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Fault control of microgrid system: A case study of Karabuk University - Turkey

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Abstract. In this paper Karabuk University microgrid system is introduced and fault control of microgrid is analyzed. The microgrid system of Karabuk University campus consists of diesel generator, solar PV panels, energy storage unit, critical and non-critical loads. Simulation of microgrid in both grid-connected and isolated operation modes are conducted on MATLAB/Simulink. The fault control has been implemented in the microgrid system to effectively manage of power in the system. The system is effectively disconnecting the microgrid from main grid within a microsecond after fault conditions. The distributed energy sources have been supplying the energy to load based load profile settings. From the simulation results, the developed control mechanisms provide stable operation in the microgrid system.

1. Introduction

In last decades, the energy demand is growing exponentially over the world. The development trends of power systems in the world require not only to increase electricity production in large power plants, but also increasing the share of distributed generation (DG) based on renewable energy sources. Photovoltaic, fuel cells, wind power, micro turbines, gas turbines and internal combustion engines are example for distributed energy resources. Distributed energy resources (DER) have advantages over centralized power generation. These advantages include: the system stability improvement, the reducing transmission and distribution overload, power losses reduction, voltage profile improvement, pollutant emission reduction

[1-3]. The reliability and power quality of electrical energy should be provided to consumers such as hospitals, multi-storage buildings, information centers, university campuses, etc. [4-6].
In general, the electricity generation from renewable energy sources is most suited method than convention energy generations. But it has some disadvantages such it is not stable due to climate change, inefficient and initial cost for installation is high. In other hand, diesel power generator used during emergency situation and peak hours and normally used for standby power to supply the peak loads and it used only in isolated area. Even though, it has some advantages such as reliable, flexible, low cost, high efficiency. Advantages of both renewable energy and diesel generations are included in microgrid [7-9]
One of main reason of microgrid interconnection to power systems is to share reserves in emergency conditions (for example, loss power in main grid) for lowing the chance of load shedding and enhancing the overall system reliability. The following advantages of MG are noted in literature [10-12]:

- The ability of MG, during a utility grid disturbance, to separate and isolate itself from the utility seamlessly with little or no disruption to the loads within the MG;
- In peak load periods it prevents utility grid failure by reducing the load on the grid;
- Significant environmental benefits made possible by the use of low or zero emission generators;
- The use of both electricity and heat permitted by the close proximity of the generator to the user, thereby increasing the overall energy efficiency;
- MG can act to mitigate the electricity costs to its users by generating some or all of its electricity needs;
- Enhancing the quality of power which is delivered to sensitive loads.

Moreover, the combination of renewable energy with distributed storage system and diesel power generator in MG is most promising solutions to assurance for continuity of power generation with moderate expenditures on equipment. Apart from these advantages of MG, there are some issues in the MG system. First one is the intermittent and fluctuant availability of RESs as a result of which there are disturbances in the system and the power quality is deteriorated. Another problem is planning, designing, and available technology at low cost to install in the MG system. Also, the precise measuring and controlling are required to maintain stable operation due to use of power electronic devices in the MG [13-15].

This paper proposes a microgrid system with power flow control in all DER along with fault control. The proposed microgrid consists of solar PV array - battery storage system with local load and diesel generator with local load. The prime objective of this work is to design and develop the control system of MG to ensure the power balance between DERs and load along with continues energy supply during the failures.

2. Methodology

The integration of DERs and energy storage devices to existing power distribution network makes problems such as to provide the operating reliability and efficiency of electricity system. Therefore, precise design and modelling microgrid system with control ensure the stability of power system.
Firstly, the initial problem of Karabuk University (KBU) electricity has evaluated. KBU is one of the great electricity consumers in Karabuk province with 435877 kW·h monthly average electricity consumption for 2018.
There are problems such as increasing utility bills, indirect carbon emissions, and also cost of maintaining a complex distribution infrastructure with trying to provide electricity a large university community. Karabuk University governance is intended to reduce the electricity consumption and attendant costs by integrating solar photovoltaic (PV) panels to the utility grid of university campus. Nowadays, PV panels are installed in five of eight main educational buildings of KBU campus. Therefore, MG planning, modeling and simulation are performed in this work on the example of Engineering Faculty at KBU.

