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Refined Hybrid Microgrid Architecture for the Improvement of Voltage Profile

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Abstract

Hybrid microgrid is emerging as a flexible and modular solution that integrates various heterogeneous energy resources and loads. This conventional hybrid microgrid architecture can also reduce the number of power conversion stages, when compared to other architectures of microgrid such as, centralized DC bus and centralized AC bus architectures. But, these conventional hybrid microgrid architectures are having poor fault tolerant capacity that leads to severe power imbalances in the microgrid system. With this aspect, this paper propose the refined hybrid microgrid architecture that can handle system uncertainties and improves the voltage profile. The proposed refined hybrid microgrid architecture consists of two layers (AC layer and DC layer) through which each and every constituent of the microgrid is connected. This provides continuity in power supply to the microgrid loads via the possibility of bi-directional power flow between AC layer and DC layer. The proposed architecture is simulated using MATLAB/Simulink®. From the results, it is observed that, this proposed refined hybrid microgrid architecture improves the voltage profile of the system during faults.

1. Introduction

Microgrid has appeared as an attractive for integration of renewable energy sources in the distribution networks which has advantages in terms of reliability and power quality. Therefore, microgrids are a suitable, reliable and clean

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solution to use local generation and also to the utility grid. Microgrids are present in different architectures based on AC and DC systems. They are AC microgrid, DC microgrid, hybrid microgrid. In AC microgrid [1] only AC main bus was exist which is connected with a utility grid through a PCC; sources, loads are connected to AC bus. An AC microgrid with DC storage was presented in [2], which has separate DC storage. In DC microgrid only DC main bus was exist which is connected with a utility grid [3], sources, loads are connected to DC bus. DC zonal microgrid architecture also presented in [4]. It has DC zonal busses are connected to a main AC bus.

The combination of AC and DC microgrid forms hybrid microgrid, [5], [6]. The AC and DC buses separated by an AC-DC bi-directional interlinking converter. The AC sources and loads are connected to AC bus through a transformer, DC sources and loads are connected to DC bus through a DC-DC converter. The battery storage system also connected to DC bus through a DC-DC bidirectional converter. The conventional hybrid micro grid is shown in Fig. 1, in which red colored line represents DC power flow and blue colored line represents AC power flow. A solid state transformer (SST) based microgrid system was presented in [7]. SST has a converter and high frequency transformer which provides power to AC and DC buses. AC and DC source, loads are connected to corresponding buses through a proper converter.

The conventional system was implemented based on [8-12]. Loads and sources are connected to either AC (or DC) bus through a bidirectional converter. The control logic and design of bidirectional converter was developed using [13]. The AC, DC filter specifications and design model was discussed in [14]. The integration of renewable energy sources to microgrid are discussed in [15, 16].
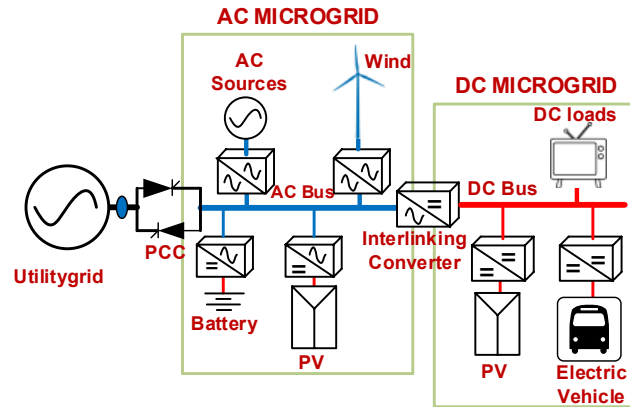

Fig. 1. Conventional microgrid architecture [5, 6].

The main drawback of a conventional hybrid microgrid architecture given in [5, 6] are:

- Power conversion losses ranges from 8-12% because of power electronic converters [17].
- If any fault occurred in AC (or DC) bus the fault part of DC (or AC) system is isolated from main system.
- Power imbalance in system because of weather conditions, i.e., PV generate DC power in daytime and wind generate AC power in presence of wind flow.
- In island operation, the difficulty in control of interlinking converter because of droop characteristics.

