International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

Design and Modeling of Karabuk University Microgrid

Nuri Almargani Almagrahi

Date of Submission: 20-02-2024 Date of Acceptance: 04-03-2024

ABSTRACT
Last decades with rapidly penetration of distributed energy resources to the power system, the interest on Microgrid is growing. Microgrid as a key component of the Smart Grid can be used in rural areas, especially in remote inaccessible areas or with main grid. Objectiveof this paper is to design and modelling of Microgrid for Karabuk University (KBU) campus for Microgrid disconnected and connected to main grid operation modes. In this paper are considered simulation models of islanded and grid-connected operation modes of Karabuk University Microgrid on MATLAB/Simulink.

Keywords: Microgrid, Distributed Energy Resources, Karabuk university, MATLAB.

I. INTRODUCTION

Nowadays it is clear that the challenges facing the energy sector are becoming acuter. The problems such as environmental protection, energy security and economic development are interrelated and global of the modern era. In recent years, the rapid development of power electronic system and innovations in small-scale distributed generation (DG), also implementation of new information and communication technology in the power systems led to the concept of smart grid (SG).

Microgrid (MG) as a key component of the Smart Grid can be used in rural areas, especially in remote inaccessible areas or with main grid. MG is intended to improve energy efficiency, a reliability of power system and decrease carbon dioxide emissions. Fluctuation and intermittence resulted from unstable micro-sources and nonlinear loads will execute considerable impacts on normal operation of the MG. The term “Microgrid” refers to the concept of MV/LV distribution network voltage associated with a small number of distributed energy resources (DERs), such as photovoltaic, wind power, hydro, internal combustion engine, and microturbine together with loads [1].In MG distribution network becomes active with integration of DER, demand side integration and energy story technologies [2].In EU research projects MG described as “Microgrids comprise LV distribution systems with distributed energy resources (DER) (microturbines, fuel cells, PV, etc.) together with storage devices (flywheels, energy capacitors and batteries) and flexible loads”[3,4]. The works [5,6,11] conducted by researchers present technical, economic and environmental benefits associated with MGs.

The high penetration of distributed generator (DG)s increases the intricacy of control, protection, and communication of distribution systems. Therefore, an important problem is how to integrate various DGs into the existing distribution networks of power system by limiting their potentially negative side-effects on distribution network operation and control.MG can be operated [7,8]:

1) in stand-alone or islanded mode, if MG operates autonomously;
2) in grid-connected mode, if MG connected to the main grid.

In stand-alone mode,microsources provide loads with necessary power energy and MG never connects to the main grid.

In grid-connected mode, MG remains connected to the main grid either totally or partially and extra power generated in MG can be exchanged with the main grid providing auxiliary services.

MG consists of a group of radial feeders (A, B and C), which could be part of a distribution system architecture and a collection of loads. The radial system is connected to the distribution system by a point of common coupling (PCC) via a static switch. The Point of Common Coupling (PCC) is on the primary side of the transformer and separates main grid from MG. Each feeder has a circuit breaker and microsource controller [6]. Local critical loads connected to the local generation resources while non-critical loads do not have any local generation. The static switch is capable to disconnect MG from main grid when fault occurs or for maintenance purposes.

II. MODELING OF MICROGRID SYSTEM

Modeling of MG is a main step to provide a suitable control.The structure of Karabuk University (KBU) microgrid is represented in Figure 1. The single line diagram of MG is illustrated in Figure 2.Karabuk University substation with TR 1A and distributed energy resources (PV-panel, diesel generator) are chosen for a case study of MG implementation on Simulink/MATLAB. Research analysis show that potential of wind energy in Karabuk region is low with 2.4 m/s annual average wind speed and 21.3 W/m^2 annual average wind density [9,10]. Therefore, modeling of MG with wind turbine for Karabuk university is not proper.

