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Research Paper

ANALYSIS OF GRID CONNECTED SYSTEM WITH TWO INTERCONNECTED MICROGRIDS

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Easy electrification of remote areas and the necessity for solving global warming problems by reducing carbon dioxide emissions in the electricity generation field has led to an increase in the interest in Micro-Grids (MGs), especially the one which includes renewable sources. This paper deals with the analysis of two interconnected micro-grids powered by PV, with one microgrid connected to the main grid. Load characteristics of both MGs are analyzed during and subsequent to different types of faults under different load conditions of the two MGs. Frequency deviations are analyzed with and without interconnection. It was observed that one MG can get power from the nearby MG if any failure occurs in the former one and vice versa. All the components and micro sources installed inside the two MGs are modeled in detail. All micro source models and controllers are built in the Matlab-Simulink environment.

Keywords: Photovoltaic models, Interconnected micro-grids, Frequency deviation analysis

INTRODUCTION

In remote places electrification from main grid is not easy. The need for reduction of carbon dioxide emissions in the electricity generation field, the recent technological developments in the micro-generation domain as well as electricity business restructuring, are the main factors responsible for the growing interest in the use of micro-generation leading to Micro-Grids (MGs). Energy investors and utility operators are attracted to the micro-grid because of its long life. Besides assisting in the reduction of the emission of greenhouse gases, they add the much needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. On the other hand, deregulation of the electric utility industry is providing an opportunity for higher penetration and use of Distributed Resources (DR). Distributed resources are generation sources that can be located at or near loads. Distributed resources can provide benefits that bulk power generation cannot. Photovoltaic systems are ideally suited for distributed

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resource applications. PV systems produce DC electricity when sunlight falls on the PV array, without any emissions (Buciarelli *et al.*,1980; Mutoh and Ohno, 2006; Femia *et al.*, 2008; Abo-Khalil and Dong-Choon Lee, 2008; Gules *et al.*, 2008; Sera *et al.*, 2008; and Scarpa *et al.*, 2009). The DC power is converted to AC power with an inverter and can be used to power local loads or can be fed back to the utility. The PV systems can be grouped depending on the scheme of interaction with utility grid as grid connected, stand alone, and hybrid. Distributed Generators (DGs) installed inside the MG can be fuelled by locally available renewable resources and an alternative mix of fuel sources (Georgakis *et al.*, 2004). Greater independency from importing petroleum fuel can be achieved by incorporating a MG that is powered by various fuel sources. MGs can support future increase in demand without investment in expansion of the existing distribution networks, by installing it very close to the new load centers. MGs can contribute to a reduction in intermittent and peak supply burdens on the utility grid by injecting power during peak periods. In this work MGs are intended to operate in the following two different operating conditions, normal interconnected mode or in the islanding mode (Katiraei *et al.*, 2005; and Lopes *et al.*, 2006).

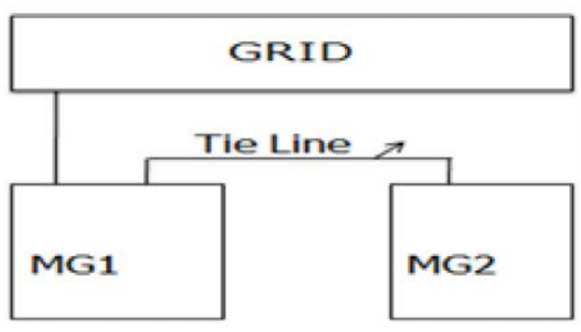
New micro source technologies (e.g., micro gas turbines, fuel cells, photovoltaic panels and several kinds of wind turbines) used in MG are not suitable for supplying energy to MG directly. They have to be interfaced with the MG through inverters. Thus, use of power electronic interfacing techniques in the MG leads to a series of challenges in the design and operation of MG (Caldon and Turri, 2003; and Georgakis *et al.*, 2004). In this present work, analysis of grid connected system with two interconnected micro-grids has been done (Kamel and Nagasaka, 2009a and 2009b; Kamel and Karmanshahi, 2010; and Rashad Kamel *et al.*, 2011) by modeling the micro-grid in Matlab/Simulink environment.

PROPOSED SYSTEM

Figure 1 shows the block diagram of the proposed system, which includes two interconnected micro grids, with one of the MG connected to the main grid. First Micro Grid (MG1) is having one PV generator and battery as micro generators. Second one is having two PV generators.

Since two micro grids are interconnected, one can supply power to the other if there is any power deficit due to failure of any micro source in the MG. MGI can also be synchronized to the main grid using a switch. If any fault occurs simultaneously in both the micro grids, grid will supply power to the loads of both the micro grids. Load characteristics of the above system are analyzed for different types of faults on both MGs. The analysis of frequency deviation before and after

Figure 1: Block Diagram of the Proposed System



interconnection of the two micro grids has also been done.

MODELING OF THE PROPOSED SYSTEM

Modeling of the proposed system includes modeling of two microgrids (MG1 and MG2) and utility grid.

Modeling of MG1

MG1 contains two micro sources, one is a PV array and the other is a battery having a capacity of 3600 W. Photovoltaic array is simulated using the equations given below.