This paper presents a novel two bus hybrid microgrid architecture design for reliable power distribution system by considering the drawbacks of conventional hybrid microgrid structure. The main contribution of this paper are:

- Design of two bus/layer hybrid microgrid architecture.
- Design of a converters suitable for the proposed architecture.
- Control scheme for the inverter which is switches between AC and DC buses.
- Comparison of proposed architecture with existing architecture.

2. Proposed two bus hybrid microgrid architecture

2.1. Description of proposed two bus hybrid microgrid architecture

Fig. 2 shows the proposed hybrid microgrid architecture, which has a red line represents AC bus, green line represents a DC bus, which connects to every equipment (both AC and DC). The DC bus in this system considered as 'hot line', which provides a continuous power supply to loads in presence of various weather conditions, load disturbances, island operation and grid uncertainty. The AC and DC busses are connected to utility grid through a SST or multiport transformers providing power to both DC and AC lines and also allows bidirectional power flow, which was discussed in [18]. DC sources are connected to DC and AC buses through DC-AC/DC converter. AC source connected to DC and AC buses through AC-DC/AC converter. Loads are connected to corresponding buses through converters, which reduces the power conversions. Battery storage system is connected to AC and DC busses via DC-AC/DC bi-directional converter, which charges during grid connected mode or excessive power in the system and discharges during island mode. The control schemes are designed for DC-AC/DC converter for a battery in such a way that it is capable to deliver/consume power from any one of the bus or from both. The interlinking converter is located in between AC and DC buses for controlling power balance and energy management. Supervisory control is designed by connecting the local converters through a control line, for different operating conditions.
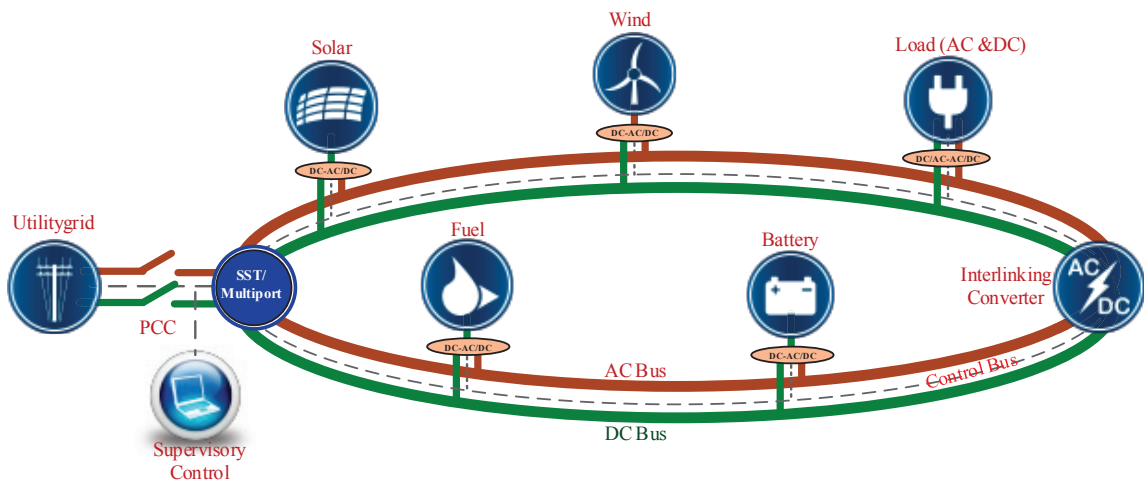

Fig. 2. Proposed two bus hybrid microgrid architecture scheme for proposed architecture

2.2. Control of proposed 2-bus hybrid microgrid architecture

The constituents (loads and sources) of proposed microgrid are connected to both AC and DC busses. Because of this, loads are always connected to sources through one of the bus (AC/DC) for fault on other bus (DC/AC), which is not the case always, in case of conventional microgrid architecture which is having single centralized bus. Different converter designs for different constituents are shown in Fig. 3. These are connected to both the busses through breakers.