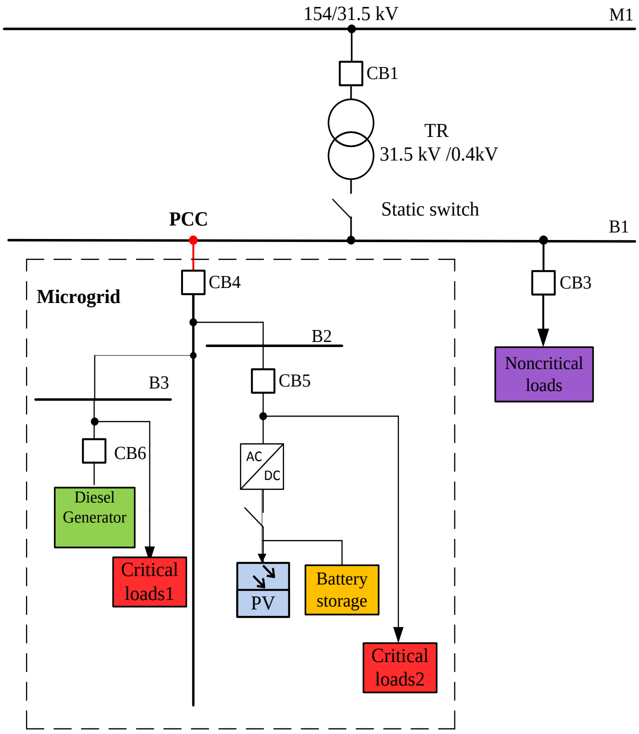


Figure 1: Structure of Karabuk university Microgrid.

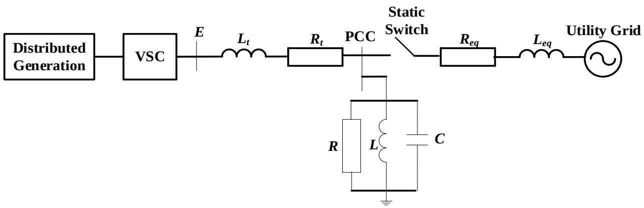


Figure 2: Single line diagram of KBU MG.

2.1. Modeling of Photovoltaic module

PV system configuration consists of solar photovoltaic cells, referred to as PV modules, a boost converter and an inverter. Equivalent electric circuit of PV cell (Figure 3) is used for modeling PV system. The output of PV systems is directly affected by solar irradiance and temperature. The output of PV module can be written as follows

$$I = I_{PV} - I_D - I_{sh} \qquad (1)$$

where:I- output current; I_{PV} - photo generated current; I_{sh} – shunt current.I_D - diode current.Using the Shockley diode equation diode current can be written:

$$I_D = I_0\left(e^{\frac{qv_D}{kT}} - 1\right) \qquad (2)$$

where:I_0 - reverse saturated current; k– Boltzmann constant $(1.381 * 10^{-23}\frac{J}{K})$;q - electron charge $(1.60217662 * 10^{-19}$ C); T - absolute temperature.

The current through shunt resistor is equals

$$I_{sh} = {}^{v_D}/_{R_{sh}} \qquad (3)$$

The voltage across the diode and the shunt resistor as follows:

$$v_D = IR_s + V \qquad (4)$$

where: V is output voltage;R_s is series resistor.

Characteristic equation of PV cell is expressed by substituting (2) – (4) into (1)

$$I = I_{pv} - I_0\left(e^{\frac{qv_D}{kT}} - 1\right) - \left(\frac{IR_s + V}{R_{sh}}\right) \qquad (5)$$

The dynamics all DGs are represented in [11]. The transfer function of PV system while network is neglected is a first-order lag as

$$G(s) = K_{PV}/(1 + sT_{PV}) \quad (6)$$

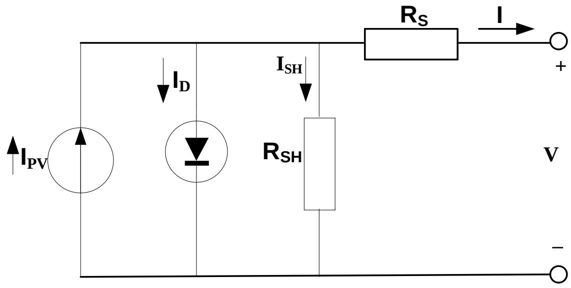


Figure 3:Equivalent electric circuit of PV cell.

2.2. Modeling of battery energy storage

Lead-acid battery is considered for the battery storage modeling. This type of battery energy storage system (BESS) is widely and effectively used element for storage unit in PV system.In Figure 4is shownthe equivalent electric circuit of battery. It consists of a controlled voltage source in series with aninternal resistance Ri. The circuit equation model is expressed in the following view [11]:

$$V_{bat} = E_b + R_i I_{bat} \quad (7)$$

$$E_b = f(SOC) \text{ and } R_i = f\left(I_{bat\,,SOC\,,T}\right) \quad (8)$$

where: V_{bat} - voltage of battery;I_{bat} - current of battery,E_b - electromotive force as a function of the battery state ofcharge(SOC), and R_i - theinternal resistance of an element.