Module current,

$$I_m = I_{pH} - I_r * \left(e^{\frac{q*(V_c + I_m * R_s)}{(n*k*T_{mk})}} - 1 \right) \quad ...(1)$$

Reverse saturation current,

$$I_r = I_r - T_{rk} * \left(\frac{T_{ak}}{T_{rk}} \right)^{3/n} * e^{\left(-b*\left(\frac{1}{T_{ak}} - \frac{1}{T_{rk}} \right) \right)} \quad ...(2)$$

$$b = E_g * \frac{q}{n*k} \quad ...(3)$$

R = 0.05Ω, k = 1.381e-23, Boltzmann's constant

q = 1.602e-19, electron charge

n = 1.62, diode ideality factor

E_g = 1.12, band gap energy

N_c = 72, no of cells per module

$V_c = V_m/N$ voltage per cell

$$I_{pH} = G * I_{sc} \quad ...(4)$$

Since PV output voltage is a varying dc voltage, a dc-dc boost converter is used to regulate dc to a fixed dc. Since both the sources produce dc voltages, an inverter is used to convert dc to ac. Thus it can supply ac

Figure 2: Simulink Model of MG1

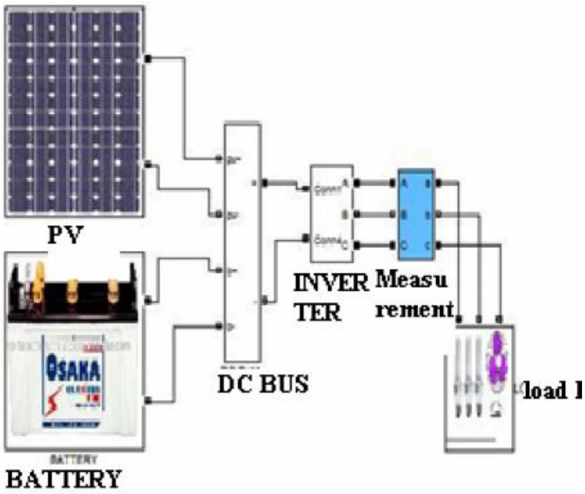
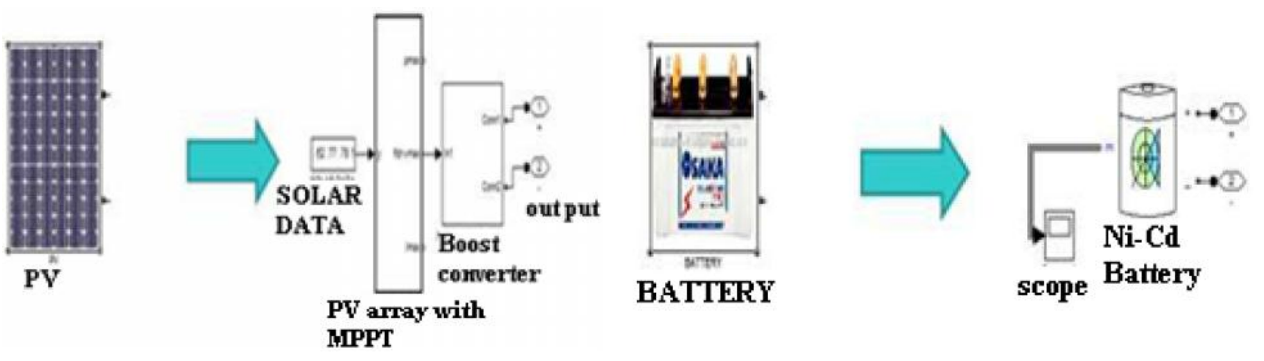


Figure 3: Subsystems in the Model of MG1



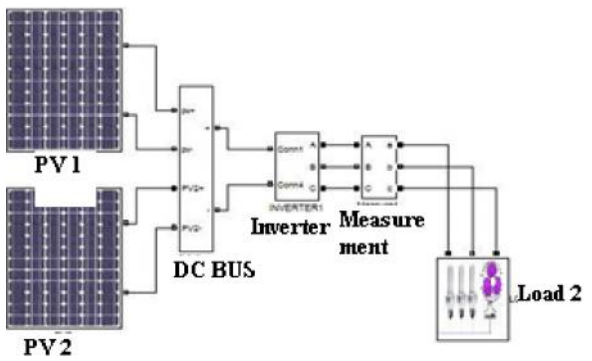
(a) (b)

as well as dc loads. The simulink model of microgrid 1 is given in Figure 2 and the two subsystems of MG1, the PV source along with a boost converter and a battery is shown in Figure 3.

Modeling of MG2

MG2 contains two micro sources, both are PV arrays (PV1 and PV2) of same capacity. MG2 is having capacity of 3300W. Simulink model of MG2 is given in Figure 4.

Figure 4: Simulink Model of MG2



Modeling of Utility Grid

An infinite bus having phase to phase voltage of 400 Vrms is considered as the grid. Simulink model of grid is shown in Figure 5. The simulink model of the proposed system is shown in Figure 6. In this MG1 and MG2 are interconnected and MG1 is connected to the utility grid. MG1 is having the capacity greater than that of MG2. Since they are interconnected, MG1 can supply power to MG2 if any fault occurs in MG2. If both the MGs fail, grid can supply loads on both MGs. Voltage and current characteristics of MG1 and MG2 at full load are shown in Figure 7.

Inverters in both the microgrids are controlled for getting a constant output voltage and transformer is used to step up this voltage

