Modeling and Control of Decentralized Microgrid Based on Renewable Energy and Electric Vehicle Charging Station

Ziyodulla Yusupov[1](✉), Nuri Almagrahi[2], Elaheh Yaghoubi[1], Elnaz Yaghoubi[1], Adib Habbal[1], and Dilshod Kodirov[3]

[1] Karabuk University, Karabuk, Turkey
{ziyadullayusupov,adibhabbal}@karabuk.edu.tr
[2] Higher Institute of Science and Technology, Souq Alkhamis Amsahal, Libya
[3] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, National Research University, Tashkent, Uzbekistan
d.kodirov@tiiame.uz

Abstract. Energy scarcity, environmental pollution, and the exponential rise in demand for energy are all significant global problems. The integration of distributed energy resources (DER) into electric power systems (EPS) and the use of electric vehicles (EVs) due to low pollution has increased in recent decades. The operating reliability and efficiency of the power systems are affected when DERs and energy storage devices are integrated into a distribution network. In a different scenario, a vital step toward low-carbon mobility is the electrification of automobiles. To integrate the widespread adoption of electric vehicles into EPS, it is necessary to coordinate the combination of centralized and decentralized control of EPS at the EV grid infrastructure. In this paper, a microgrid (MG) with decentralized control of renewable energy and an EV charging station is designed and modeled for Karabuk University campus. In the proposed mathematical model, the Park transformer is applied based on injection current in the Point of Common Coupling (PCC) and using the PI controller to control active power. This technique can keep the frequency and power in both grid-connected and islanded modes, also significantly reducing the number of harmonics in the grid-connected mode.

Keywords: Microgrid · Renewable energy · Electric vehicle charging station

1 Introduction

The global need for energy is rising rapidly. Resources derived from hydrocarbons are scarce and subject to depletion. Global difficulties in the modern era include issues with energy security, environmental protection, and economic progress. Maintaining the functionality of electricity systems while taking all technical, economic, and environmental requirements into account is challenging year after year [1, 2].

R. A. Aliev et al. (Eds.): WCIS 2022, LNNS 912, pp. 1–7, 2024.
https://doi.org/10.1007/978-3-031-53488-1_11

In recent years, the proportion of renewable energy sources (RES) in the production of energy has been rising [3], because they have a favorable effect on tackling environmental issues as a clean energy source, have cheap operating and maintenance costs, and are simple to set up [4]. In the meantime, distributed generation (DG) and MG are growing in importance because of their unique properties [3]. MG aims to boost reliability, reduce carbon dioxide emissions, and improve power system operation and maintenance [5, 6]. MGs usually use distributed generation sources in their systems, such as micro-turbines, photovoltaic (PV) panels, fuel cells, wind turbines, etc. Also, for storing the energy in MGs, we can use batteries, super capacitors, flywheels, etc. [7]. Through a single Point of Common Coupling (PCC), the utility grid and the microgrid can be interconnected [6]. There are two operation modes for microgrids, including grid-connected and islanded modes, and this state conversion is possible by a fast semiconductor switch which is a so-called static switch [8].

Furthermore, the use of EVs is increasing at a faster rate because of the decreased greenhouse gases. EVs have access to AC and DC charging stations. The EV battery requires a direct current charge, therefore the current must be converted either onboard or off board [9].

This study is aimed at designing and modeling decentralized Karabuk University Microgrid (KBU MG) based on renewable energy and EV charging station considering the technical and environmental conditions of the region.

2 Methods

Considering the environmental conditions of the Karabuk region, the solar panels and battery energy storage systems have applied in MG to generate electricity in islanded mode. Figure 1 depicts a single line of the MG system based on a PV-system, a storage battery, and an EV charging station.

The voltage of the distributed generation is altered to DC voltage, and it is connected to the main grid by a bidirectional voltage source converter (VSC). Plenty of power control methods based on current control theory (CCT) have been proposed in order to improve the effectiveness, reliability, and safety of the VSCs for grid-connected MGs [10]. Therefore, in this modeling and simulation, we applied the Park transformer by using the injection current in PCC. During the simulation, the Phase-Locked Loop (PLL) is applied to give a phase angle to the Park transformer because using PLL is utterly common for getting the phase angle of the grid voltage or synchronizing the grid [11].

Plenty of power control methods based on current control theory (CCT) have been proposed. At the first step, during the simulation, the voltage of the distributed generation is altered to DC voltage and connected to the main grid by a bidirectional voltage source converter (VSC). In the second step, the Phase-Locked Loop (PLL) is applied to give a phase angle to Park transformer for getting the phase angle of the grid voltage or synchronizing the grid [10–12].