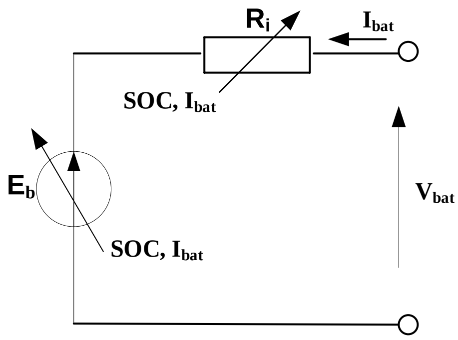


Figure 4:Equivalent electric circuit of battery model.

In [11] proposed the model for discharging and charging of lead-acid battery.

The discharge model:

$$V_{bat} = E_o - R_i - K(Q/Q - it)(it + i^*) + Exp(t) \quad (9)$$

The charge model:

$$V_{bat} = E_o - R_i - K\left((Q/it - 0.1Q)i^*\right) - K\left((Q/Q - it)it\right) + Exp(t)$$

(10)

where:E_o - battery constant voltage; i^*- filtered current; Q -battery capacity (Ah); it - actual battery charge; K -polarization constant (V/(Ah)) or polarization resistance (Ω).The simplified transfer function of battery energy storage system (BESS) can be given as follows:

$$G(s) = K_{BESS}/(1 + sT_{BESS})(11)$$

2.3. Modeling of boost converter with MPPT

Themaximum output power of PV module varies and to obtain the maximum power from PV system maximum power point tracking (MPPT) is used. There are many different methods described in [12,13,14] to maximizing the power from PV system. In this work is used classical perturbation and observation method (P&O) by the reason it is much simplerand needs fewer measured variables.The boost converter provides maximum efficiency operation of PV system by extracting maximum achievable power from PV system.The P&O method is based on to create a perturbation by decreasing or increasing the duty cycle of boost converter and then observing the direction of change of PV output. The algorithm of P&O method is illustrated in Figure 5. Firstly, PV voltage and current must be initially measured. Then the change in the voltage (ΔV) and the change in the power (ΔP) must then be calculated.The PV voltage must be perturbed by a constant value. If the perturbation in the voltage causes the power to increase, the next perturbation must be kept in the

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

same direction; otherwise, the next perturbation mustbe reversed [15].

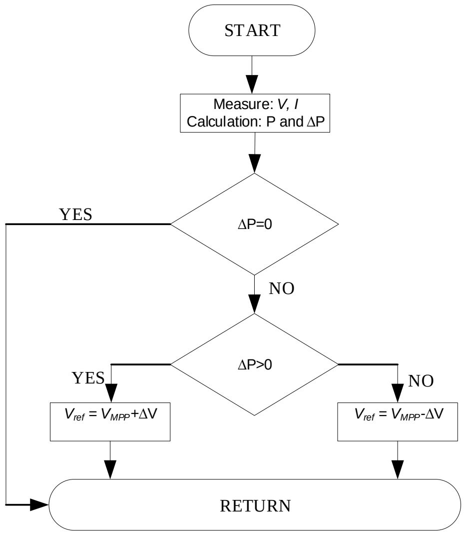


Figure 5: Flow chart of P&O method.

2.4. Modeling of voltage source inverter

In MGs the three-phase voltage source inverter (VSI) is used to connect DC bus to AC grid [16,17]. The purpose of the inverter is to invert DC into AC voltage in real-time. The equivalent model of three-phase invertersis shown in Figure 6[18]. The circuit consists of voltage source vrin series and output impedance $Z_0\angle\theta$, where δ is power angle – difference between vrand v_0,E is the amplitude of the voltage source andδ.

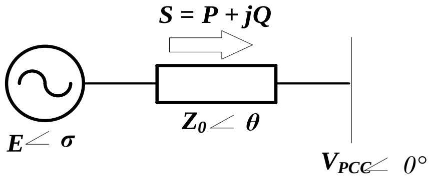


Figure 6: The equivalent model of three-phase inverter.

In several papers [16-20] the block diagramof VSI control loopwasdeveloped in detailfor MG systems. One of this block diagram of VSI control loop isillustrated in Figure 7.

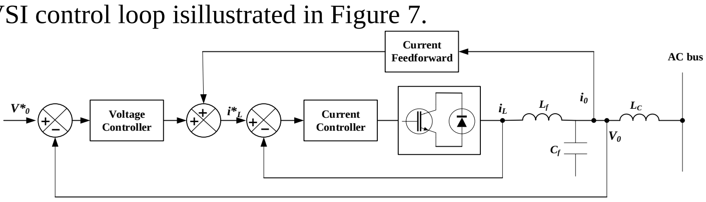


Figure 7: Block diagram of VSI control loops.