Figure 5: Simulink Model of Utility Grid

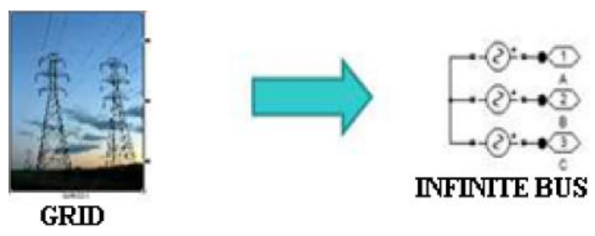


Figure 6: Simulink Model of the Proposed System

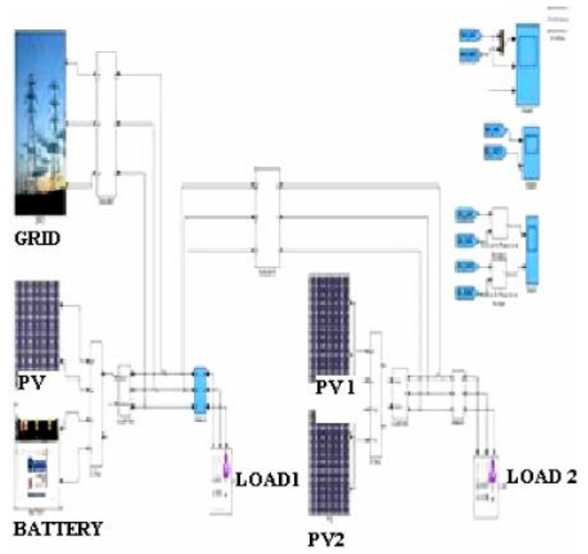
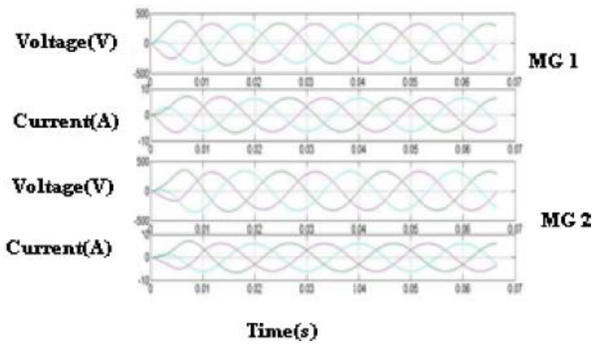
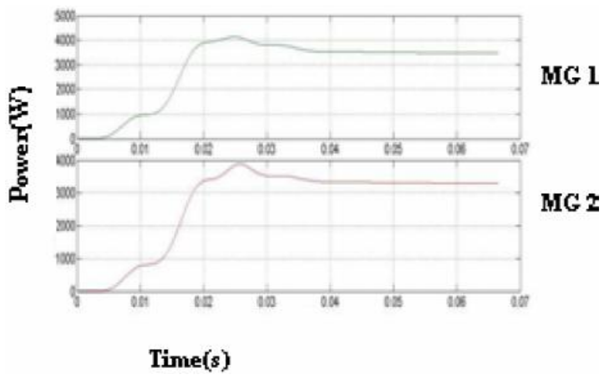


Figure 7: Voltage and Current Characteristics of MG1 and MG2 Respectively



to 350 Vpp as shown above. Power Vs time characteristics of MG1 and MG2 are shown in Figure 8. The powers obtained at this load are

Figure 8: Power Curve of MG1 and MG2 Respectively



3600 W and 3300 W respectively for MG1 and MG2.

RESULTS AND DISCUSSION

As a first stage of this work, only two microgrids (MG1 and MG2) were considered. Analyses have been done in these MGs for different types of faults with and without interconnection between them. For that inverter control has been done in both microgrids for varying loads.

Inverter Voltage Control

Simulink model of inverter voltage control in MG1 is shown in Figure 9. The voltage and current waveforms obtained from the above simulation are shown in Figure 10. It is observed that voltage remains unchanged with changing loads.

Analysis of MG1 and MG2 Load Characteristics with Faults

Load characteristics of MG1 and MG2 have been analyzed for different types of faults listed below.

Case 1: A three phase fault on load side of MG2.

Case 2: Failure of source of MG2.

Figure 9: Simulink Model for Inverter Voltage Control

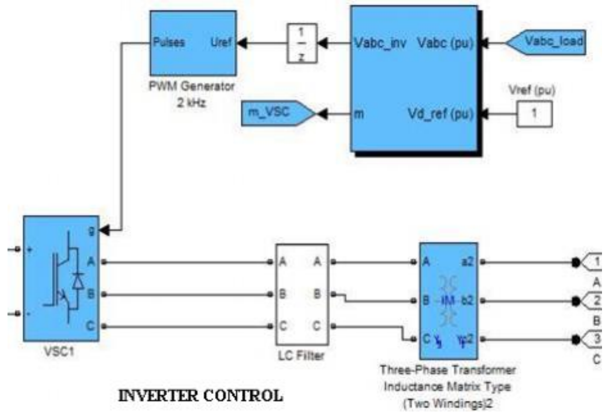
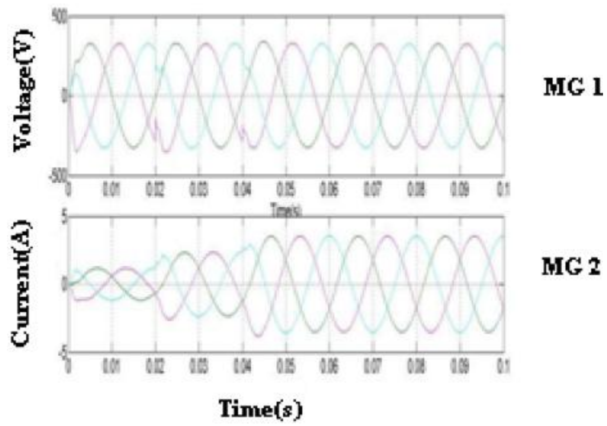


Figure 10: Voltage and Current Characteristics of Inverter



Case 3: Failure of inverter of MG1.

Case 4: Failure of 2nd source of MG2.

Case 5: Failure of source 1 of MG1.

By applying different types of faults to MGs, MG1 and MG2 have been simulated and load voltage, load current and power in MG1 and MG2 are plotted. Analysis with different faults is given in detail below. The analysis has been performed by considering only 55% of loads on both MGs.

Case 1: A three phase fault on load side of MG2

When a three phase fault occurs on load side, load should be isolated from the source as early as possible. Here a control signal is given to a three phase breaker in load side by sensing the load voltage. If rms value of voltage is below the full load rms voltage, breaker will open and the load is isolated.

Voltage Vs time characteristics of MG1 and MG2 are shown in Figure 11.

It is observed from Figure 11 that the load voltage of MG1 is constant. Since the fault is on the load side of MG2, the voltage on that load is getting reduced to zero even though MG2 was interconnected to MG1 at 0.03 sec, because the load on MG2 was isolated from the system.The load current characteristics of MG1 and MG2 are shown in Figure 12.