From DC bus, breakers SP, SB, SD, SLD are connected to solar, battery, utility grid and DC loads respectively. From AC bus breakers SW, SA, SLA are connected to wind, grid and AC loads respectively. The following equation (1) is the objective function for the operation of the proposed architecture, where P is the generating power in which U is the utility and i, j are the represents solar and wind or combination of both, B represent battery, P_L represents load and x, y are represents either AC or DC or combination of both.

$$P_U + P_i + P_j \pm P_B > P_{Lx} + P_{Ly} \tag{1}$$

The equation (1) represents power balance objective function. The power balance is achieved by connecting source and loads to corresponding buses with different switching combinations. The possible switching combinations are shown in Table. 1.
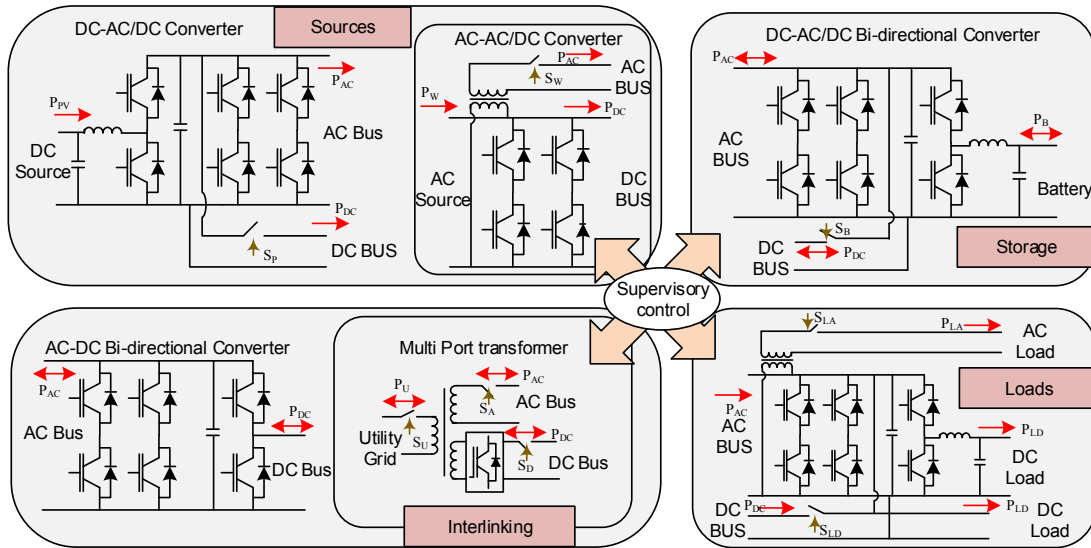

Fig. 3. Converters design for proposed microgrid architecture

Table 1. Switching combinations in different conditions

Mode No.	Description	Status	Grid-Connected Mode		Islanded mode	
			AC Loads	DC Loads	AC Loads	DC Loads
Mode-1	Only PV generation	ON	S_U, S_A, S_{LA}	S_U, S_D, S_P, S_{LD}	S_A, S_{LA}	S_D, S_P, S_B, S_{LD}
Mode-2	Only wind generation	ON	S_U, S_A, S_W, S_{LA}	S_U, S_D, S_{LD}	S_A, S_W, S_{LA}	S_D, S_B, S_{LD}
Mode-3	Only battery	ON	S_U, S_A, S_{LA}	S_U, S_D, S_B, S_{LD}	S_A, S_{LA}	S_D, S_B, S_{LD}
Mode-4	PV+ Wind	ON	S_U, S_A, S_W, S_{LA}	S_U, S_D, S_P, S_{LD}	S_A, S_W, S_{LA}	S_D, S_P, S_B, S_{LD}
Mode-5	PV+ Battery	ON	S_U, S_A, S_W, S_{LA}	S_U, S_D, S_P, S_{LD}	S_A, S_{LA}	$S_D, S_B, S_{P,} S_{LD}$
Mode-6	Wind+ Battery	ON	S_U, S_A, S_W, S_{LA}	S_U, S_D, S_B, S_{LD}	S_A, S_W, S_{LA}	S_D, S_B, S_{LD}
Mode-7	PV+ Wind+ Battery	ON	S_U, S_A, S_W, S_{LA}	S_U, S_D, S_B, S_{LD}	S_A, S_W, S_{LA}	S_D, S_B, S_P, S_{LD}

3. Performance analysis

In order to test the proposed system, performance analysis is done by considering different indices mentioned as follows.

