Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering
15 (4) (2023) 0017~0026

Research article

Analysis and simulation of Island mode operation in inverter-based microgrids with voltage droop controllers

Babak Keyvani-Boroujeni[1,2], Bahador Fani[1,2], Ghazanfar Shahgholian[1,2*], Mahnaz Hashemi[1,2]

[1]*Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

[2]*Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran*

*shahgholian@iaun.ac.ir

(Manuscript Received --- 25 Sep. 2023; Revised --- 28 Oct. 2023; Accepted --- 04 Nov. 2023)

Abstract

Renewable energy sources are used as distributed generation (DG) sources in distribution networks. Inverter microgrids (MGs) in island operation are nonlinear systems with multiple dynamic modes. One of the main advantages of a microgrid is its ability to operate in islanded mode, where the DGs are responsible for providing both active and reactive power requirements by themselves. The distinguishing feature of distributed generation, with power electronic interfaces, which usually work as voltage source inverters, is the flexibility to provide controlled and high-quality energy. In this paper, the dynamic model of a microgrid based on inverter voltage sources in the first level of control is used. The behavior of a microgrid in the time domain is simulated and the performance of a microgrid is shown in three different modes. The inverter source control model including power control loops, voltage control and current control loops as well as the LC filter of the source output in the dq biaxial reference device are used. The simulation results show that with conventional dropout strategies, the active power distribution is done properly between sources, but it is not accurate enough to distribute the reactive power between the resources of a microgrid.

Keywords: Inverter-Based Microgrid, Droop Control, Island Mode

1- Introduction

Energy has a basic role in increasing industrial productivity, in other words, when energy is available in sufficient quantity and on time, economic development will be possible [1,2]. Energy exists in various forms including heat, light, mechanical, electrical, chemical and nuclear. Energy sources are divided into two categories: renewable and non-renewable [3, 4].

In recent years, traditional electrical power systems have undergone continuous and rapid changes to reduce environmental concerns and respond to consumer demands [5,6]. One of the solutions proposed in this field is the use of renewable and environmentally friendly resources [7,8]. Renewable energy sources such as solar energy [9, 10], wind energy [11, 12], sea wave energy [13,14], and geothermal energy [15,16] are used as distributed generation sources in distribution networks.

A microgrid is a small-scale power grid, consisting of a number of distributed generation units and part of the loads close to these sources, in the field of electrical energy systems [17, 18]. The microgrid is normally connected to the power grid, but it is designed in such a way that in the event of a fault in the upstream grid or prior planning, it can continue to operate as an island and autonomous [19,20]. The islanding capability of the microgrid makes it possible to feed the sensitive loads in the microgrid in the event of a fault in the upstream network. This feature improves reliability for in-network consumers [21, 22]. With the separation of the microgrid from the main network, the control tasks and objectives of the distributed resources in it undergo fundamental changes. In islanded operation mode, the inverter source controller in the microgrid must control the system voltage and frequency and distribute the set of loads according to the source capacity between them [23, 24]. Today, the use of renewable distributed generation sources in medium and low voltage microgrids is of great importance [25, 26]. Typically, voltage source inverters (VSIs) with high switching frequency, are used to connect such sources to distribution networks to produce sinusoidal voltage of the desired quality [27, 28]. A microgrid system that benefits from distributed generation resources has a non-linear and time-varying nature which encounters the control problem with some difficulties [29, 30]. So far, various researches have been done to analyze the dynamic performance of microgrids based on inverter sources.

A small signal model for the inverter microgrid is extracted in [31]. Then, using special value analyze, the effect of different control parameters on microgrid stability has been investigated. The selection of an inappropriate range to change the parameters and their effect on the stability of the inverter microgrid has been studied. Then, using the genetic algorithm, the optimal range for the coefficients of the drop characteristics and the gains of the PI controllers is determined.