Since the load on MG2 was isolated from the system at the instant of fault, the load current is getting decreased to zero. But in MG1 current is constant for all the time, except a small disturbance at the time of interconnection. Power curves of both MGs are shown in Figure 13. It is observed that power in MG2 is decreasing to zero after the three phase fault.

Case 2: Failure of source of 2nd Microgrid

The fault considered here is the failure of source of MG2. If there is no interconnection

Figure 11: Voltage vs Time Characteristics of MGI and MG2

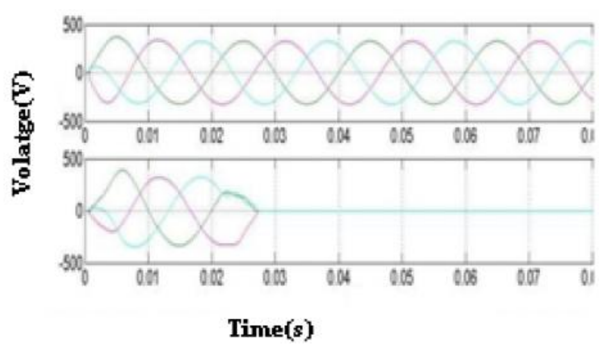


Figure 12: Load Current vs Time Characteristics of MG1 and MG2 Respectively

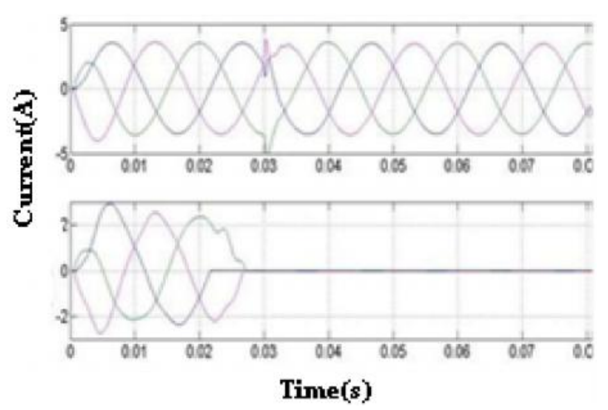


Figure 13: Power vs Time Curves of MG1 and MG2 Respectively

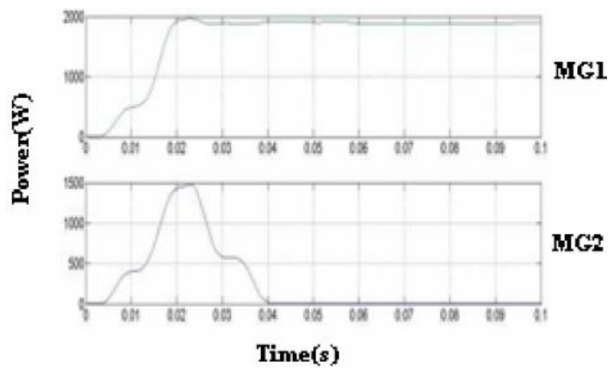
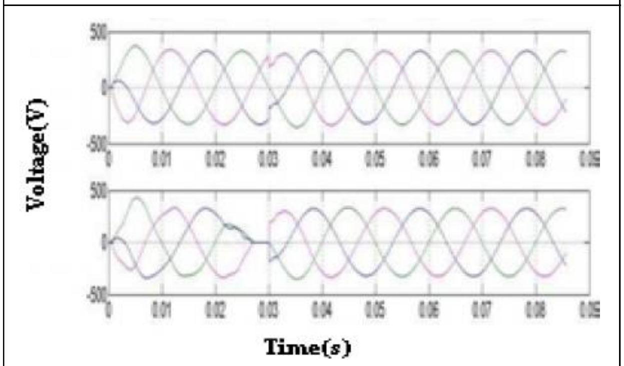


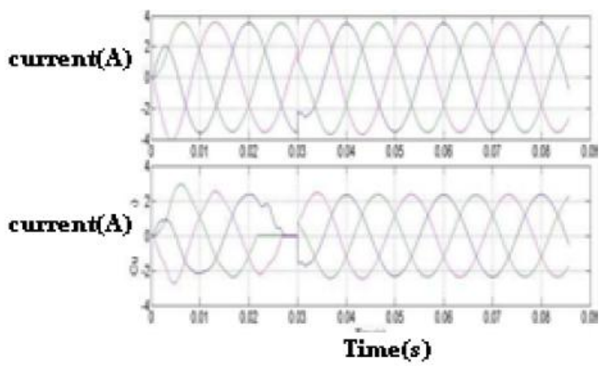
Figure 14: Load Voltage vs Time Characteristics of MG1 and MG2 Respectively



between MGs, voltage and current supplied to the load of MG2 will decrease to zero. When interconnecting, load of MG2 can be supplied by MG1, as it is not fully loaded. The load voltage characteristics of MG1 and MG2 are shown in Figure 14.

From the Figure 14 it is observed that, the voltage across the load of MG1 is constant except for a small disturbance at the point of interconnection. Load voltage of MG2 is going to zero and continues up to 0.03s due to the fault on the source of MG2, but it is increasing to nominal value when both were interconnected at 0.03s. That means MG1 is supplying the load of MG2 after interconnection. Load current Vs time characteristics of MGs are shown in Figure 15. It is observed that load current in the MG2 is decreased to zero after the occurrence of the fault at 0.02s and continues up to 0.03s. The load is getting power from MG1 after interconnection at 0.03s. Load current in the MG1 remains unchanged. Power curves of MGs are shown in Figure 16. Power is constant in the case of MG1. Power of MG2 starts to decrease after the fault, but increased after interconnection, as it is supplied by MG1.

Figure 15: Load Current vs Time Characteristics of MG1 and MG2 Respectively



Case 3: Failure of inverter of 1st Microgrid (MG1)

If there is any fault in the inverter, it cannot supply power to the load. So the load voltage and current tends to zero. Here the fault is in MG1. If there is an interconnection with MG2, it can get power from MG2. In this case MG2 cannot supply load of MG1 fully, as its capacity is lesser than that of MG1.