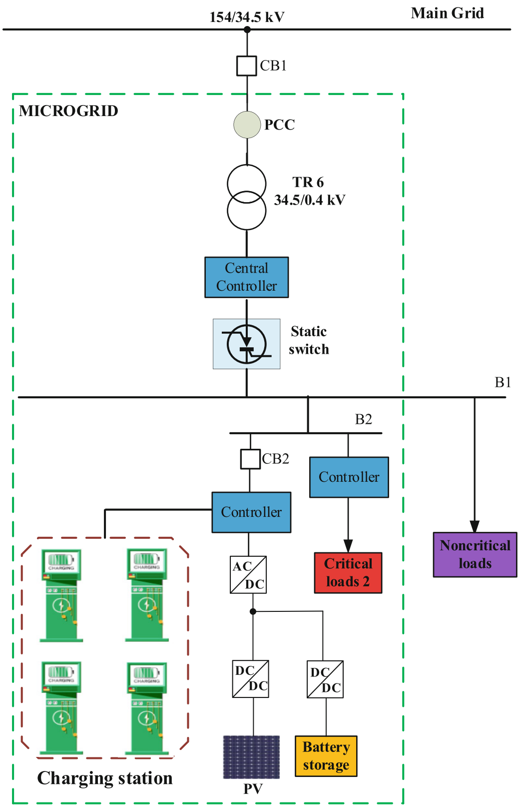

Fig. 1. Single line of proposed KBU MG system.

2.1 Mathematic Modeling

Since it is difficult to work in the time domain as the voltage and current amplitudes change every moment in time, the Park transformer is applied in this modeling. The Park transformer is a synchronous reference device which takes the amplitudes of all three phases ABC and multiplies them by a factor and changes them to *dq*-axis.

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{pmatrix} cos(\theta) & cos\left(\theta - \frac{2\pi}{3}\right) & cos\left(\theta + \frac{2\pi}{3}\right) \\ -sin(\theta) & -sin\left(\theta - \frac{2\pi}{3}\right) & -sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{1}$$

d and q are perpendicular to each other in the balanced device:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{pmatrix} cos(\theta) & sin(\theta) \\ -sin(\theta) & cos(\theta) \end{pmatrix} \begin{bmatrix} u_a \\ u_b \end{bmatrix} \tag{2}$$

where, θ equals:

$$\theta = \omega t + \lambda \tag{3}$$

Suppose we use a voltage reference frame and align the synchronous frame with the voltage. So, $\theta = \omega t$

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{pmatrix} u_m sin\omega t sin(\omega t) + u_m cos\omega t cos(\omega t) \\ u_m cos\omega t sin(\omega t) - u_m sin\omega t cos(\omega t) \end{pmatrix} = \begin{bmatrix} u_m \\ 0 \end{bmatrix} \quad (4)$$

Hence, the active power, voltage, and current can be described as follow, respectively:

$$P = \frac{3}{2}(V_d I_d + V_q I_q) \quad (5)$$

$$V_q = 0 \rightarrow P = \frac{3}{2}(V_d I_d) \quad (6)$$

$$V_d = v_{PCC} \rightarrow I_d^* = \frac{2}{3}\left(\frac{P_{ref}}{V_{PCC}}\right) \quad (7)$$

$$V_{DG}^d + I_d \times R_c - I_q * L_c = V_{PCC}^d \quad (8)$$

$$V_{DG}^d + I_d \times L_c - I_q * R_c = V_{PCC}^q \quad (9)$$

Based on I_d in the PCC and adding the PI controller, the active power and frequency can be controlled in both grid-connected and island modes.

3 Results and Discussion

The simulation results were carried out on MATLAB/Simulink for KBU MG based on PV panels, battery storage, and EV charging station. To gain the maximum power from the photovoltaic system, a maximum power point tracker (MPPT) is applied by Perturb and Observe (P&O) algorithm.

Figure 2 shows the result of active power of VSC in both operation modes of MG. The red line belongs to the active power of the DC link and the blue line demonstrates the active power of the AC link. PV panels generate energy between 0 to 6 s for the storage device and EV charging station, and then inject the remaining power to the main grid. While the system is still in grid-connected mode, the utility is responsible for supplying active power to the EV charging station and storage device according to the inversion of power during 6 to 10 s. as shown by the blue link. Moreover, between 6–10 s., some of active power is supplied by the remaining energy in the photovoltaic system. After 10 s., when the main grid is broken out by a static switch by the reason of failure, MG is working in island mode. There is no power from PV panels in the system and, the storage device supports the essential power to the EV charging station.

