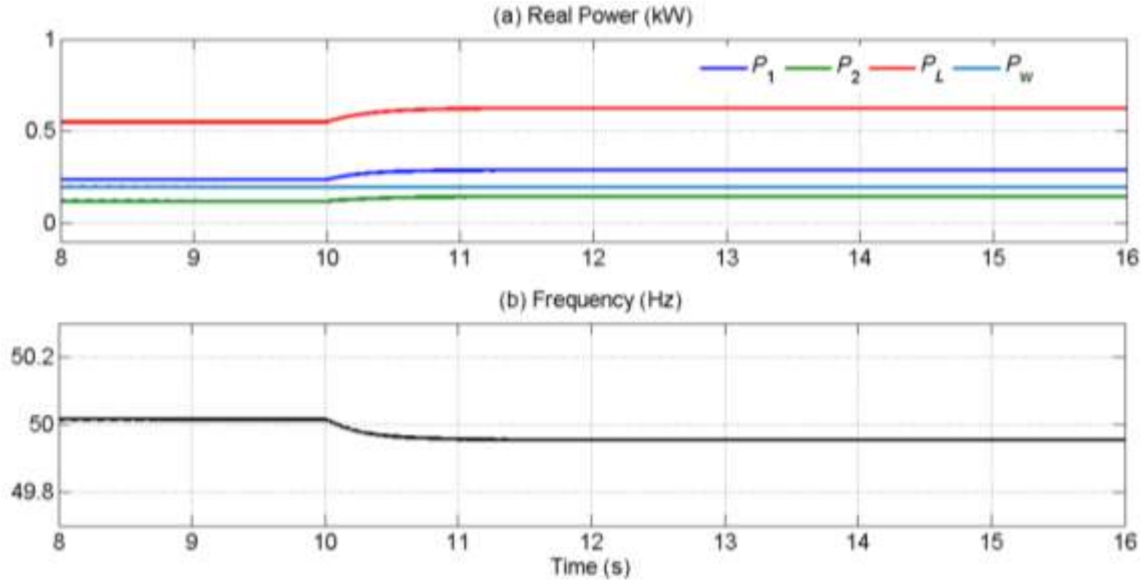


Figure 12 Real power flows in microgrid with WECS (switched @ 2s) and microgrid frequency with considering load variations