Load current characteristics of MG1 and MG2 are shown in Figure 17. When a fault occurred at 02s load current is decreased to zero. After interconnecting it to MG2 at 0.03s, MG1 is getting power from MG2. Since the capacity of MG2 is lesser than that of MG1,

Figure 16: Power Curves of MG1 and MG2 Respectively

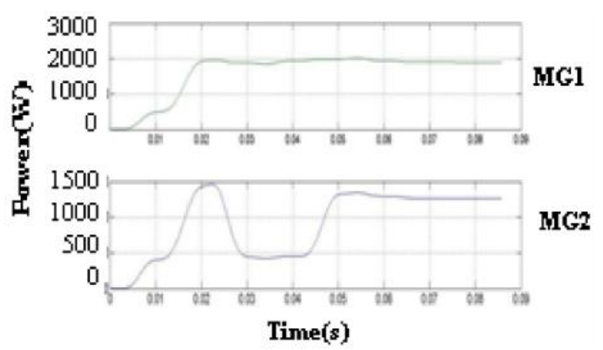


Figure 17: Current vs. Time Characteristics of MG1 and MG2 Respectively

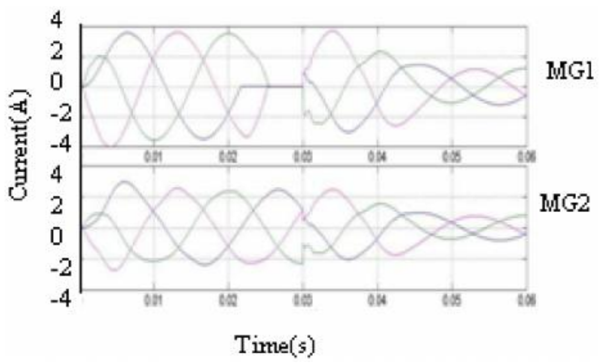
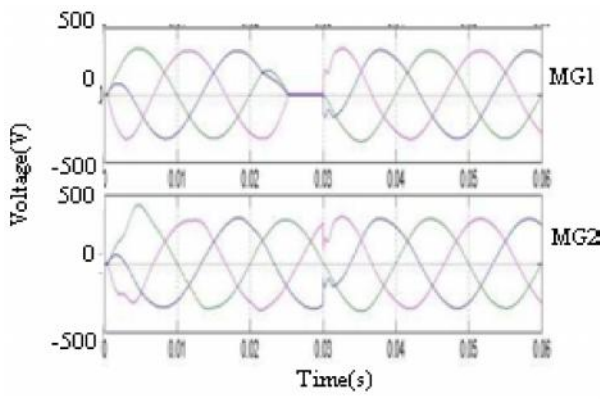


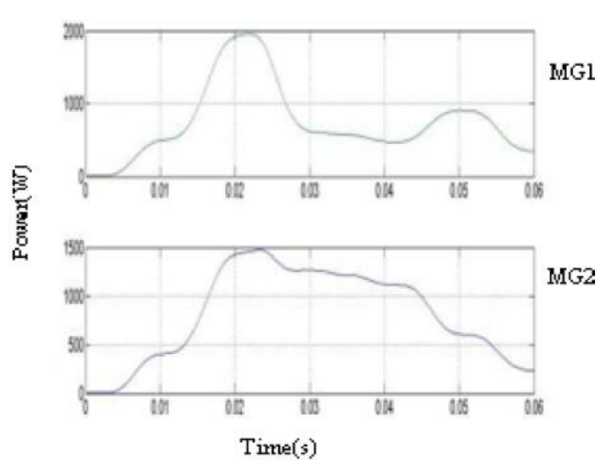
Figure 18: Load Voltage vs. Time Characteristics of MG1 and MG2 Respectively



current is decreased to half of the value in both the MGs. Figure 18 shows load voltage Vs time characteristics of MGs. It is seen that the voltage of MG1 is decreasing to zero after the fault and it is increased to nominal value after interconnection at 0.03s. Load voltage on MG2 remains unchanged.

Figure 19 shows the power curves of MGs. From the Figure 19, it is observed that power in MG1 is reduces due to the fault. After interconnection, it is increasing but not up to the required level. Power in MG2 is also decreasing after interconnection. This means that MG2 can't supply full power to the loads in MG1.

Figure 19: Power Curves of MG1 and MG2 Respectively



To analyse the working of the system at reduced loads, some loads are cut down from both MGs. Figure 20 shows the load current characteristics of both MGs. It is observed that in this condition MG2 can supply power to the load of MG1. Problems in the previous case like reduction in the load current of MG2 are not seen here. Figure 21 shows the load voltage characteristics of both MGs. Voltage on MG1 is decreasing after fault, but increased up to the nominal level after interconnection at 0.03s. Voltage on MG2 remains unchanged.