1. Frequency deviation during different fault conditions,
2. Load voltage profile during different fault conditions, and
3. Voltage profile under sudden load changes.

The conventional and proposed hybrid microgrid architectures are tested and compared by conducting simulations in MATLAB/Simulink with respect to the simulation parameters shown in Table. 2.

Table 2. Simulation parameters for modeling the conventional and proposed hybrid microgrid systems

Parameter	Value	Parameter	Value
Grid		Transformer	
Phase-phase rms voltage	11kV	Nominal power	500kVA
3-phase short-circuit level	200MVA	Primary voltage (Vrms ph-ph)	11kV
Base voltage (Vrms ph-ph)	11kV	Secondary voltage (Vrms ph-ph)	415V
X/R ratio:	10	Nominal frequency	50Hz
Wind capacity	10kW	Primary & Secondary resistance	0.02pu
Solar capacity	10kW	Primary & Secondary inductance	0.08pu
Battery capacity	415V*30Ah	DC filter	
DC loads	5kW	Series resistance, inductance	0.03Ω, 6mH
AC load		Parallel Capacitance	100μF
Nominal phase-to-phase voltage	415V	AC filter	
Nominal frequency	50Hz	Series Resistance	0.02Ω
Active power	33.2kW	Series Inductance	4.5mH
Inductive reactive power	24.9kVAR	Parallel Capacitance	1000μF

3.1. Fault tolerant analysis of proposed and conventional microgrid systems

The 3-phase fault, line-line-ground (LLG) fault, line-line (LL) fault and line-ground (LG) fault are created on AC bus at the instant of 0.4 sec and cleared at 0.8 sec. The fault duration was 0.4 sec. The corresponding frequency plots of conventional and proposed hybrid microgrid architectures are shown in Fig. 4. The main observations are listed below. The overall performance analysis is tabulated in Table. 3.

Table 3. Performance of conventional and proposed system with different faults on AC bus

Type of Fault	Max frequency deviation (Hz)		Voltage at AC bus during fault (pu)	
	Conventional	Proposed	Conventional	Proposed
3 phase fault	0.28	0.19	0.01	1.0
LLG fault	0.21	0.17	0.35	1.0
LL fault	0.20	0.16	0.5	1.0
LG fault	0.19	0.15	0.65	1.0