III. SIMULATION STUDY

Simulation model of KBU MG is implemented on three-phase, 3-bus, 0.4 kVfor islanded and grid-connected operation modes on MATLAB/Simulink. Simulation model is developed according to the structure scheme of KBU MGinFigure 1 (Figure 8).Details of DER and loads which are used for MG simulation are given in Table 1.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

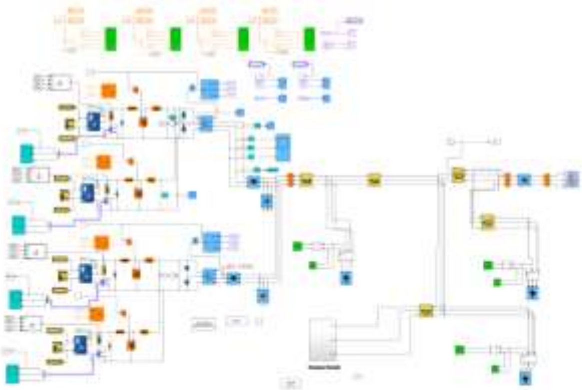


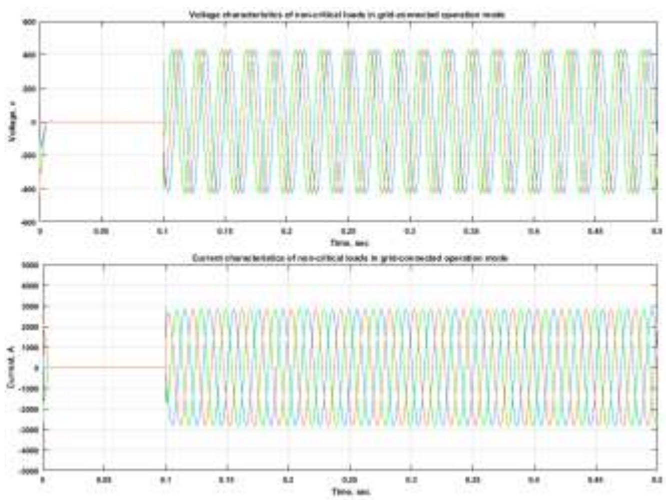
Figure 8: Simulation model of KBU Microgrid on MATLAB/Simulink.

DER	**Units number**	**Min. Power, kW**	**Max. Power, kW**
PV	4	21	24
Diesel Generator	1	375	400
Loads			
Critical loads1	20	216.4	226.57
Critical loads2	3	14.18	21
Non-critical loads	35	520	550
Total Loads		**750.58**	**797.57**

Table 1: Details of DER and Loads of KBU MG.

3.1. Grid-connected operation mode

In grid connected mode MG becomes as load that control by main grid. Similar to power system in this mode the distributed generations are controlled to generate active and reactive power. PV loads, diesel generator loads and noncritical loads dynamical performances are illustrated in Figures 11, 12 and 13 respectively. Simulation result of three-phase voltage at PCC shows while the interconnection from islanded to grid-connected mode there is delay time of 0.1 sec (Figure 14). The results demonstrate that control of DERs and coordination of loads sharing is an effective way to provide the reliability of MGs. Therefore, the purpose of the DG is to control the output real power and reactive power.



International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

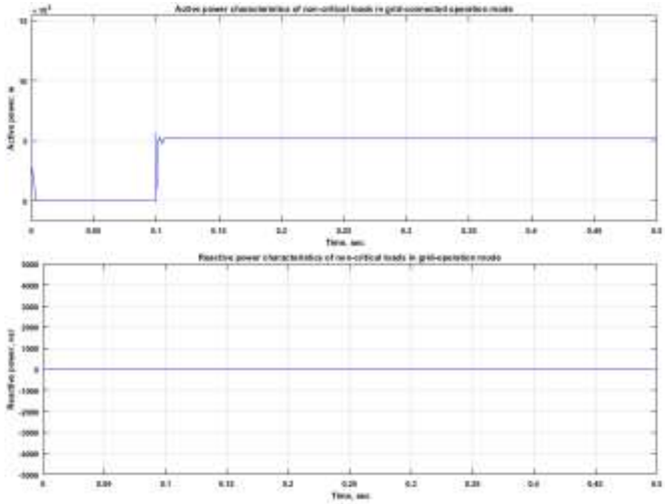


Figure 12: Dynamical performances of non-critical loads in grid-connected operation mode.