Technical data, load profiles and equipment characteristics of Engineering Faculty are used as initial data for simulation on MATLAB/Simulink. During the planning of KBU Microgrid the Engineering faculty is chosen as case study for microgrid simulation, because this faculty is the biggest building in the KBU campus. The planning of KBU MG are implemented based on initial data. The modeling and simulation of microgrid have executed on MATLAB/Simulink. Fault control strategy of KBU MG is developed on MATLAB/Simulink as next stage of the research. And the results are discussed as last stage of this research work.

2.1. Microgrid of Karabuk University

KBU MG has the followig main components:

1. Diesel generator;
2. PV-system;
3. Energy storage system (battery storage unit).
4. Critical and non-critical loads.

Demir Celik Campus is the central campus of Karabuk University (KBU) with building area 3.5 million m^2. The electric power of Karabuk University campus is supplied by power supply substation of BAŞKENT EDAS A.Ş. Demir Celik Campus of KBU with Engineering faculty building is shown in Figure 1.

Figure 1. Engineering Faculty in Demir Celik campus of Karabuk University.

Power supply of the Engineering faculty building is provided by substation TR 6. The proposed KBU MG single line diagram is illustrated in Figure 2.

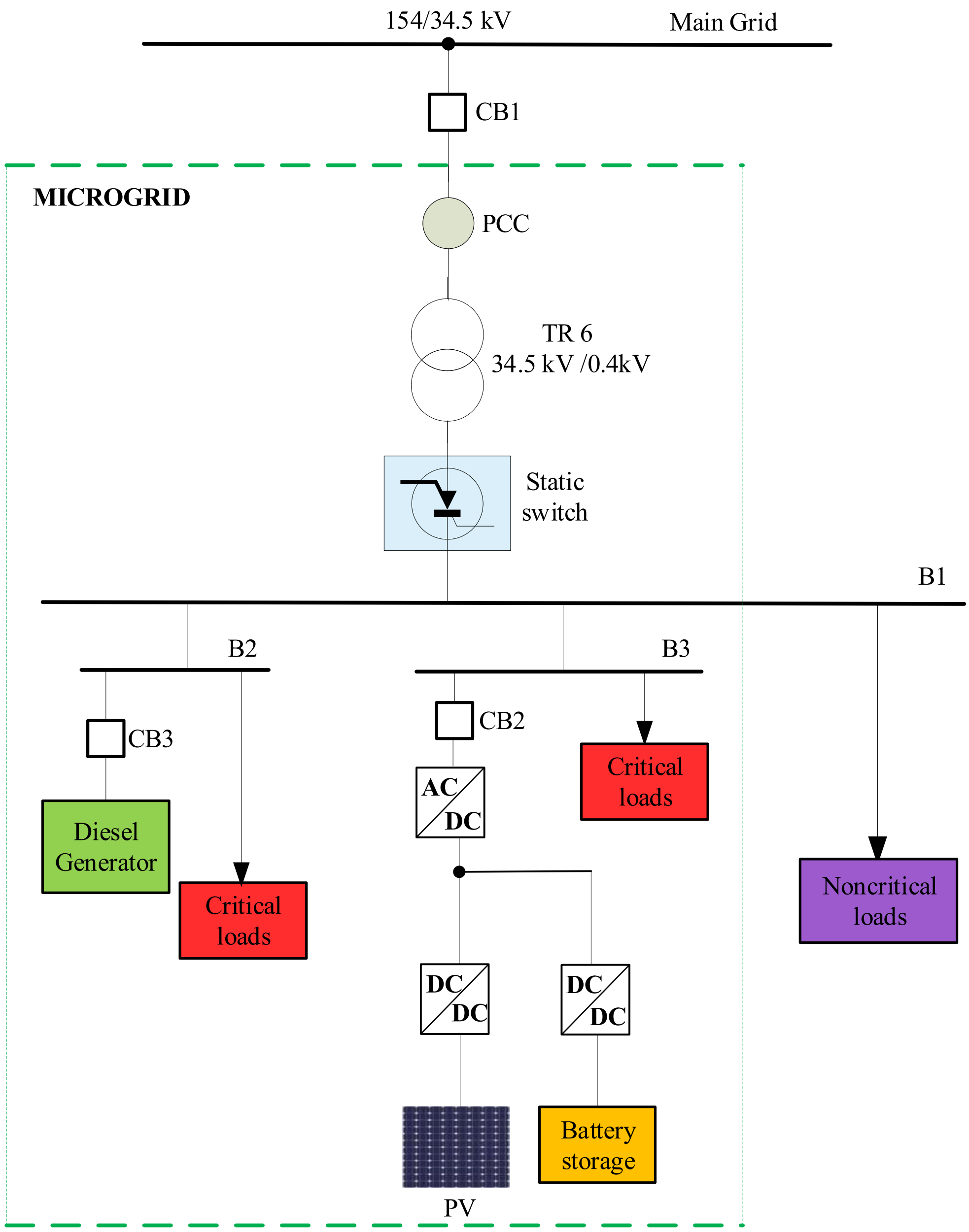

Figure 2. Single line diagram of Karabuk university microgrid

3. Results and Discussion

The KBU microgrid system has been created on MATLAB/Simulink environment. Technical parameters of rating of the studied system is given in the Table 1. The simulation is executed in the Windows 10 64 bit OS, a dual-core 1.7 GHz Intel Core i5 processor. The Simulink model of the overall KBU microgrid is shown in the Figure 3.

Table 1. Specification of KBU Microgrid

	Grid	Solar PV	Battery	Diesel generator	Transformer	Load
Power	154 MW	41 kW	41 kW	440 kW	154 MVA	Critical load 1 – 400 kW at diesel generator
Voltage	34.5kV	400 V	480 V	400 V	34.5 kV/0.4 kV	Critical load 2 – 40 kW At solar battery inverter
Frequency	50 Hz	50 Hz (Inverter frequency)	50 Hz (Inverter frequency)	50 Hz	50 Hz	Non-critical load – 500 kW at grid bus
Capacity			500Ah			