Figure 20: Load Current vs. Time Characteristics of MG1 and MG2 Respectively

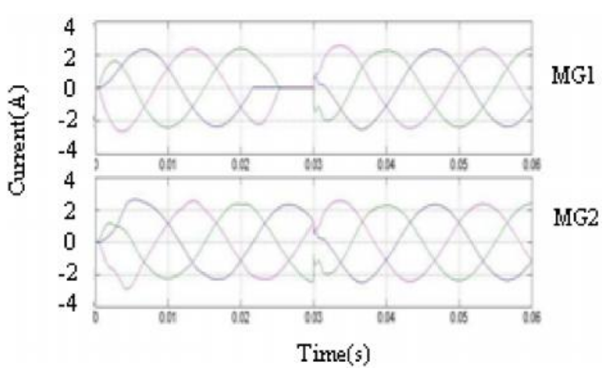


Figure 21: Load Voltage Characteristics of MG1 and MG2 Respectively

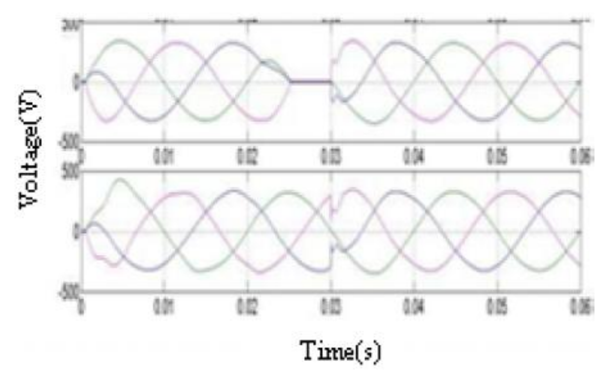


Figure 22: Power Curves of MG1 and MG2 Respectively

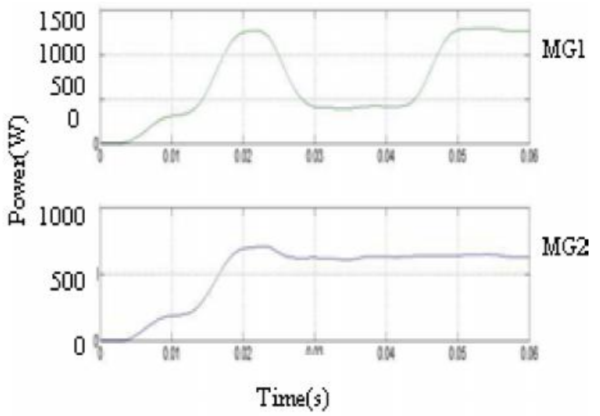


Figure 22 shows power curves of both MGs. Power in MG1 decreases after the fault, but it is increased to nominal value after interconnecting it to MG2. Power in MG2 remains unchanged.

Case 4: Failure of 2nd source of 2nd Microgrid

Here fault is on the 2nd source of MG2. The load characteristics will not be disturbed by this fault because 1st source of MG2 itself can supply power, since the load is only half.

Figure 23 shows the current characteristics of MGs. In both MGs, the current remains undisturbed throughout the simulation. The load voltage characteristics of MGs are shown in Figure 24. Voltage in both MGs also remains constant.

Figure 23: Load Current vs Time Characteristics of MG1 and MG2 Respectively

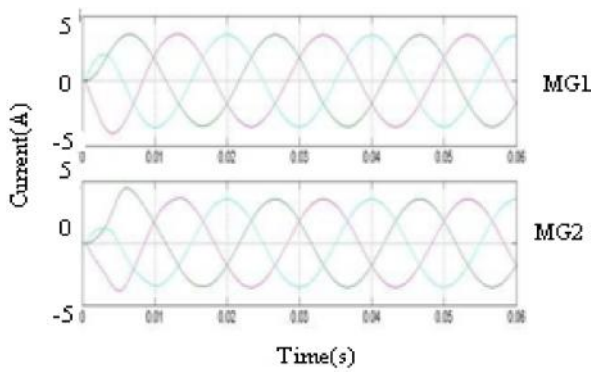


Figure 25 shows power curve of MG1 and MG2 respectively. From the plot it is observed that the powers are also undisturbed by the fault.

Figure 24: Load Voltage vs Time Characteristics of MG1 and MG2 Respectively

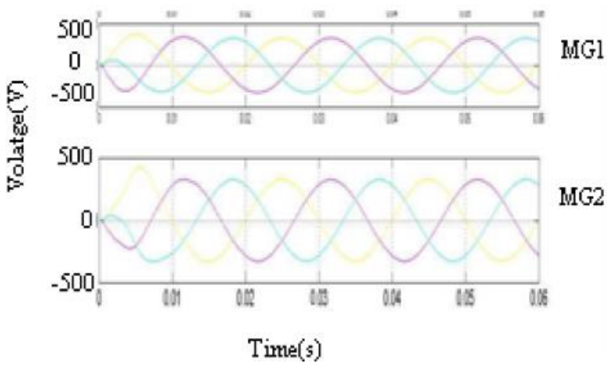
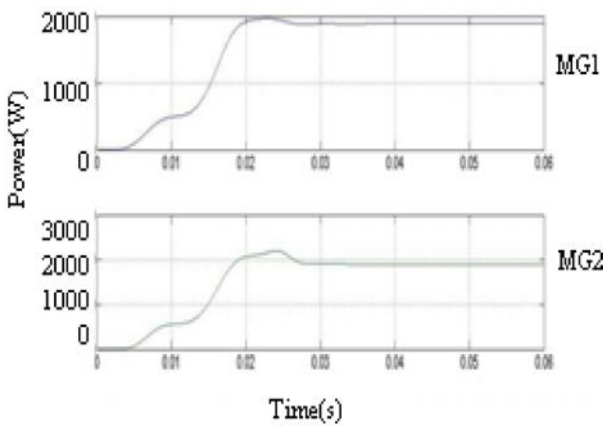


Figure 25: Power vs Time Curve of MG1 and MG2 Respectively



Case 5: Failure of 1st source of 1st Micro grid

In this case faults occurred in the 1st source of MG1. Since the capacity of battery source in MG1 is greater than that of PV source, battery itself can compensate for the power deficit in MG1 due to PV source failure. Figure