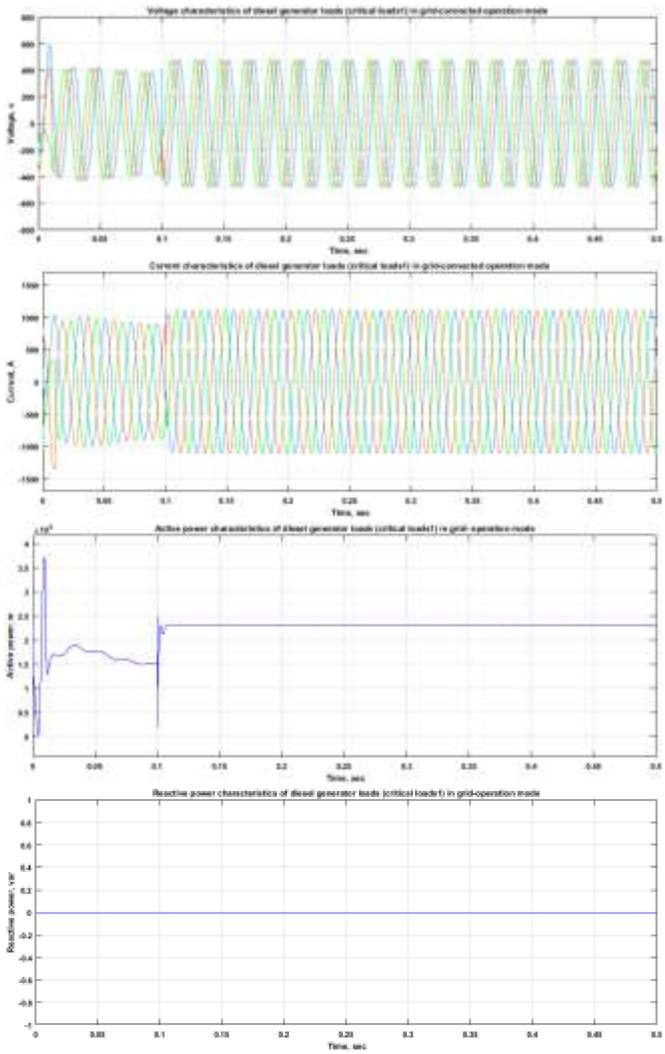


Figure 12: Dynamical performances of diesel generator loads (crtical loads1) in grid-connected operation mode.

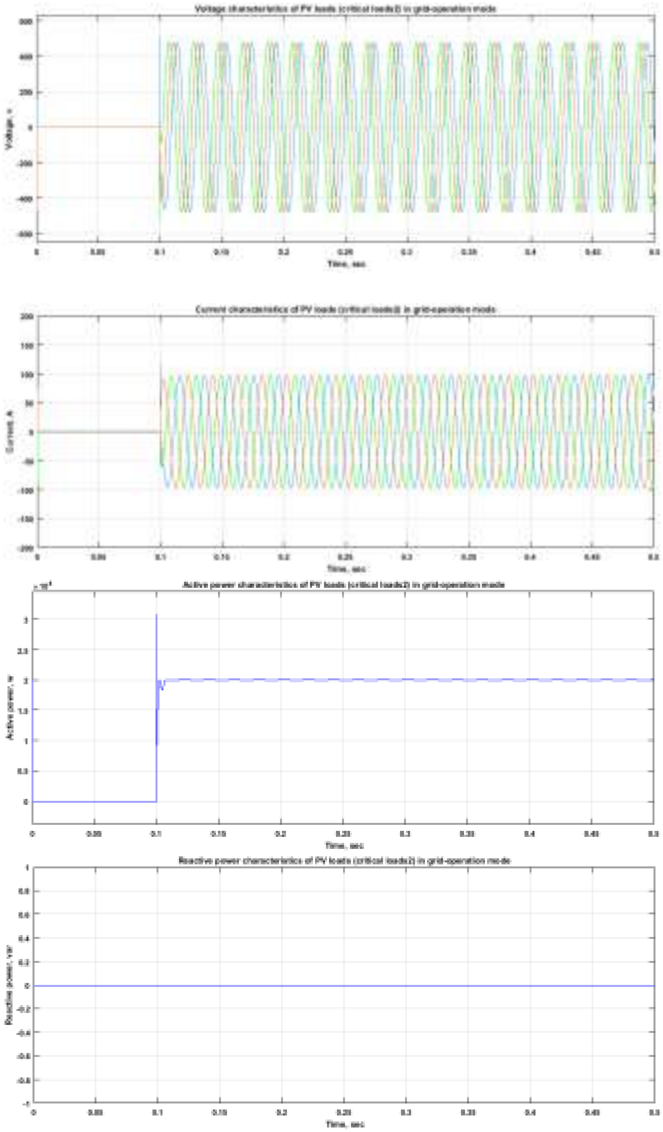
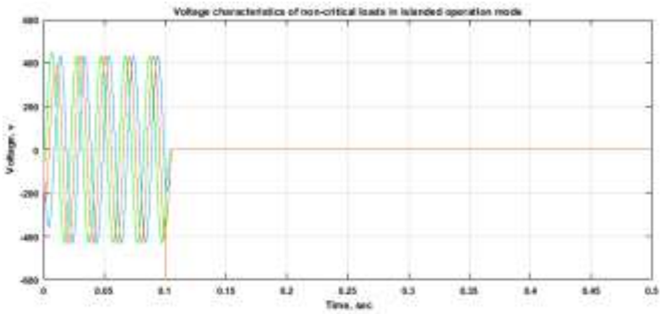