2.2 Interconnection of Photo Voltaic Conversion System (PVCS) with microgrid

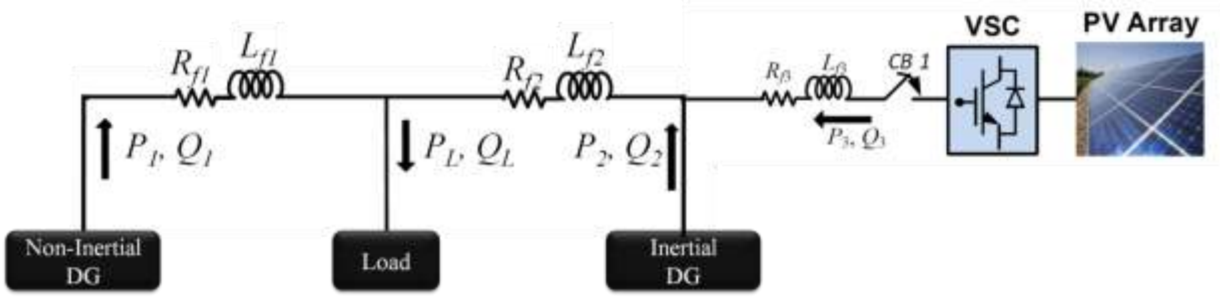


Figure 13 Schematic of PVCS integrated with microgrid Test system-B

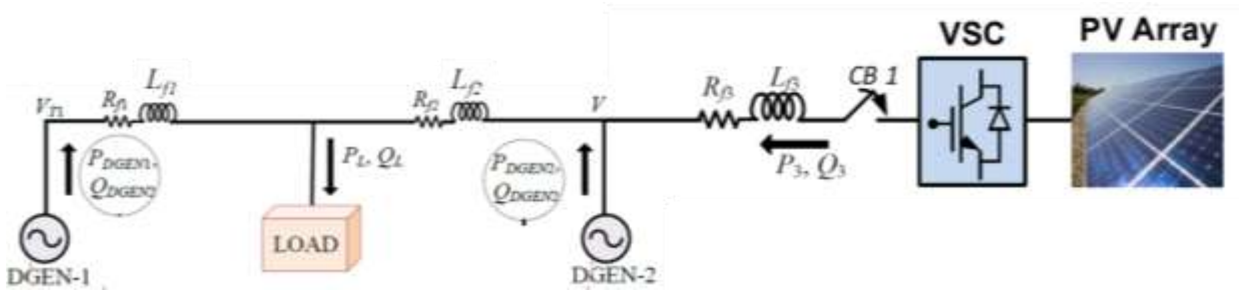
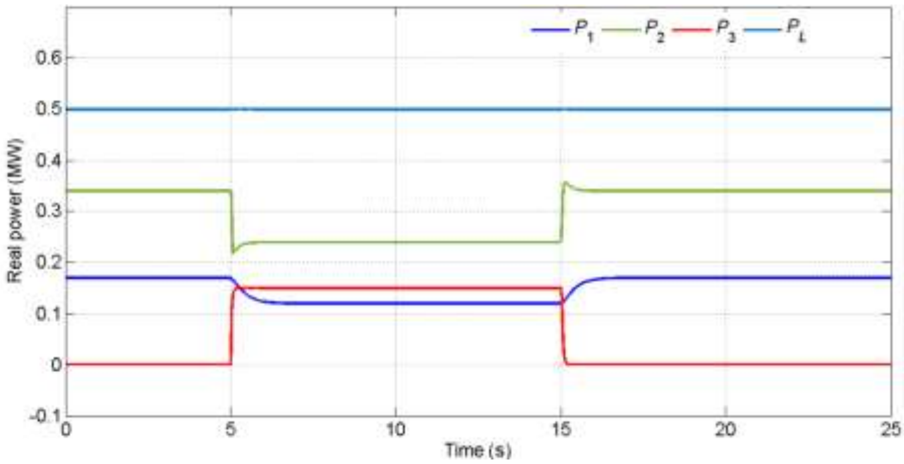


Figure 14 Schematic of PVCS integrated with microgrid Test system-A

a)



b)

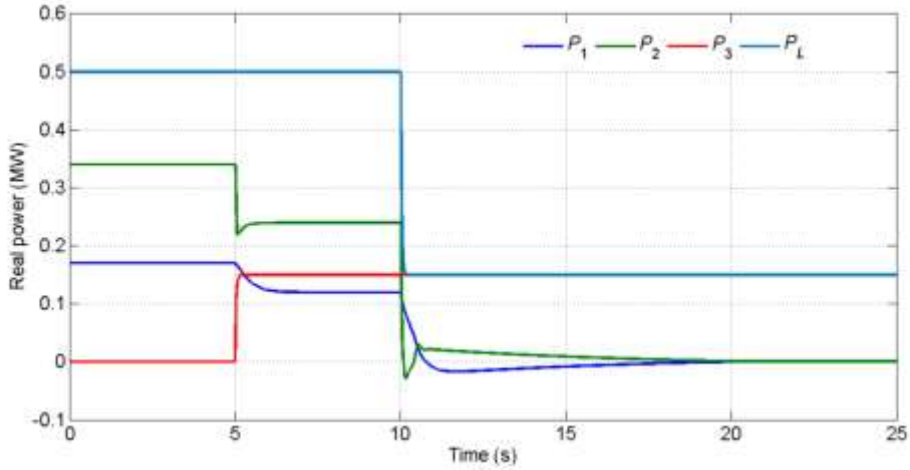


Figure 15 Real power flows in microgrid with PVCS (switched @ 5s) a) without considering load variations b) with considering load variations

3 Reliability enhancement strategies for autonomous hybrid microgrid

For an autonomous hybrid microgrid, to maintain reliability and to prevent overloading of existing DG units (if total demand plus losses exceed the combined available power of all DG units then overloading can occur) methods like resizing of DG units and load shedding strategies are not preferable. Thus integration of Battery energy storage systems is a viable option to maintain reliability of islanded microgrid.