The use of a distributed framework to evaluate and improve small signal stability in inverter microgrids has been proposed in [32]. In this study, by selecting a DG bus as the leader, the necessary information is received from adjacent buses. Then, by designing an algorithm, the Jacobin matrix of the system is formed and its stability is evaluated. A local control approach at each inverter based on an event-driven operation of a parameter-varying filter is presented in [33], which, it active power sharing and controllable accuracy for frequency restoration without requiring the exchange of control data between inverters over the communication network. A decentralized power control method in a single-phase flexible ac microgrid is investigated in [34], where, to enhance the dynamics of the power loop, droop control is used together with a derivative controller in island mode. In addition, for the mode connected to the grid, in order to accurately control the power factor, at the common connection point, a droop method is used with an integral controller. An islanded microgrid voltage and frequency control based on fractional order control and an improved droop control scheme are presented in [35], where a sparrow search algorithm is used to adjust the parameters of the fractional-order proportional integral derivative filter controller, and the simulation results show that the proposed controller outperforms the traditional proportional integral controller in efficiency and flexibility.

The dynamic model of a microgrid based on inverter voltage sources in the first level of control is used in this paper. The behavior of a microgrid in the time domain and its performance are simulated in three different modes. The simulation results show the non-distribution of reactive power between the sources of a microgrid using conventional methods. The simulation results show that in the presented method, unlike common loss methods, by using the frequency parameter, active power distribution between sources is done correctly.

2- Control Structure of Distributed Generation Based on Inverter Converter

Fig. 1 of the block diagram of a voltage source inverter (VSI) with the corresponding controllers shows that the inverter is connected to the microgrid via the LC filter and the inductor.

The control structure of the inverter consists of two parts: an external power control loop and an internal control loop, including voltage control loops and current control loops [36, 37].

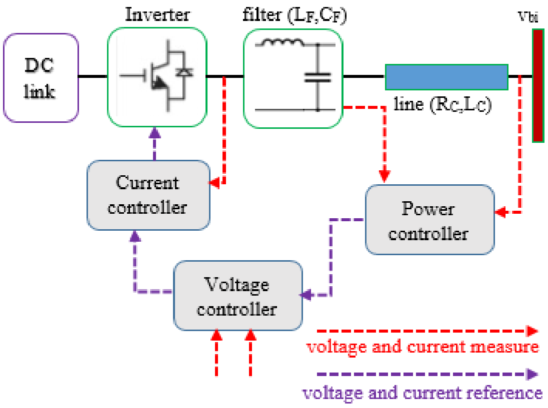


Fig. 1. Inverter microgrid under study (single phase block diagram)

In the power control loop, a local controller is used in each DG to maintain the voltage and frequency in the range of predetermined values, and to increase the reliability of the inverter microgrids in the island operation mode [38,39].

The coordination between the local controllers according to the following equations is obtained by the methods of frequency-active power droop and voltage-reactive power in the power control loop.

$$\omega=\omega_o - m_p P \tag{1}$$

$$V_{or}=V_n - n_q Q \tag{2}$$

Where m_p and n_q are the coefficients of active power droop and reactive power droop of each DG unit, respectively.

The angular frequency of the DG is ω and the nominal frequency of the system is f_o ($\omega_o=2\pi f_o$). V_{or} is the magnitude of the reference voltage is the output of the power controller. The nominal voltage of the system is 380 V. P and Q are the mean values of the active and reactive powers measured at the output of the DGs. The inverter output voltage is regulated by the voltage controller. Usually, a current control loop is used to increase internal stability, increase power quality, and prevent system overload. This controller minimizes the difference between the current passing through the inductor and the current reference calculated by the voltage controller. The output of this controller is the input voltage signal to the inverter.

3- Microgrid model

Microgrid has many benefits for consumers and for power generation companies [40, 41].

Microgrid is an electrical energy generation and distribution system, and it consists of different parts such as distributed generation, energy storage systems, loads and protection equipment [42, 43].

Microgrids have three main structures: AC microgrid, DC microgrid and combined AC-DC microgrid [44, 45]. One of the most important advantages of a microgrid is to improve power quality, provide diverse services to loads, and reduce the influence of distributed generation [46, 47]. Also, microgrids help distribution networks by self-repairing after a fault occurs, due to their independent performance ability.

Microgrids as a new style of distribution network with production control and local consumption can be operated in two functional modes connected to the network and separated from the network (island) [48,49].

The linearized equation of the node voltages in the network can be represented as follows:

$$\left[\Delta v_{bDQ}\right] = R_N (M_{Inv}\left[\Delta i_{oDQ}\right] + M_{Load}\left[\Delta i_{LoadDQ}\right] + M_{Net}\left[\Delta i_{lineDQ}\right]) \tag{3}$$

4- System under study

The single-line diagram of the autonomous inverter microgrid 380 V, 50 Hz studied is shown in Fig. 2 [50].