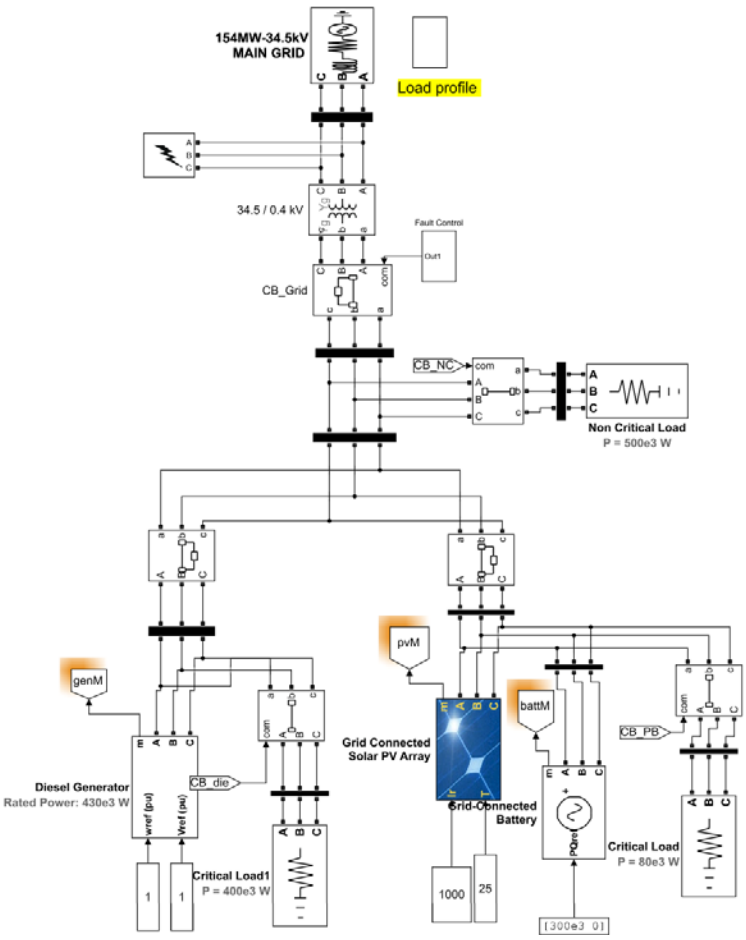

Figure 3. Simulink model of KBU MG system with fault and power flow control

The Simulink model of the fault control system is shown in Figure 4. In this Simulink model, root mean square (RMS) value of the fault lines are compared with rated value. If the actual voltage is less than the rated value, trip signal is sent to corresponding circuit breaker to isolate from the remaining healthy system.

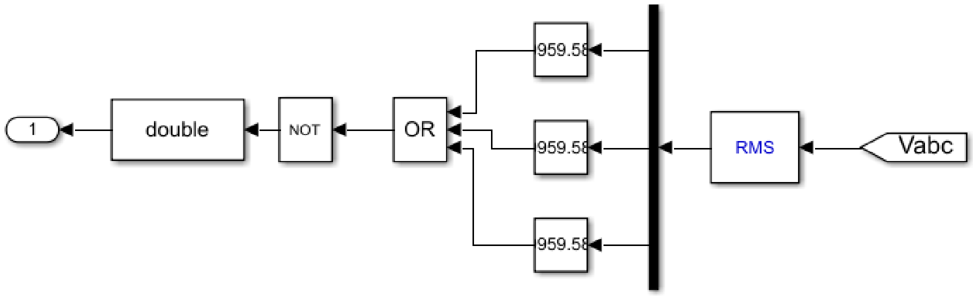

Figure 4. Simulink model of the fault control system

The load profile settings for open and close conditions of the critical and non-critical loads circuit breakers are demonstrated in Figure 5. We can see how the load profile results change when circuit breakers of critical load 1 (supplied by diesel generator), critical load 2 (supplied by PV-battery-inverter system) and non-critical load disconnected and connected from power sources. While the circuit breakers of all load are connected in 0 – 2 sec. interval the load profile is 980 kW; when the circuit breaker of critical load 1 is connected, but the circuit breakers of critical load 2 and non-critical load are disconnected from 2 sec. to 2.5 sec. the load profile is 400 kW; in 2.5 – 3 sec. interval when the circuit breaker of critical load 2 is connected, but the circuit breakers of critical load 1 and non-critical load are disconnected the load is 80 kW; while the circuit breaker of non-critical load is connected, but the circuit breakers of critical load 1 and critical load 2 are disconnected from 3 sec. to 3.5 sec., the load is 500 kW; and in 3.5 – 4 sec. interval the load is again 980 kW.