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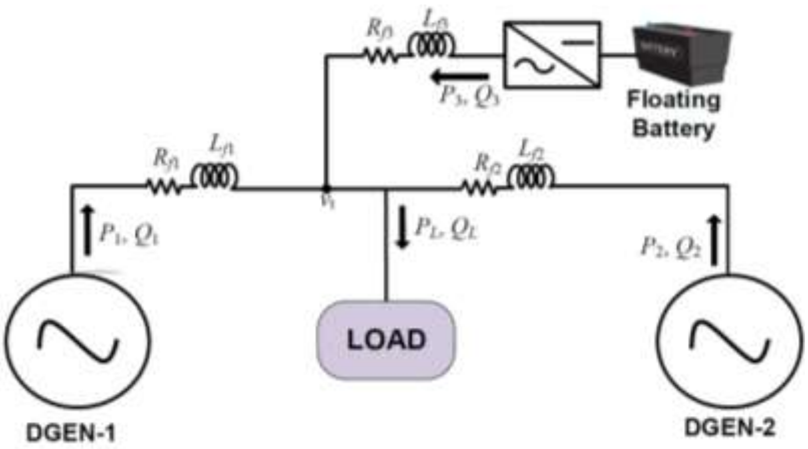

Figure 16 Structure of autonomous hybrid microgrid (Dispatchable DG units) with BESS

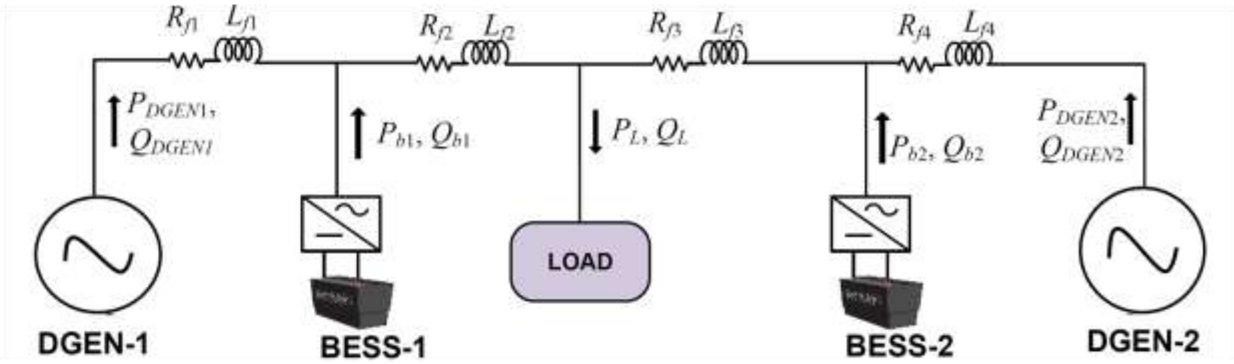

Figure 17 Structure of autonomous hybrid microgrid (Non-dispatchable DG units) with BESS