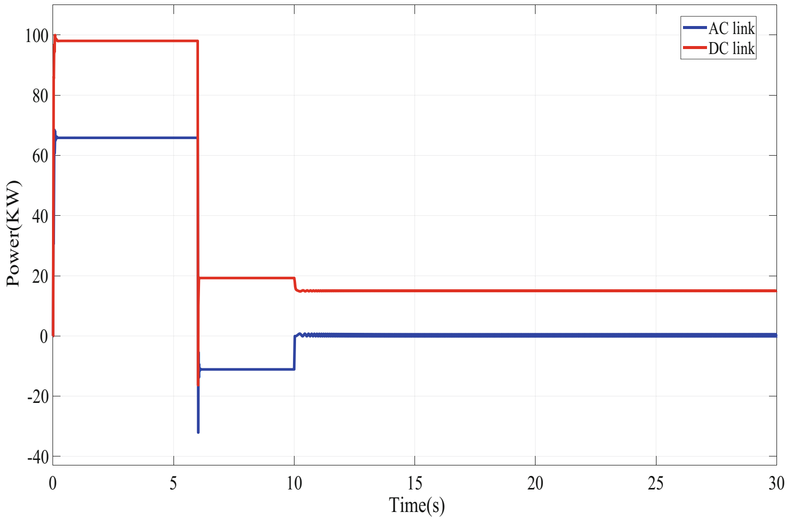

Fig. 2. Active power at PCC.

For the first ten seconds, battery rate of the state of charge (SoC) increases, after that, it goes down as it provides power for the EV charging station, as given in Fig. 3. Besides we could maintain the stability of the EV charging station during the time based on using the park transformer for managing the current and getting feedback and also putting PLL for controlling the frequency. Furthermore, the SoC of the EV charging station remains steady because first of all the photovoltaics, then the main grid, and lastly, the battery storage provides enough power for it as shown in Fig. 4. Moreover, in this condition the storage device is able to act like a slack bus to manage frequency and power.