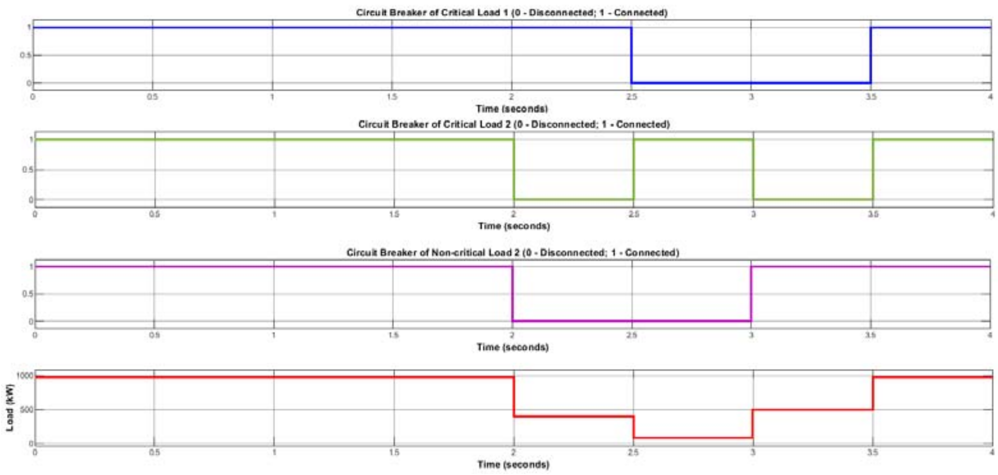

Figure 5. Load profile and circuit breaker signal for different loads

In order to verify the effectiveness of the system, the following test cases have been taken for analyses:

- Three phase faults at grid line conditions;
- Optimal load sharing conditions.

The active power characteristics of grid, solar PV, battery and diesel generator are illustrated in Figure 6. Also, island mode and grid connected mode of the Microgrid system is presented in the Table 2 and this table provide the sharing of the active power of the grid and distributed energy sources such as PV, battery and diesel generator.

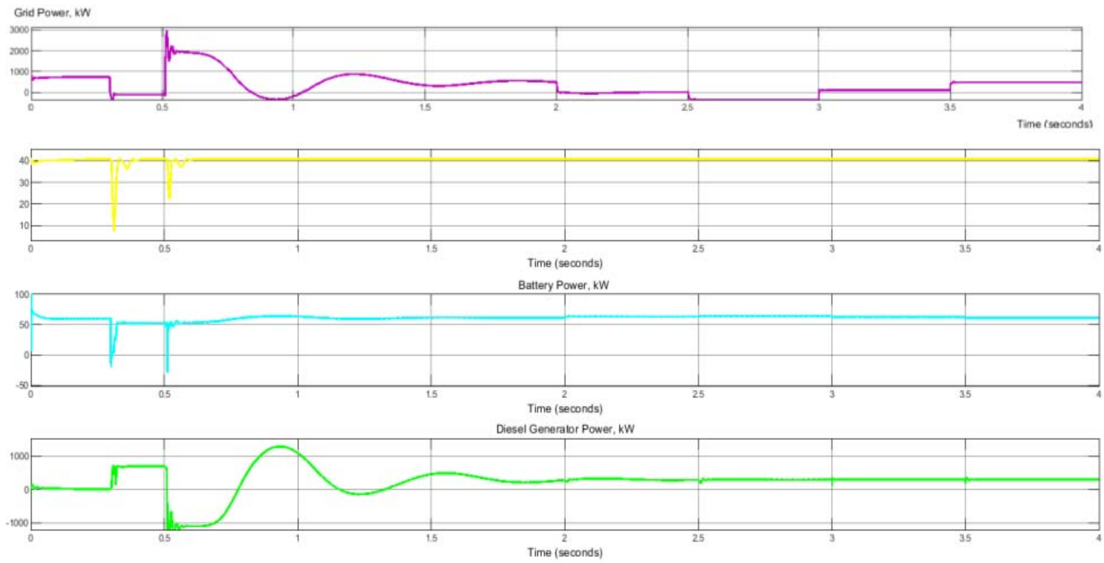

Figure 6. Power characteristics of grid, solar PV, battery and diesel generator

Table 2. Active power sharing of the Microgrid system in grid connected and island modes

Time (sec.)	0 - 0.3 sec.	0.3 - 0.5 sec.	0.5 - 2 sec.	2 - 2.5 sec.	2.5 - 3 sec.	3 - 3.5 sec.	3.5 - 4 sec.
	Load Profile (kW)						
	980	980	980	400	80	500	980
Power Source (kW)	Grid (901) PV-Battery (79)	Grid (0) PV-Battery (80)	Grid (470) PV-Battery (80)	Grid (-110) PV-Battery (80)	Grid (-430) PV-Battery (80)	Grid (-10) PV-Battery (80)	Grid (470) PV-Battery (80)
	Diesel (0)	Diesel (900)	Diesel (440)	Diesel (440)	Diesel (440)	Diesel (440)	Diesel (440)
Operation mode	Grid Connected	Island	Grid Connected	Grid Connected	Grid Connected	Grid Connected	Grid Connected