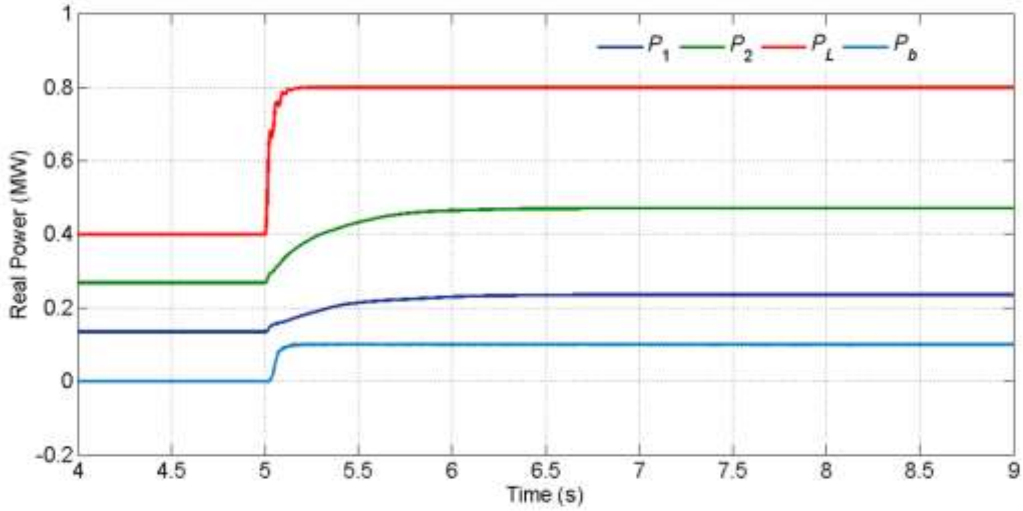

Figure 18 Real power flows of autonomous hybrid microgrid with BESS considering load variation @ 5s

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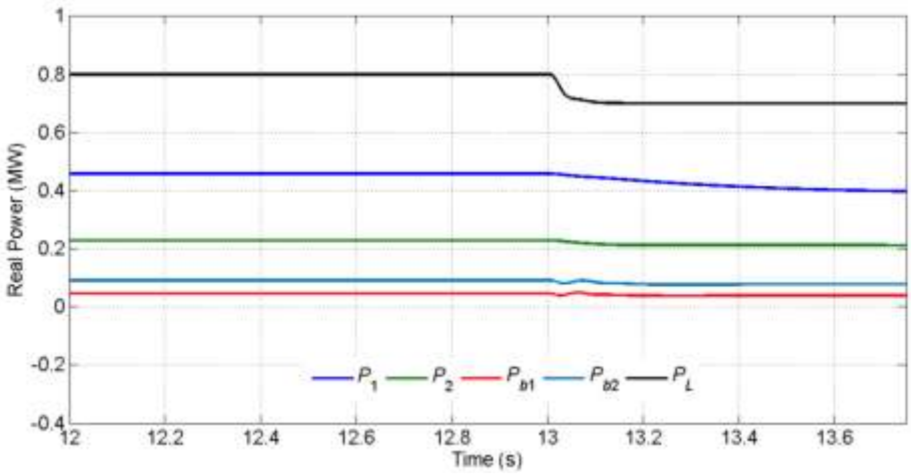

Figure 19 Real power flows of autonomous hybrid microgrid with BESS considering load variation @ 13s

Table 4 Summary of results of real power flows through microgrid with BESS units

	Micro grid with 2 dispatchable DG units & 1 BESS unit				Micro grid with 2 Non- dispatchable DG units & 2 BESS units				
	P_1	P_2	P_B	P_L	P_1	P_2	P_{B1}	P_{B2}	P_L
Load Sharing (kW) before load variation	100	300	0	400	440	210	50	100	800
Load Sharing (kW) after load variation	210	440	150	800	400	200	30	70	700

4 Reliability enhancement through integration of various autonomous microgrids

Microgrids installation can be beneficial in remote locations where there is no provision of tapping from existing high voltage line or where drawing such lines is not economically feasible. A microgrid in such locations is expected to operate in autonomous mode. To maintain reliability in such scenarios, when there exist two microgrids in close proximity, they can be interconnected together through a back to back converter such that each can nominally operate independent of other.