Figure 26: Load Current Characteristics of MG1 and MG2 Respectively

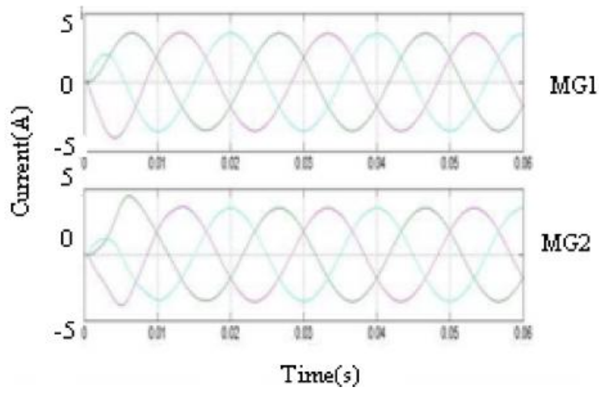


Figure 27: Load Voltage Characteristics of MG1 and MG2 Respectively

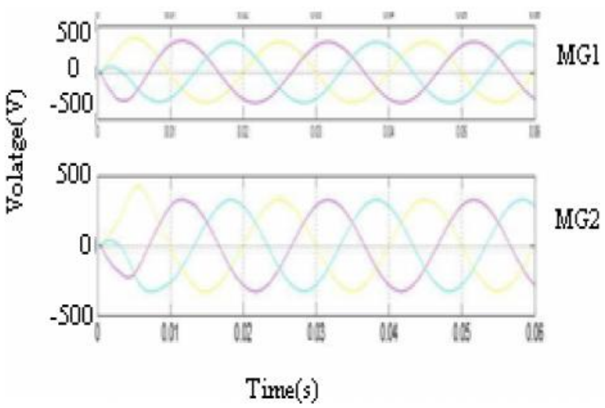
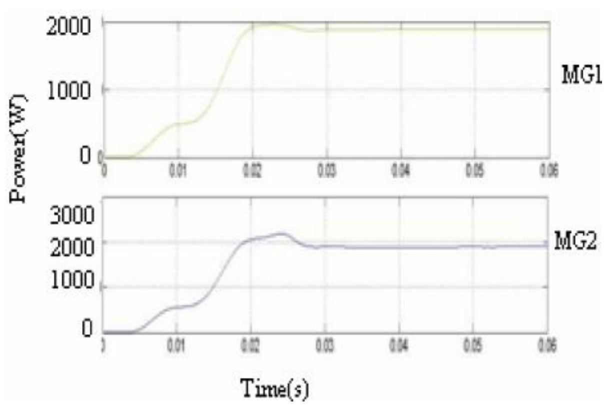


Figure 28: Power Curve of MG1 and MG2 Respectively



26 shows load voltage vs time characteristics of MG1 and MG2 respectively.

Load currents in both MGs remain constant because MG1 itself is compensating for the power deficit due to the fault. Load voltage characteristics are shown in Figure 27. From Figure 27, it has been observed that voltage remains constant in the case of both MGs. Power vs time characteristics of microgrids are shown in Figure 28. It is observed that power remains undisturbed in both MGs.

From all the above analysis it has been observed that one microgrid can compensate for any power deficit in the nearby microgrid if they are interconnected.

As a second stage of the analysis, MG1 has been interfaced with utility grid. For that, the utility grid is modeled in Matlab/simulink as an infinite bus having 400Vrms. To interface MG1 with grid, the load voltage of both MG1 and MG2 are stepped up to 400 Vrms by increasing the turn's ratio of the transformers. Since the microgrids MG1 and MG2 are already interconnected and now MG1 is interfaced to grid, grid can supply power to both microgrids if any failure occurs in any or both the MGs.

Analysis of Grid Connected System

A grid synchronization circuit has been modeled for analysis of the grid connected system. Type of fault considered for this analysis is failure of source of microgrids MG2 and MG1 respectively.

For synchronizing MG1 voltage to the grid voltage, magnitude, phase and frequency of both voltages were measured and voltage of MG1 has been varied for matching this to the grid voltage. The breaker is controlled by the signal from the relational operator. When the difference becomes zero, MG1 will be connected to the grid. Simulink model for the analysis in grid connected mode is shown in Figure 29.

From the results of above simulation, it is observed that, when a failure in the source of MG2 occurred, the load of MG2 is supplied by MG1. After some time, when a failure occurred in the source side of MG1, it was observed that grid is supplying power to the loads of both MGs since MG1 and MG2 are interconnected. Load voltage Vs time curves of MGs and grid are shown in Figure 30.

From the Figure 30, it is observed that when source of MG2 failed at 0.05s, the load was not getting supply without interconnection up to 0.1s. At 0.1s MG2 is interconnected with MG1 and it gets power from MG1 up to 0.15s. Now at 0.15s source of MG1 failed. Then both MGs were blacked out until it is connected to utility grid. After interconnecting to the grid at 0.2s, loads of both MGs are supplied by the grid. From the Figure 31, it is seen that grid is supplying total load current of 6A for both MGs on the occurrence of fault.