Figure 11: Dynamical performances of PV loads (critical loads2) in grid-connected operation mode.

3.1. Islanded operation mode

If in the main grid occurs faults or power outages, MG is disconnected from main grid and non-critical loads cut-off from power system. The dynamic performances of PV loads in islanded operation mode are shown in Figures 9. The characteristics shows that at 0.5 sec. PV system reaches steady operation. Another critical load – diesel generator loads dynamic characteristics are shown in Figure 10.



International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

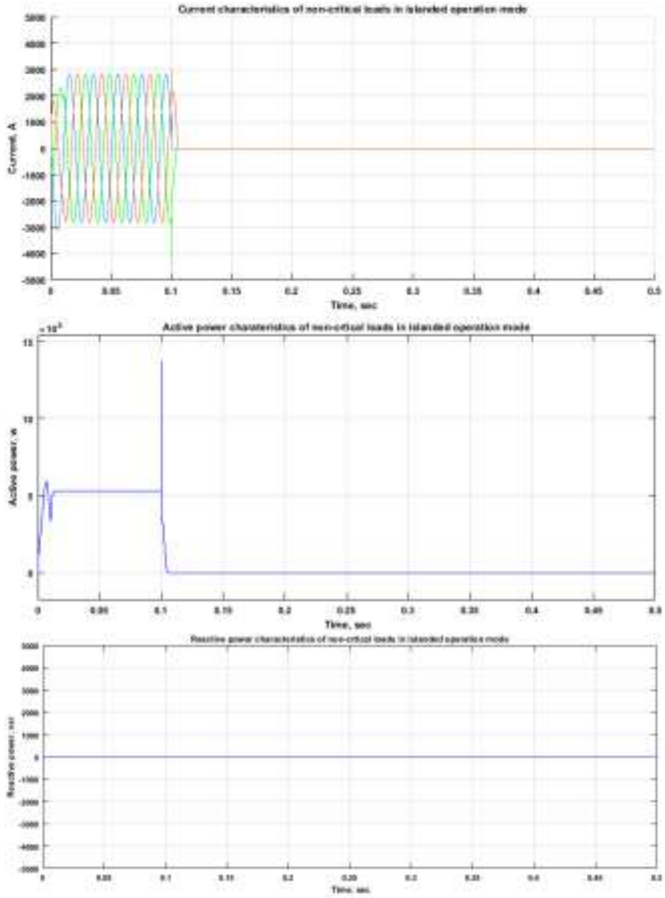
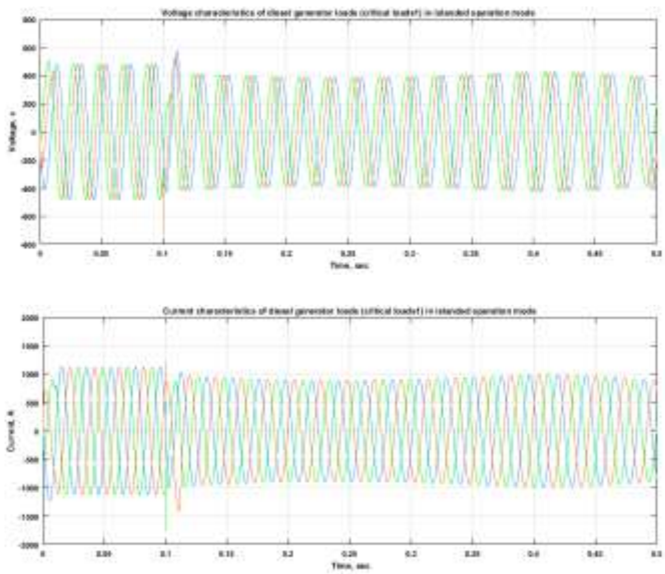


Figure 9: Dynamical performances of non-critical loads in islanded operation mode.