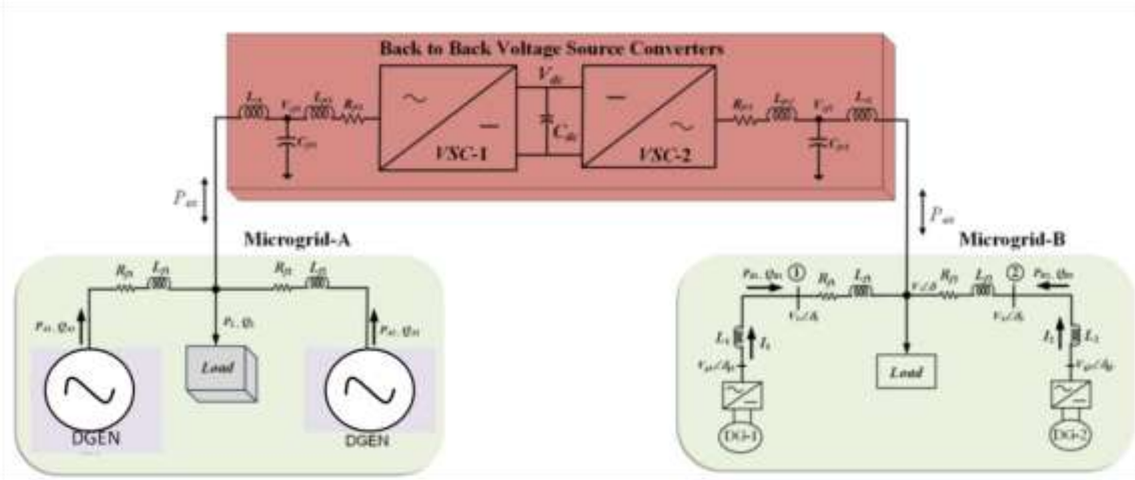

Figure 20 Two microgrids interconnected together through a back to back converter

The back to back converter system comprises two VSCs – VSC-1 and VSC-2. VSC-1, connected to Microgrid-A, holds the dc capacitor voltage (Vdc) constant by drawing power from MG-A through angle control. VSC-2, which is connected to Microgrid-B, controls the power flow in either direction. For this, it needs the information of operating status of all DGs in microgrid (e.g. the ON/OFF status of their coupling circuit breakers).