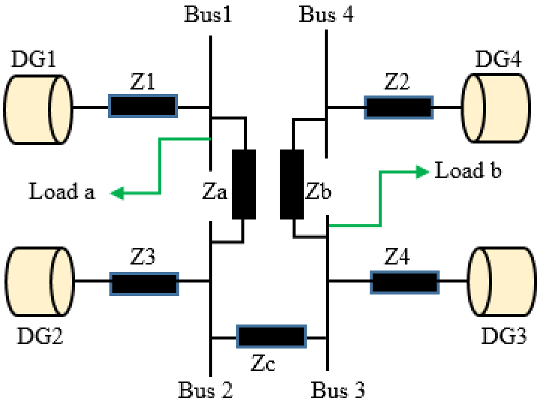


Fig. 2. Inverter microgrid under study (single phase block diagram)

This microgrid includes four distributed generation inverters, which are connected to buses 1 to 4. The capacity of sources 1 and 2 is 33 kVA and the capacity of sources 3 and 4 is 25 kVA.

The buses are connected to each other by 3 transmission lines. The X / R ratio of the lines is very important in the microgrid stability. Therefore, the lines with different X/R ratios are selected, so that the micro-grid does not have a dominant resistance mode or a dominant inductor.

Loads L1 and L2 are connected to buses 1 and 3, and they are powered by sources in the microgrid. Each source is connected to its local bus by a coupling impedance Z_C=0.03+j0.11.

The impedance lines are: Za=0.23+j0.10 Ω, Zc=0.35+j0.58 Ω and Zb=0.23+j0.10 Ω.

5- Simulation results

The scenarios considered for the microgrid simulation are:

(A) examine with the presence of the usual droop strategy

(B) investigation of power sharing status, voltage and frequency adjustment after sudden change of load in microgrid

(C) system performance analysis to enter a source into the microgrid.

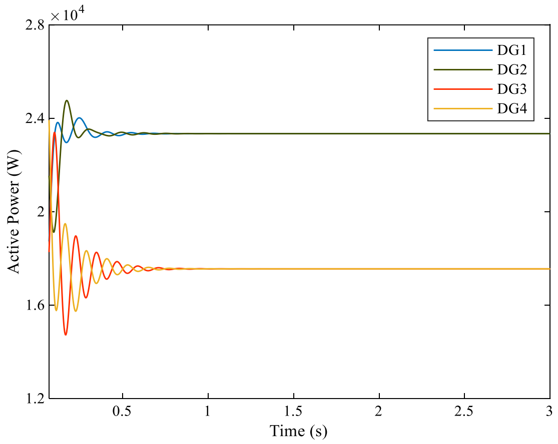
Examine with the presence of the usual droop strategy

The studied microgrid is started with the presence of two loads in the mode of island operation.

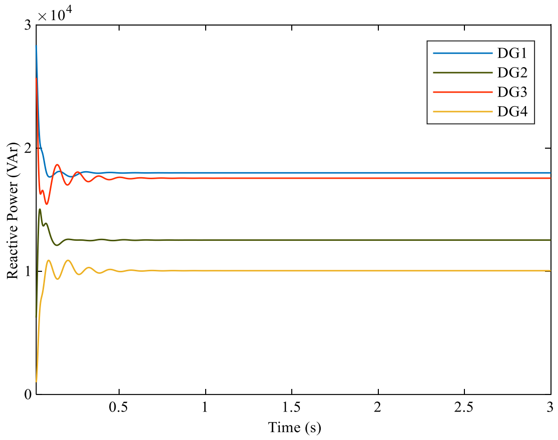
Fig. 3 shows the changes in active power and reactive power. Due to the same capacity and coefficients of droop characteristics of sources 1 and 2 and similar for sources 3 and 4, it is expected that the required active power will be divided between them in proportion to the capacity of the resources.

As can be seen, the ideal active power distribution is achieved between the sources, and all four sources, in proportion to their capacity, contribute to the actual power supply many times over.

But unlike active power, reactive power is not divided according to the capacity of the resources.