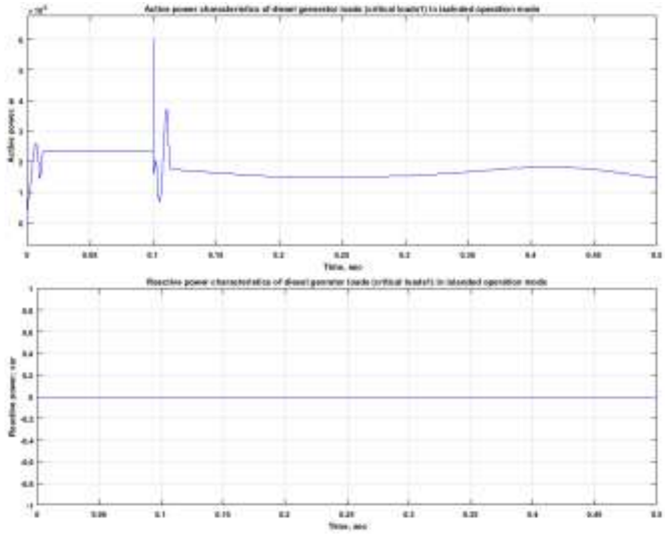
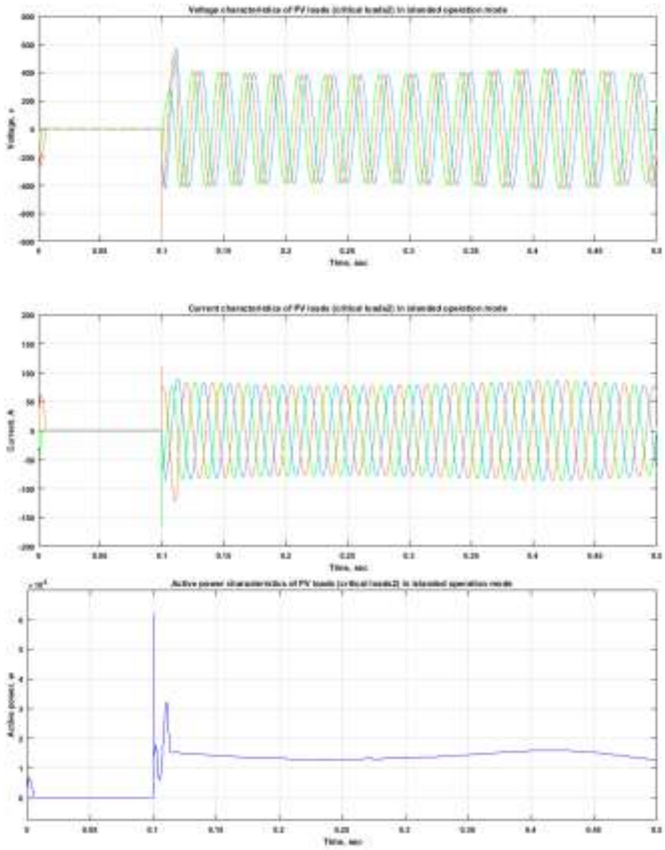


Figure 11: Dynamical performances of diesel generator loads (critical loads1) in islanded operation mode.



International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 02 Feb 2024, pp: 456-466 www.ijaem.net ISSN: 2395-5252

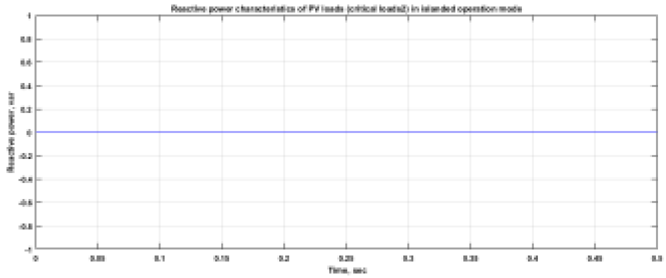


Figure 11: Dynamical performances of PV loads (critical loads2) in islanded operation mode.

IV. CONCLUSION

Microgrid is consists of DERs, energy storage units and loads in LV distribution network. The integration of DERs into distribution network requires to provide the stability and reliability operation of MG by the reason of fluctuation and intermittence of micro-sources and nonlinear loads.

The mathematical and simulation models of KBU MGare developed in this paper. The case studies of KBU MG simulation are carried out on three-phase, 3-bus, 0.4 kV for disconnected and grid-connected operation modes.The simulation results of KBU MGoperation modes show that control of distributed energy resources and coordination of loads sharing is an effective way to provide the reliability of MG. Results and conclusions that obtained in this work will apply to integrate distributed generation in KBU campus.