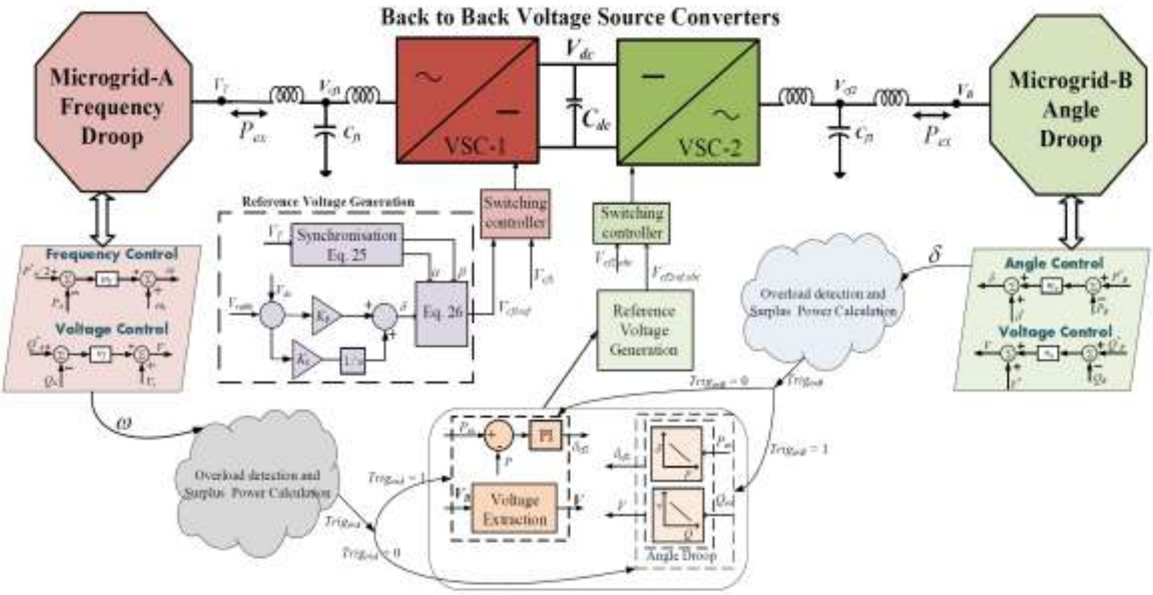

Figure 21 Schematic showing control strategies of interconnected microgrids

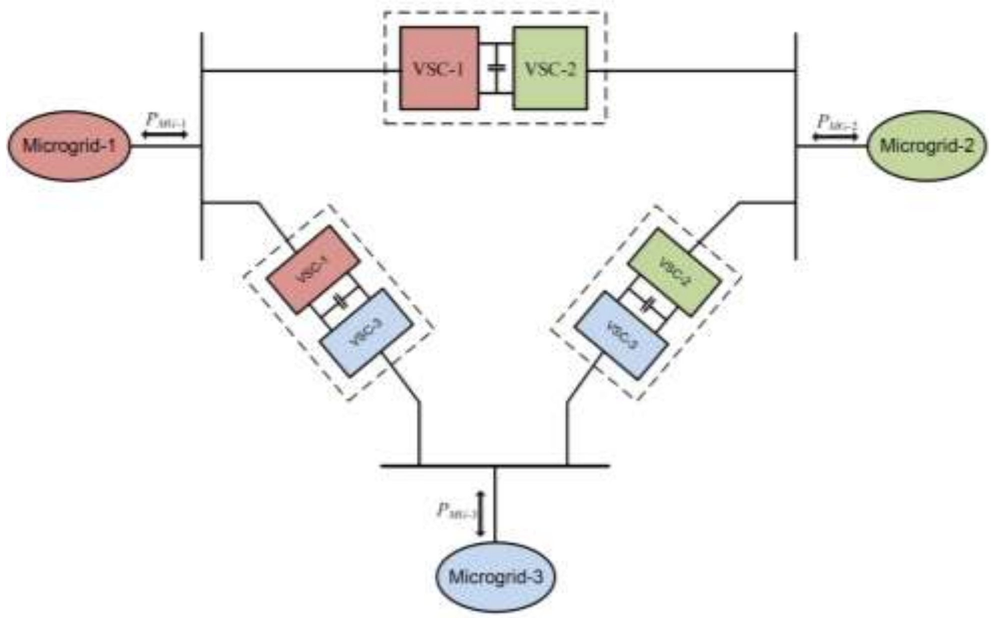

Figure 22 Three microgrids interconnected through back to back converters

In figure 22, each microgrid is interconnected through a back to back converter to exchange power between them during situations of contingency. The operation of the back to back converter can be the same as discussed above for two interconnected microgrids. However, there may be several microgrids that need to be interconnected. Thus direct back to back connection is not always feasible. A cluster of microgrids can be interconnected through common ac feeder to support during contingency in any microgrid. Each microgrid in such a cluster must be connected through an interlinking converter such that each microgrid can operate independent of all other microgrids.

Conclusions

A microgrid containing inertial and non-inertial generators, the difference in their time responses can lead to large transient oscillations. To avoid this, the response speed of converter interfaced generators can be made slower using the virtual inertia concept that imitates a governor action, as well as includes a swing equation. Load sharing among inertial and non-inertial DG units has been demonstrated through graphs. For the interconnection of non-dispatchable DGs with an autonomous microgrid that is operating in a frequency droop, two strategies can be employed. One of these strategies includes a synchronization algorithm, which requires only the instantaneous measurements of bus voltages. In the other strategy, an isochronous controller can be integrated with frequency droop control such that the system operating frequency always remains at 50 Hz. The real power flows and frequency deviations during synchronization of non-dispatchable DG units have been explained through waveforms considering the load variations. Energy storage devices (e.g. BESSs) are required to prevent collapse in an autonomous microgrid due to an overload and to maintain reliability of the system. Various strategies to enhance the reliability of the autonomous hybrid micro grid structures have been discussed.

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