The fault simulation status and RMS voltage of the system are shown in Figure 7. The fault is occurred at 0.3 sec in main grid and resets at 0.5 sec. During the fault RMS voltage is less than rated value and due to that open command is given to corresponding circuit breaker to isolate the system.

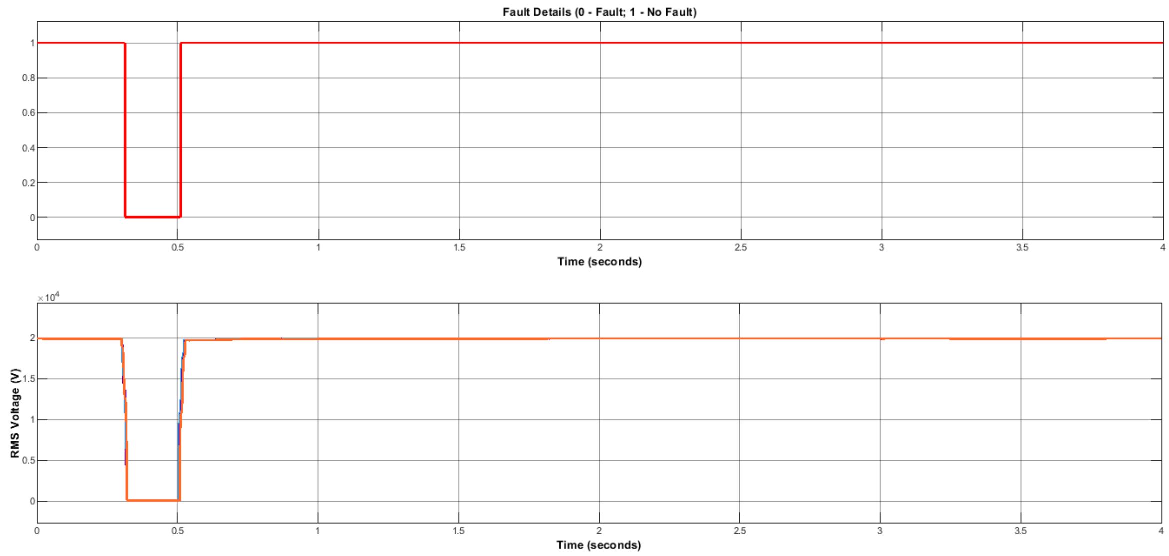

Figure 7. Fault details and fault voltage at area

The critical and non-critical load profiles while the fault in main grid are shown in Figure 8.