Observations

- During fault, frequency deviation of the proposed microgrid system is very less i.e., in the range of ± 0.05 Hz. As per the standards of the Indian utility power grid allowable frequency tolerance should be ± 2% for 50 Hz frequency [16].
- At fault instant, conventional microgrid system has more frequency deviation due to the disconnection of loads on AC bus from supply. But, in the proposed microgrid system loads on AC bus are transferred to DC bus after fault instant and again transferred to AC bus when fault was cleared.
- During switching (fault ON and clearing instants) proposed microgrid system reaches to its steady state in a very less time.
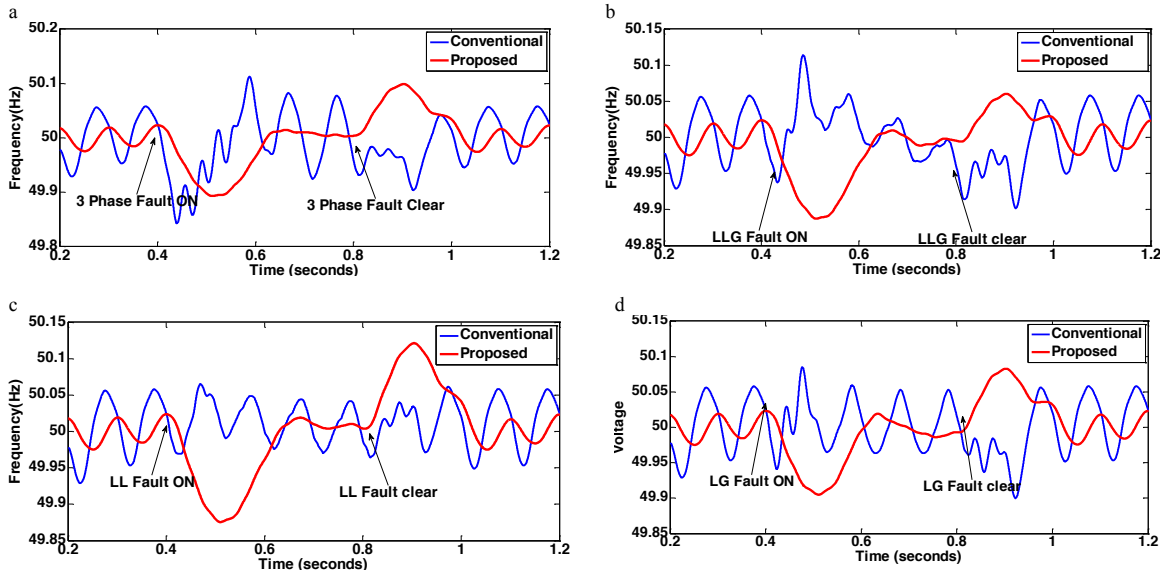
Fig. 4.   Frequency deviation during (a) 3-phase fault (b) LLG fault (c) LL fault (d) LG fault

3.2. Voltage profile under fault conditions

The voltage profile of conventional and proposed microgrid systems are monitored by creating different types of faults on AC bus and results of both the systems are compared using per unit load voltages. Fig. 5 shows the per unit load variations of conventional and proposed microgrid systems under different fault conditions (LL, LLG, LG, 3-phase faults).
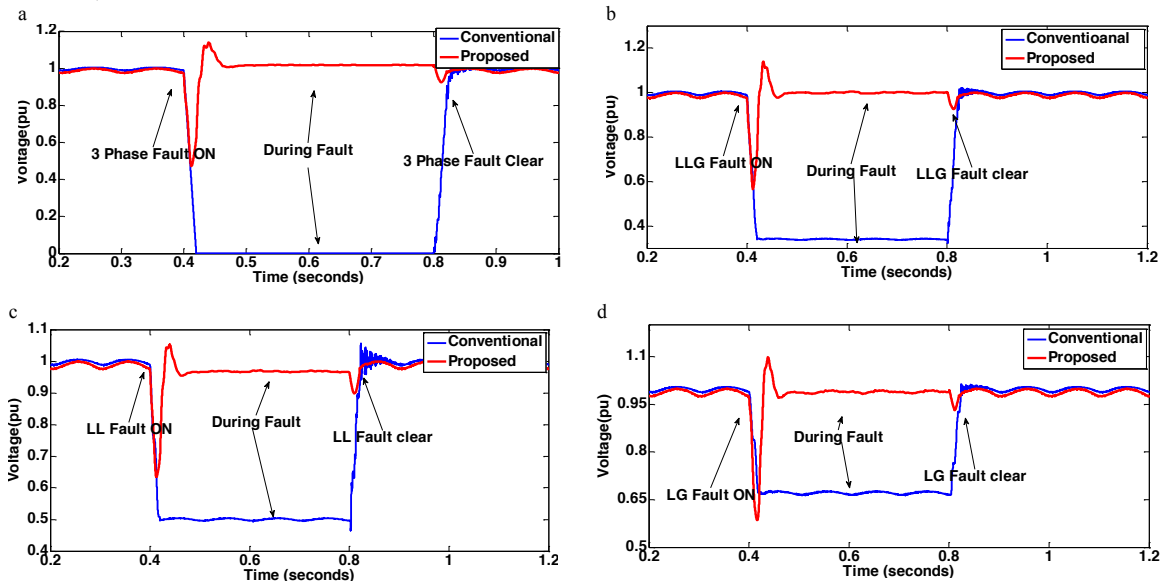