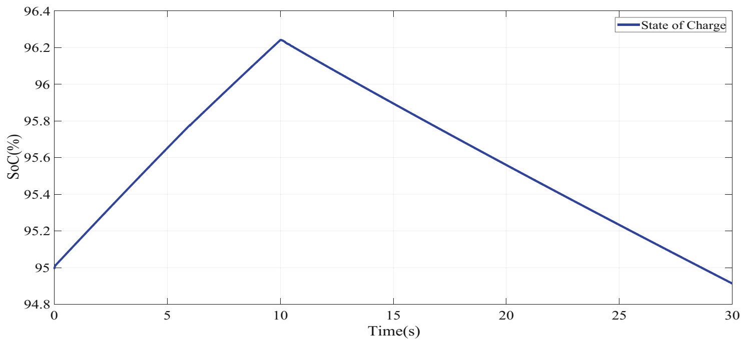

Fig. 3. SOC of battery storage device

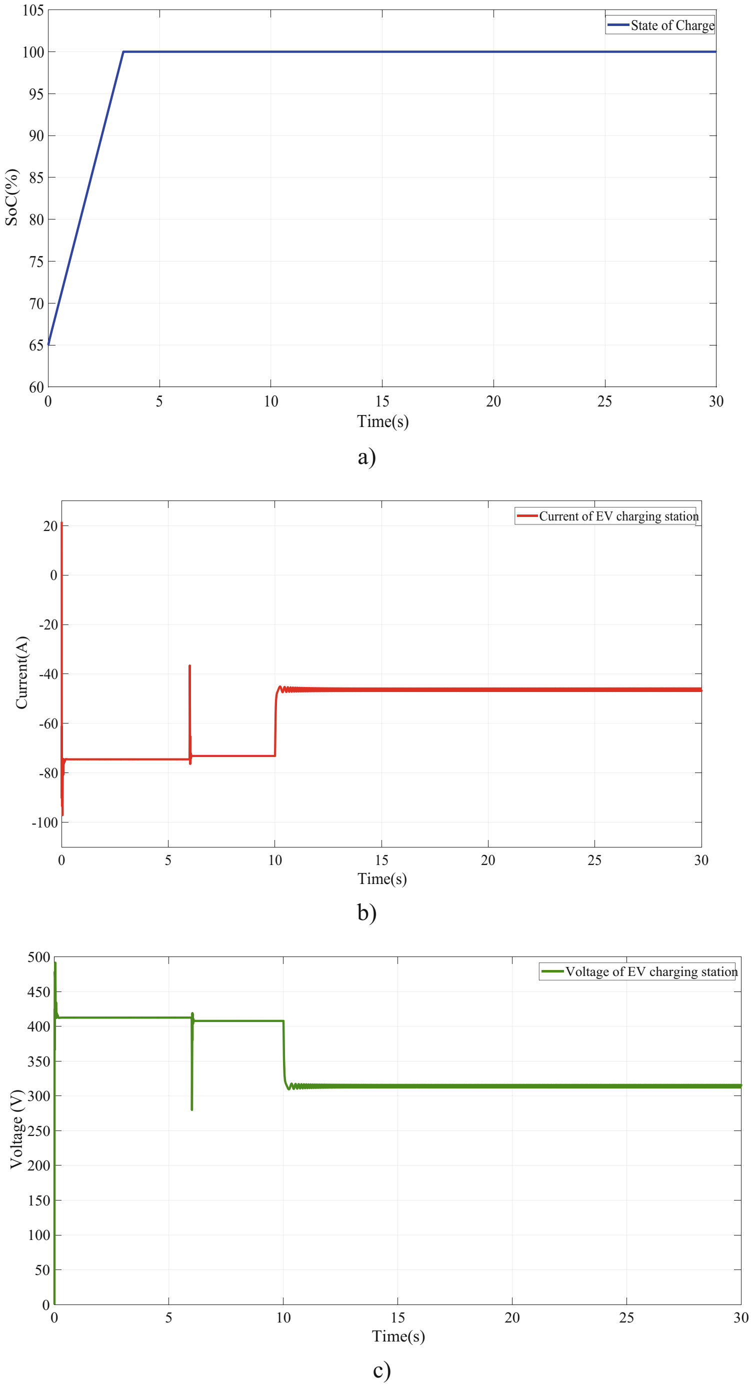

Fig. 4. EV charging station results: a) SOC; b) current; c) voltage.

4 Conclusion

The Karabuk University Microgrid that consists of PV-systems, battery storage device, and EV charging station has been designed according to the university's energy consumption conditions.

A mathematical model of the KBU microgrid was developed by Park Transformer based on current in PCC and using the PI controller for controlling active power. PLL is applied in this design to control the frequency.

Analyzing the results of the simulation reveals that the harmonics of the MG system in grid connected mode have been mitigated. Also, the results show that if there is no power from PV-system and the main grid breaks out, the storage device can play the rules of slack bus for the system to control the power and frequency in the design.

References

1. Zhou, X., Guo, T., Ma, Y.: An overview on microgrid technology. In: IEEE International Conference on Mechatronics and Automation (ICMA), pp. 76–81. (2015). doi: https://doi.org/10.1109/ICMA.2015.7237460
2. Lopes, JA Pecas, et al.: Integrating distributed generation into electric power systems: a review of drivers, challenges and opportunities. J. Electric Power Syst. Res. **77**(9), 1189–1203 (2007). https://doi.org/10.1016/j.epsr.2006.08.016
3. Llaria, A., Curea, O., Jimenez, J., Camblong, H.: Survey on microgrids: unplanned islanding and related inverter control techniques. J. Renewable energy. **36**(8), 2052–2061 (2011). https://doi.org/10.1016/j.renene.2011.01.010
4. Stigka, E.K., Paravantis, J.A., Mihalakakou, G.K.: Social acceptance of renewable energy sources: a review of contingent valuation applications. J. Ren. and Sust. Energy Rev **32**, 100–106 (2014)
5. Yusupov, Z., Guneser, M.T.: The deployment of microgrid as an emerging power system in Uzbekistan. Intern. J. Energy Appli. Technol. **3**(2), 32–36 (2016)
6. Mahmoud, M.S., Hussain, S.A., Abido, M.A.: Modeling and control of microgrid: An overview. J. Franklin Inst. **351**(5), 2822–2859 (2014). https://doi.org/10.1016/j.jfranklin.2014.01.016
7. Lasseter, R.H.: Microgrids distributed power generation. IEEE Power Eng. Soc. Winter Meeting **1**, 146–149 (2001)
8. Paul, S., Maity, N., Sinha, S., Basu, S., Mondal, S., Porel, R.: A Comprehensive Review of the Available Microgrid Protection Schemes and Their Challenges. In: Gao, X.Z., Kumar, R., Srivastava, S., Soni, B.P. (eds) Applications of Artificial Intelligence in Engineering. AIS Springer, Singapore (2021). https://doi.org/10.1007/978-981-33-4604-8_45
9. Khalid, M.R., Alam, M.S., Sarwar, A., Jamil Asghar, M.S.: A Comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid. J. eTransportation **1**, 100006 (2019). https://doi.org/10.1016/j.etran.2019.100006
10. Worku, M.Y., Hassan, M.A., Abido, M.A.: Real time energy management and control of renewable energy based microgrid in grid connected and island modes. J. Energies **12**(2), 276 (2019). https://doi.org/10.3390/en12020276
11. Shameem, A., Mekhilef, S., Mokhlis, H.: An improved power control strategy for grid-connected hybrid microgrid without park transformation and phase-locked loop system. Inter. Trans. Elect. Energy Syst. **31**(7), (2021). https://doi.org/10.1002/2050-7038.12922
12. Fazeli, S.M., Ping, H.W., Abd Rahim, N.B., Ooi, B.T.: Individual-phase decoupled P-Q control of three-phase voltage source converter. IET Gener. Transm. Distrib. **7**(11), 1219–1228 (2013). https://doi.org/10.1049/iet-gtd.2012.0417