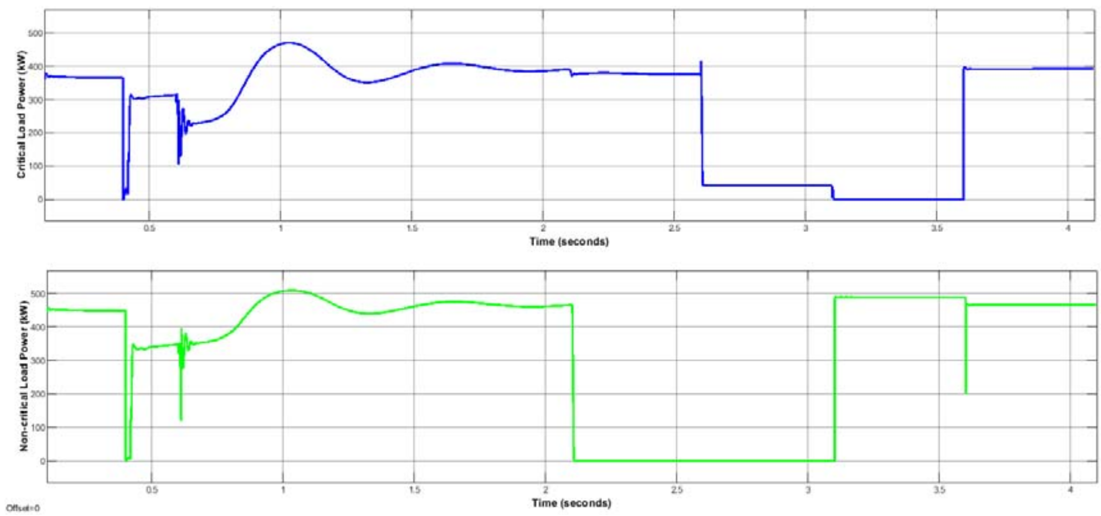

Figure 8. Critical and non-critical load profiles while the fault

Figure 9 and Figure 10 show the variation of the voltage and current at PV battery bus, diesel generator bus, the voltage and current of the loads at diesel generator bus and PV-battery bus, respectively. Variation of the voltage and current follow the load profile settings. The system effective work in both cases such fault control case and optimal load sharing case.

Figure 9 shows the voltage and current of the PV-battery bus. The load is maintained of 230 V at the following intervals: 0 – 0.3 sec.; 0.5 sec. – 2 sec.; 2.5 sec. – 3 sec.; 3.5 sec. – 4 sec. while faults occur. The voltage is slightly reduced to 230 V. Load is disconnected during 2 sec. to 2.5 sec. and 3 sec. to 3.5 sec. based on load profile settings. The current of the system is varying according to load and fault conditions.