(a) active power



(b) reactive power

Fig. 3. Changes in power

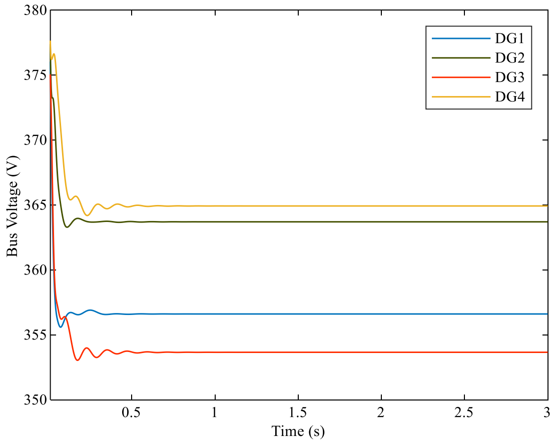


Fig. 4. Changes of sources output voltage

The changes of output voltage shown in Fig. 4.

Fig. 5 shows the frequency changes of the sources. The output voltage of the sources is not equal due to differences in line parameters. However, when the frequency drop controller is applied, the operating frequency of all resources is directed to a common value, which is the operating frequency of the microgrid.

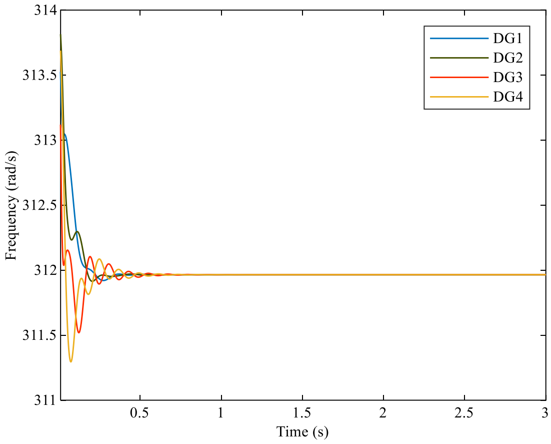


Fig. 5. Change of sources frequency

Sudden change of load in microgrid

In this part, the conditions of change of the working point, due to the sudden change of load, are simulated in the microgrid. After the load changes in the microgrid, the power control units are expected to respond quickly to load changes and distribute it appropriately between resources.

First, the microgrid is set up with the presence of loads.

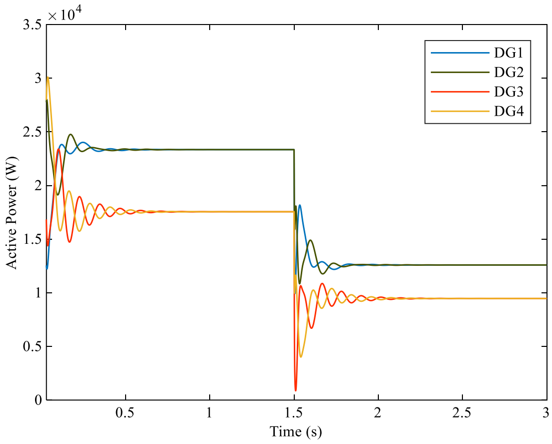
Then at time t=1.5 second, both loads are halved. Fig. 6 shows the active and reactive powers due to load change.

As can be seen, after the reduction of microgrid loads, the share of resources in providing active power is proportional to their capacity.

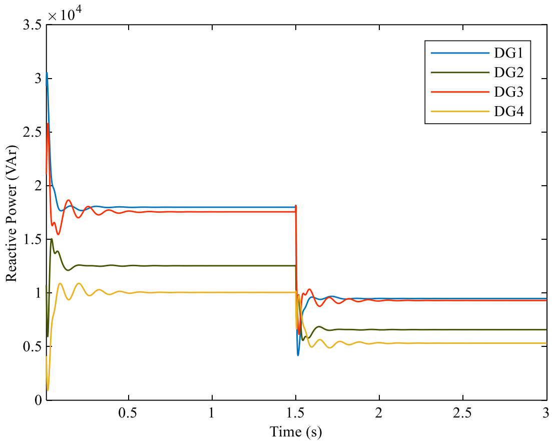
But reactive power is still unequally distributed among resources. Therefore, sudden load changes have no effect on active power sharing. The output voltage and frequency of the sources due to load changes are shown in Figs. 7 and 8.