Acknowledgements
This work was supported by the Karabuk University Scientific Research Projects Unit under the Support for Overseas Activities Project.

REFERENCES

[1]. R.H. Lasseter, P. Paigi, "Microgrid: A Conceptual Solution", Proceedings of the 2004 Power Electronics Specialists Conference (PESC'04),**vol.** 6, pp. 4285-4290, (2004).

[2]. R. H. Lasseter, "Microgrids and distributed generation," J. Energy Eng., **vol**. 133, no. 144, (2007)

[3]. J. A. P. Lopes, "Management of microgrids", presented at the Int. Elect. Equipment Conf., Bilbao, Spain, (2003).

[4]. K. Basu, S. Chowdhury, and S. P. Chowdhury, "Strategic deployment of CHP-based distributed energy resources in microgrids," in Proc. IEEE Power Energy Soc. General Meeting, pp. 1–6, (2009).

[5]. S. Abu-Sharkh et al. "Can microgrids make a major contribution to UK energy supply?",Renewable and Sustainable Energy Reviews,**vol**.10, pp.78-127, (2006).

[6]. A.K. Basu, S.P. Chowdhury, S. Chowdhury, S. Paul,"Microgrids: energy management by strategic deployment of DERs – a comprehensive survey",Renewable and Sustainable Energy Reviews;**vol**. 15, pp.4348-4356, (2011).

[7]. F. Katiraei, M.R. Iravani, and P.W. Lehn, "Micro-grid autonomous operation during and subsequent to islanding process," IEEE Trans. Power Del., vol. 20, no. 1, pp. 248–257, (2005).

[8]. H. Karimi, H. Nikkhajoei, and M.R. Iravani, "Control of an electronically-coupled distributed resource unit subsequent to an islanding event",IEEE Trans. Power Del., **vol.** 23, no. 1, pp. 493–501, (2008).

[9]. E. Erdogdu. "On the wind energy in Turkey", Renewable and Sustainable Energy Reviews,**vol**. 13, pp. 1361-1371, (2009).

[10]. A.Ilhan, M.Bilgili. "An Overview of Turkey's Offshore Wind Energy Potential Evaluations", Turkish Journal of Scientific Reviews,**vol**. 9 (2): 55-58, (2016).

[11]. M. Mahmoud, S.A. Hussain, M. Abido, "Modeling and control of microgrid: an overview", Journal of Franklin Institute, **vol**. 351, vo.5, pp. 2822-2859, (2014).

[12]. O. Gergaud, G. Robin, B. Multon, B. Ahmed, "Energy modelling of a lead-acid battery within hybrid wind/photovoltaic systems",SATIE – Brittany Branch, EPE, (2003).

[13]. R. Jordehi. "Maximum power point tracking in photovoltaic systems: A review of different approaches", Renewable and Sustainable Energy Reviews,**vol**. 65, pp. 1127-1138, (2016).

[14]. D. Freeman, "Introduction to Photovoltaic Systems Maximum Power Point Tracking", Texas InstrumentsApplication Report SLVA446, (2010).

[15]. S. Singh, L. Mathew, S.L. Shimi, "Design and Simulation of Intelligent Control MPPT Technique for PV Module using MATLAB/SIMSCAPE", International

Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE), vol. 2, issue 9, pp. 4554-4565, (2013).

[16]. A.M. Noman, Kh.E. Addoweesh, and H.M. Mashaly, "DSPACE Real-Time Implementation of MPPT-Based FLC Method," International Journal of Photoenergy, vol. 2013, Article ID 549273, 11 pages, (2013).

[17]. J.C. Vasquez, J.M. Guerrero, M.Savaghebi, J. Eloy-Garcia, and R. Teodorescu, "Modeling, analysis, design of stationary-reference-frame droop-controlled parallel three-phase voltage source inverters", IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1271–1280, (2013).

[18]. F. Ding, P. Li, B. Huang, F. Gao, C. Ding, and C. Wang, "Modeling and simulation of grid-connected hybrid photovoltaic/battery distributed generation system", in Proceedings of the China International Conference on Electricity Distribution (CICED '10), pp. 1-10, (2010).

[19]. Zhong Q C, Zeng Y, "Universal Droop Control of Inverters with Different Types of Output Impedance", IEEE Access, vol. 4, pp. 702- 712, (2016).

[20]. Pogaku, N., Prodanovic, M., and Green, T.C. "Modeling, analysis and testing of autonomous operation of an inverter-based microgrid",IEEE Transactions on Power Electronics, vol. 22(2), pp. 613–625, (2007).