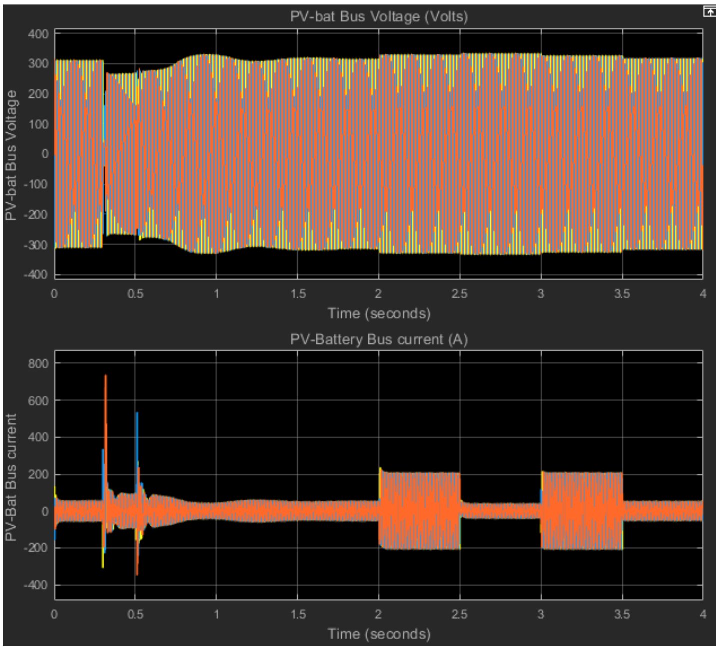

Figure 9. PV-battery bus voltage and current

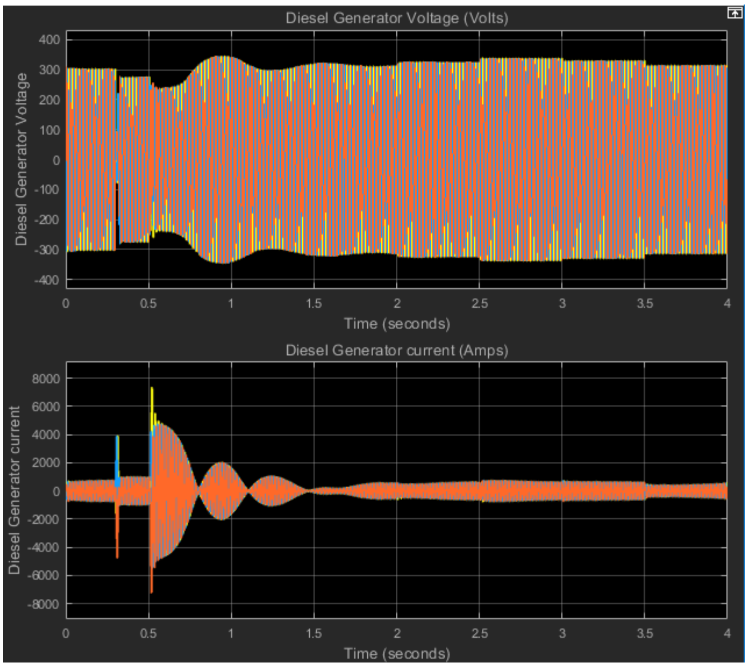

Figure 10. Voltage and current of diesel generator

The voltage and current of diesel generator are shown in Figure 10. Load is maintained of 230 V at intervals 0 – 0.3 sec. and 0.5 sec. – 4 sec. during fault conditions, voltage is slightly reduced to 230 V. The load is disconnected during 2.5 – 3.5 sec. based on load profile settings. The current of the system is varying according to load and fault conditions.
The frequency analysis of the microgrid system is shown in Figure 11. From 0 to 0.3 sec, the frequency of the system is maintained of 50 Hz. When fault occur during 0.3 to 0.5 sec., the frequency is reduced to 48 Hz. After fault cleared, the frequency of the system is restored to 50 Hz after 2 seconds. After fault it takes 1.7 seconds to restore to rated frequency.