Enter a source into the microgrid

In real microgrids, the ability of resources to enter and exit the microgrid is very important in its reliable performance. This capability creates conditions in the microgrid that DG can be added to the microgrid without changing the control system [51].



(a) Active power



(b) Reactive power

Fig. 6. Changes in power due to load change

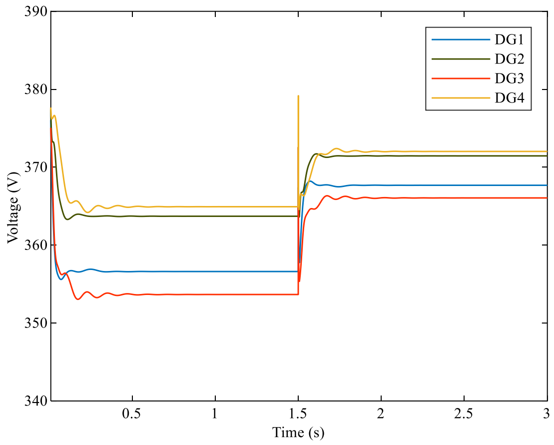


Fig. 7. Changes of sources output voltage due to load change

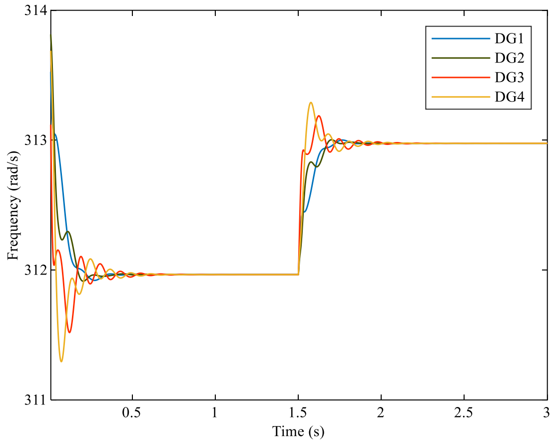
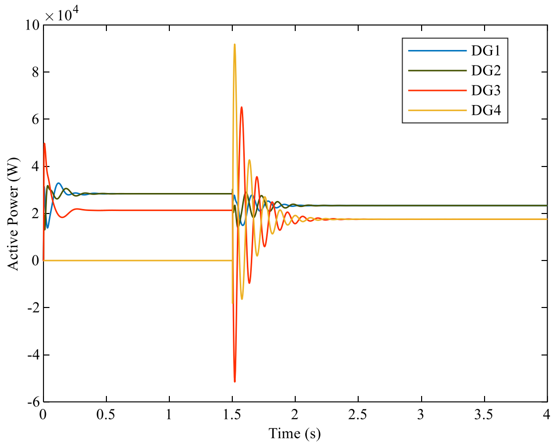
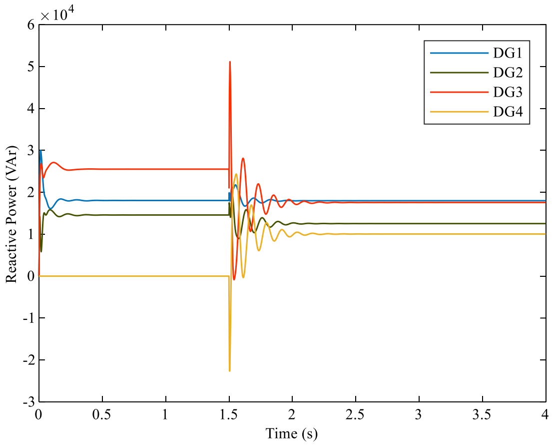


Fig. 8. Change of sources frequency due to load change



(a) Active power



(b) reactive power

Fig. 9. Changes in power due to source entry

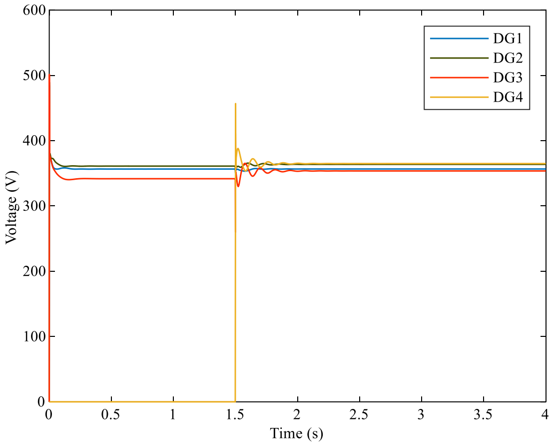


Fig. 10. Changes of sources output voltage due to source entry

In this section, first the microgrid is launched with the presence of only three sources. Then at time t=1.5 sec, the fourth source is connected to the microgrid. Changes in power due to source entry and Changes of sources output voltage due to source entry are shown in Figs. 9 and 10, respectively.