Fig. 5.   Voltage profile during (a) 3-phase fault (b) LLG fault (c) LL fault (d) LG fault

Observations

- The positive sequence per unit load voltage of the proposed microgrid system remained same during any fault condition.
- The conventional microgrid system per unit load voltage is less than base voltage and varies according to type of faults.
- Because of sudden switching (AC to DC), the per unit load voltage is distorted and settled quickly in proposed microgrid system.

3.3. Voltage profile under sudden load changes

The large inductive and capacitive loads are connected to AC bus. The analysis is carried out by switching on inductive load during (0.5-1) sec and a capacitive load during (1.5-2) sec. The per unit voltage profile during sudden load variations are shown in Fig. 6. This analysis is performed based on ANSIC 84.1 [21].

Observations:

- Because of grid support, conventional and proposed systems have same voltage profile under sudden load changes.
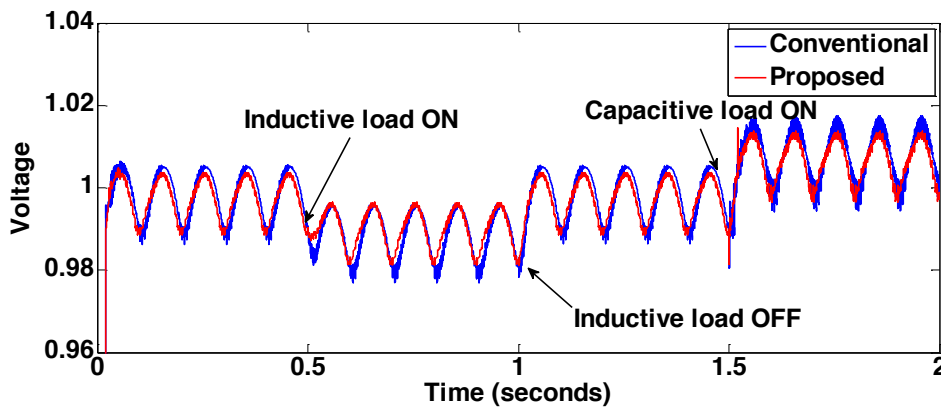

Fig. 6.   Voltage profile when sudden load changes

4. Case study

Consider the proposed and conventional microgrid systems, initially the source and loads are connected to respective buses. The proposed and conventional microgrid applications are observed by creating fault on following cases:

1. Fault on AC bus.
2. Fault on DC bus.

4.1. Case 1: fault on AC bus in grid connected mode

A fault is created on AC bus and it is inferred that in conventional system only DC loads will be operating as the AC bus i.e., zone 1 in Fig. 7(a) is islanded. Also DC bus i.e., zone 2 in Fig. 7(a) will provide power to loads based on the availability of DC source. Where as in proposed system, dotted line indicates the faulty bus as shown in Fig. 7(b), and it is noticed that there is no isolation of loads, as the loads are transferred to DC bus based on the control logic, thus providing the advantage of uninterrupted power supply. Fig. 8 shows the voltage at load bus in conventional systems under different fault conditions. Fig. 9 shows the voltage at load bus in proposed system.
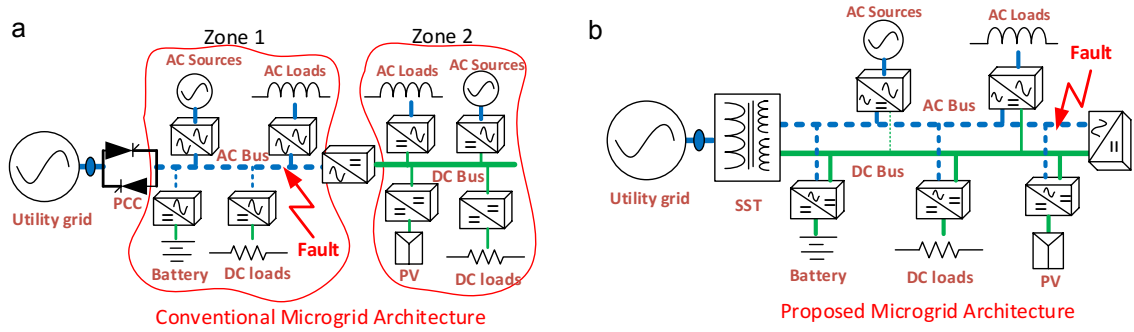
Fig. 7. Fault on AC bus of a) conventional hybrid microgrid b) proposed hybrid microgrid architectures
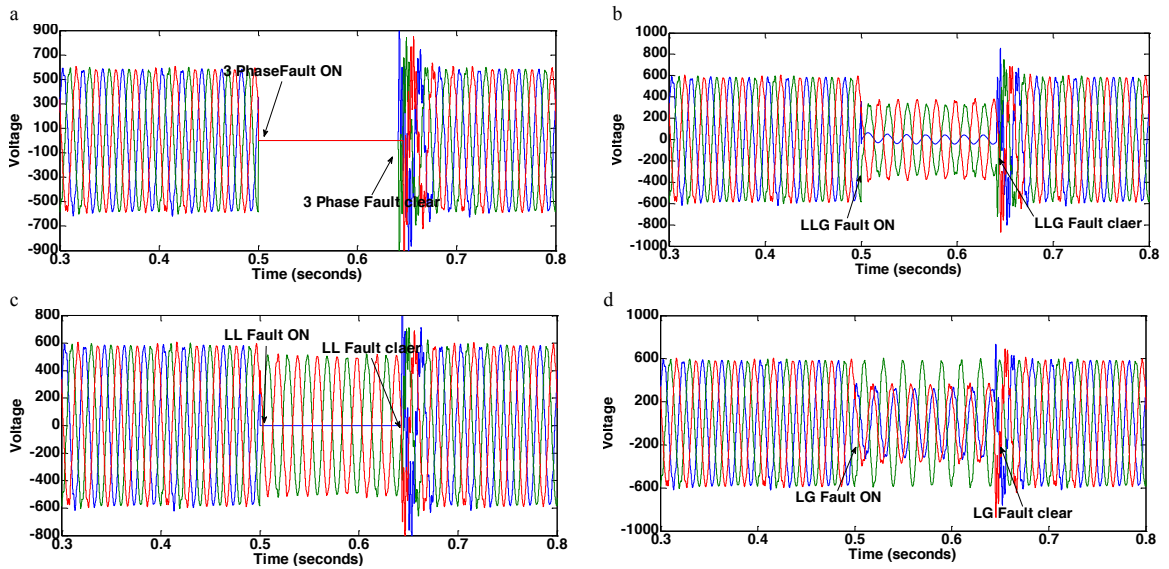

Fig. 8. Voltage at load bus in conventional microgrid system during (a) 3-phase fault (b) LLG fault (c) LL fault (d) LG fault
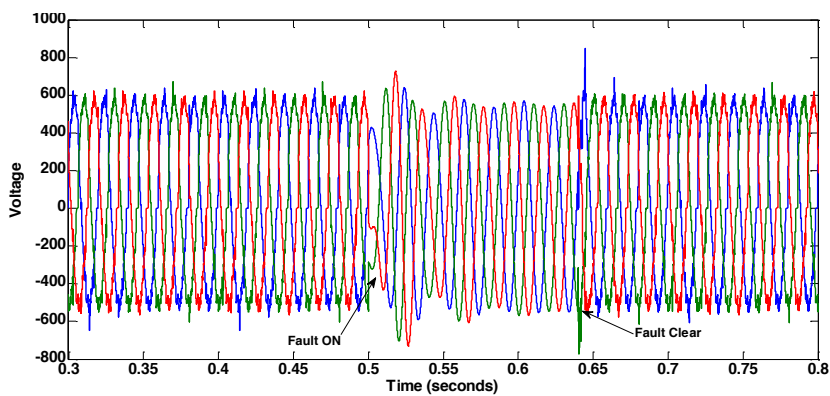