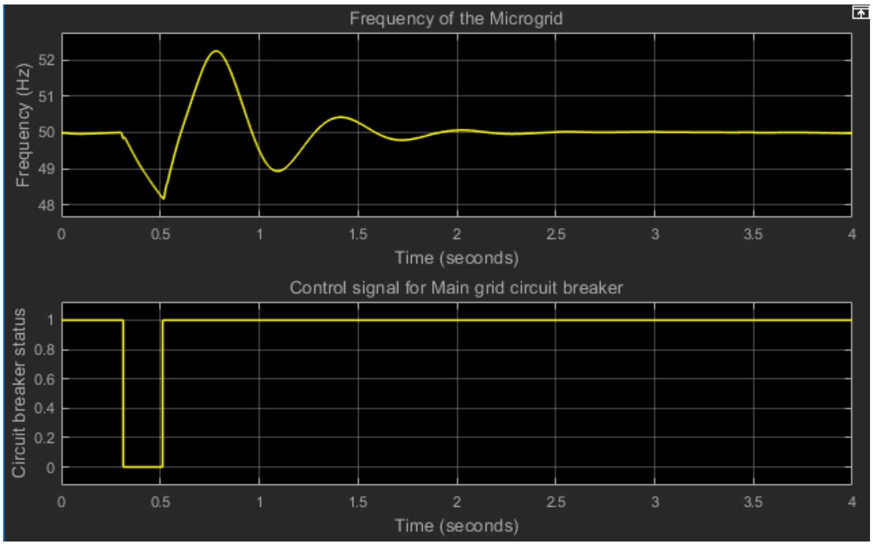

Figure 11. Frequency response during grid and island mode

4. Conclusions

The microgrid architecture for Karabuk University (KBU) was introduced and analyzed in this paper. This microgrid includes a diesel generator and solar PV systems with battery storages. Simulation of microgrid in both grid-connected and isolated operation modes has implemented on MATLAB/Simulink. The fault control has been implemented in the microgrid system to effectively manage the power in the system. The system is effectively disconnecting the microgrid from main grid within a microsecond after fault conditions. The distributed energy sources have been supplying the energy to load based load profile settings. In addition, microgrid control strategy in grid connected mode and isolated grid mode was proposed.

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