6- Conclusion

One of the basic characteristics of microgrids is that they have the ability to work in grid-connected mode or island mode. In this paper, microgrids including voltage source inverter dynamics, network dynamics and load dynamics are used. In this regard, in order to perform properly and reliably, the first and second levels of a hierarchical control structure are used in the permanent working mode of the autonomous inverter microgrid. Three different scenarios are implemented on a sample microgrid. The results of the simulations have been investigated under different operating conditions such as changes in the microgrid operating point or the entry of resources into the system during operation. The simulation results also showed that due to the universality of the frequency parameter in the whole microgrid, the active power distribution is done properly between the sources, but the common drop strategies for reactive power distribution between the resources of a microgrid are not accurate enough.

References

[1] Zanjani SM. (2023). Dynamic model of static synchronous compensator in single-machine infinite-bus power system. Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering, 15(1), 5-13.

[2] Mozafarpoor-Khoshrodi, S.H., Shahgholian, G. (2016). Improvement of perturb and observe method for maximum power point tracking in wind energy conversion system using fuzzy controller. Energy Equipment and Systems, 4(2), 111-122.

[3] Ghorbani, H., Majidi, B. (2019). Power density optimization through optimal selection of PM properties in a PM-SyncRM using FEM analysis. Proceeding of the IEEE/PEDSTC, 44-49, Shiraz, Iran.

[4] Motaghi, A., Alizadeh, M., Abbasian, M. (2019). Reactive power compensation and reducing network transmission losses by optimal placement of parallel and series FACTS devices with fuzzy-evolutionary method. Journal of Intelligent Procedures in Electrical Technology, 9(35), 27-38.

[5] Zangeneh, M., Aghajari, E., Forouzanfar, M. (2022). Implementation of smart fuzzy logic strategy to manage energy resources of a residential power system integrating solar energy and storage system using arduino

boards. Journal of Intelligent Procedures in Electrical Technology, 13(49), 115-131.

[6] Mesrinejad F, Yaghoubi S, Fani B. (2022). Secondary frequency control for improved dynamic performance in interconnected power system. Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering, 14(4), 5-12.

[7] Taheri, N., Orojlo, H., Ebrahimi, F. (2022). Damping controller design in offshore wind power plants to improve power system stability using fractional order PID controllers based on optimized exchange market algorithm. Journal of Intelligent Procedures in Electrical Technology, 13(51), 89-108.

[8] Fani, B., Karbaschi, A. (2018). Adaptive coordination of fuse– recloser in a distribution system with high PV penetration. Journal of Intelligent Procedures in Electrical Technology, 9(35), 11-18.

[9] Su, H., Liu, T., Hong, H. (2020). Adaptive residual compensation ensemble models for improving solar energy generation forecasting. IEEE Trans. on Sustainable Energy, 11(2), 1103-1105.

[10] Babaei, M., Jahangiri, M., Raeiszadeh, F., Aboutalebi, G. R., Jafari, A., & Nariman, A. (2023). The feasibility of using solar heating in the Yazd hospital: A case study. Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering, 15(2), 17-28.

[11] Cortes-Vega, D., Ornelas-Tellez, F., Anzurez-Marin, J. (2021). Nonlinear optimal control for pmsg-based wind energy conversion systems. IEEE Latin America Transactions, 19(7), 1191-1198.

[12] Hemmati, R. (2025). Optimal operation of electric vehicle charging station based on 100% renewable energy for supplying cryptocurrency mining farm and critical loads in off-grid and grid-tied states. Journal of Intelligent Procedures in Electrical Technology, 16(61), 177-195.

[13] Zhang, Y., Li, G. (2020). Non-causal linear optimal control of wave energy converters with enhanced robustness by sliding mode control. IEEE Trans. on Sustainable Energy, 11(4), 2201-2209.