Figure 29: Simulink Model of the Grid Connected System

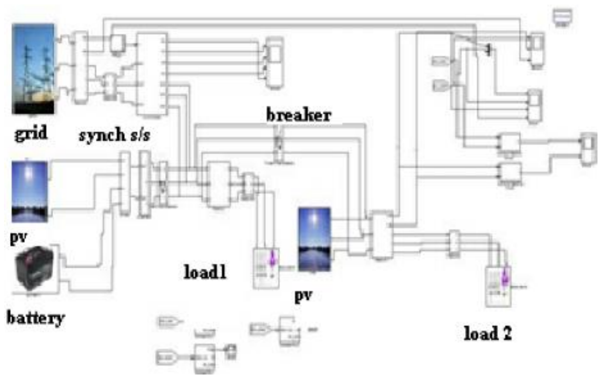


Figure 30: Load Voltage vs Time Curves of MGs and Grid

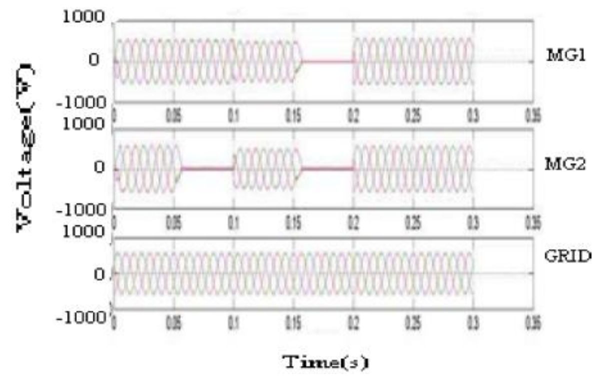
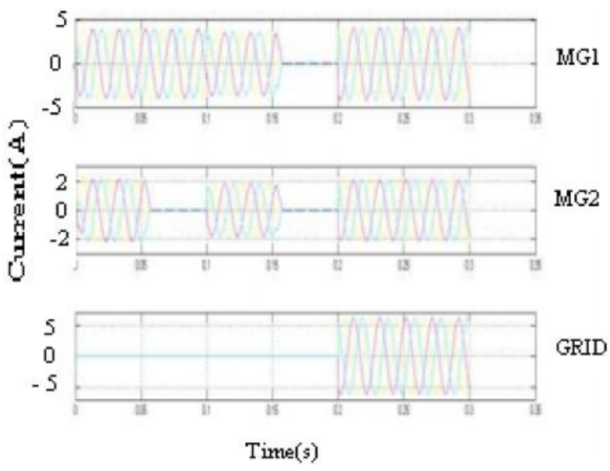


Figure 31: Load Current vs Time Curves of MG1, MG2 and Grid Respectively



Analysis of Frequency Deviation

Analysis on frequency deviation has been done in the proposed system during islanding from the utility grid with and without interconnection between two microgrids. It has been observed that the frequency deviation can be improved by interconnecting nearby microgrids. The frequency Vs time curve of both MGs during islanding from main grid with and without interconnection between MGs are shown in Figures 32, 33, 34 and 35 respectively. It is observed that frequency deviation is reduced by interconnecting two MGs. It is also observed that the frequency deviation in MG1 is reduced from 0.325 Hz to 0.19 Hz and the frequency deviation in MG2 is reduced from 0.38 Hz to 0.19 Hz by interconnecting both MGs.

Figure 32: Frequency of MG1 Without Interconnection

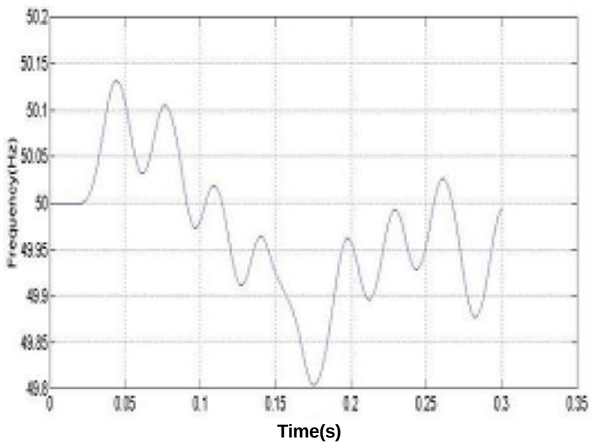


Figure 33: Frequency of MG1 with Interconnection

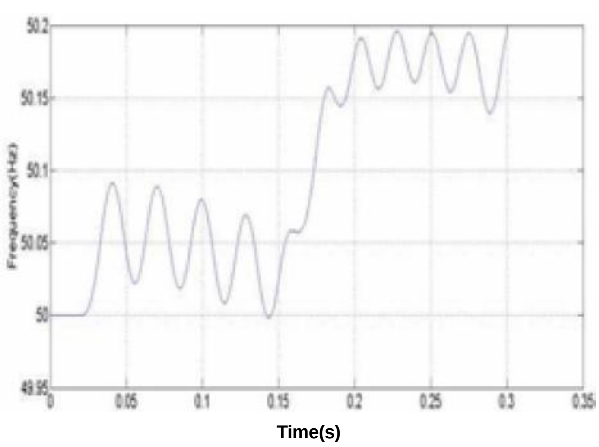


Figure 34: Frequency of MG2 Without Interconnection

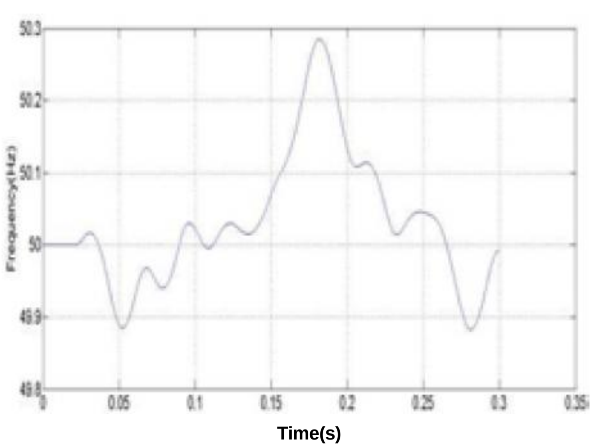
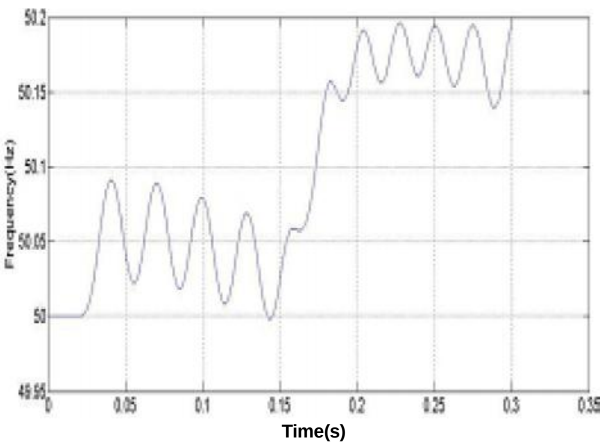


Figure 35: Frequency of MG2 with Interconnection



CONCLUSION

A grid connected system with two interconnected microgrids has been modeled and analyzed with different types of faults in two microgrids. It has been observed that one microgrid can compensate for the power deficit in the other and grid can supply the loads of the two MGs when fault occur simultaneously in the two systems. It is also observed that the dynamic performance like frequency deviation can be reduced by interconnecting nearby microgrids.

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