Fig. 9. Voltage at load bus in proposed microgrid system during all types of faults

4.2. Case 2: fault on DC bus in grid connected mode

Similar to the above case a fault is created on DC bus. As shown in Fig. 10(a), zone 2 indicates the faulted area and zone 1 is connected to utility grid which results in islanded mode operation of DC micro grid in conventional system. Whereas in proposed system, based on its control logic the DC loads located on DC bus and source are shifted to AC bus as shown in Fig 10(b). Even under this condition the proposed system is capable of delivering uninterrupted power supply. Simulation results for this case is presented in Fig. 11.
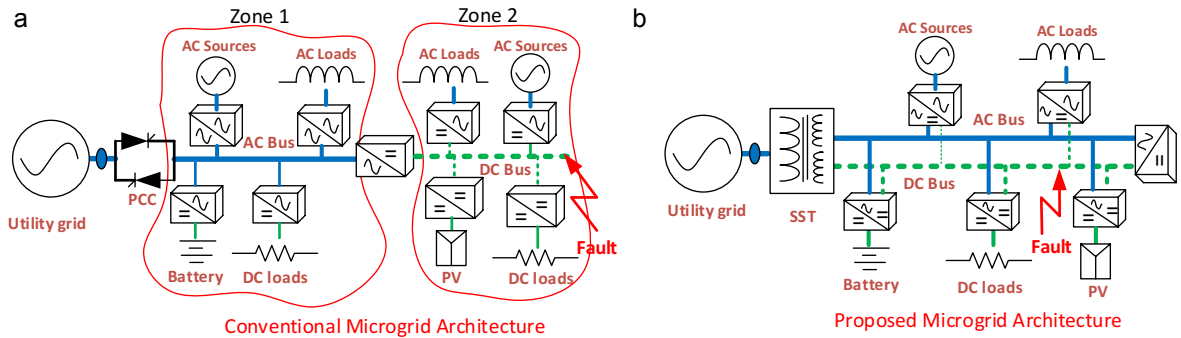

Fig. 10. Fault on DC bus of a) conventional hybrid microgrid b) proposed hybrid microgrid architectures
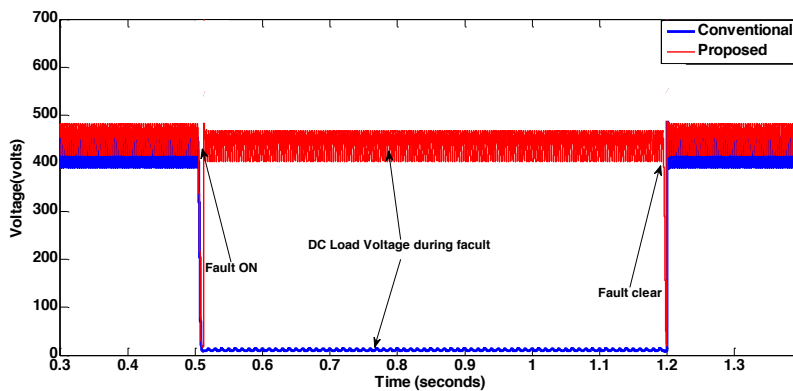

Fig. 11. DC load voltage during fault

5. Conclusion

Based on simulation results we can conclude that the conventional hybrid microgrid system has fails to supply power during fault conditions, it leads to uncertainty in microgrid. Whereas, proposed two bus hybrid microgrid architecture provides an uninterrupted power supply to loads even during the fault conditions. The proposed system is capable in resolving the uncertainties in voltage profile, as it is capable of delivering power under all conditions this system is fault tolerant. Even though more number of power converters present in a system, it results in a better voltage profile because of sources and loads in microgrid are connected to the corresponding buses.

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