[14] Cappelli, L. (2014). Linear tubular permanent-magnet generators for the inertial sea wave energy converter. IEEE Trans. on Industry Applications, 50(3), 1817-1828.

[15] Jouanne, A.V., Brekken, T.K.A. (2017). Ocean and geothermal energy systems. Proceedings of the IEEE, 105(11), 2147-2165.

[16] Bamisile, O., Cai, D., Adun, H., Taiwo, M., Li, J., Hu, Y., Huang, Q. (2023). Geothermal energy prospect for decarbonization, EWF nexus and energy poverty mitigation in East Africa; the role of hydrogen production. Energy Strategy Reviews, 49, 101157.

[17] Rahbarimagham, H. (2019). Optimal control of micro-grid (MG) to improve voltage profile including combined heat and power system. Journal of Intelligent Procedures in Electrical Technology, 9(36), 43-50.

[18] Movahedpour, M., Mohammadi, S., Kiani, M.J., Niknam, T., Zadehbagheri, M. (2019). Optimal design of residential microgrids with regard to fault occurrence and possibility of power outage. Journal of Intelligent Procedures in Electrical Technology, 10(39), 29-44.

[19] Akrami H, Shojaeian S, Lotfi M. (2013). Presenting a new algorithm for determining optimal replaceable capacity of conventional power plants by renewable power plants based on monte carlo method. Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering, 6(3), 47-54.

[20] Hagh-Parast, M., Ahmarinejad, A., Rezaee-Jordehi, A., Javadi, S., Hosseini-Aliabadi, M. (2025). A multi-layer model for energy management of multi-microgrids integrated with smart homes and electric vehicles. Journal of Intelligent Procedures in Electrical Technology, 16(63), 83-108.

[21] Patarroyo-Montenegro, J.F., Andrade, F., Guerrero, J. M., Vasquez, J. C. (2021). A linear quadratic regulator with optimal reference tracking for three-phase inverter-based islanded microgrids. IEEE Trans. on Power Electronics, 36(6), 7112-7122.

[22] Kazemi, Y., Rezaei, M.M. (2023). A grid forming control for wind energy conversion systems. Energy Reports, 9, 2016-2026.

[23] Fani, B., Shahgholian, G., Alhelou, H.H., Siano, P. (2022). Inverter-based islanded microgrid: A review on technologies and control. e-Prime- Advances in Electrical Engineering, Electronics and Energy, 2, 100068.

[24] Zamanian, S., Sadi, S., Ghaffarpour, R., Mahdavian, A. (2021). Inverter-based microgrid dynamic stability analysis considering inventory of dynamic and static load models. Journal of Intelligent Procedures in Electrical Technology, 11(44), 91-109.

[25] Aybar-Mejía, M., Villanueva, J., Mariano-Hernández, D., Santos, F., Molina-García, A. (2021), A review of low-voltage renewable microgrids: generation forecasting and demand-side management strategies. Electronics, 10, 2093.

[26] Dixit, S., Singh, P., Ogale, J., Bansal, P., Sawle, Y. (2023). Energy Management in Microgrids with Renewable Energy Sources and Demand Response. Computers and Electrical Engineering, 110, 108848.

[27] Aghajani, G., Mirabbasi, D., Alfi, B., Hatami, H.S. (2017). Demand side management in a smart micro-grid in the presence of renewable generation and demand response. Journal of Intelligent Procedures in Electrical Technology, 8(30), 55-70.

[28] Faiz, J., Shahgholian, G., Ehsan, M. (2011). Modeling and simulation of the single phase voltage source UPS inverter with fourth order output filter. Journal of Intelligent Procedures in Electrical Technology, 1(4), 63-58.

[29] Shahedi, R., Sabahi, K., Tayana, M., Hajizadeh, A. (2019). Self-tuning fuzzy PID controller for load frequency control in ac micro-grid with considering of input delay. Journal of Intelligent Procedures in Electrical Technology, 9(35), 19-26.

[30] Gorji, S., Zamanian, S., Moazzami, M., (2020). Techno-economic and environmental base approach for optimal energy management of microgrids using crow search algorithm. Journal of Intelligent Procedures in Electrical Technology, 11(43), 49-68.

[31] Yu, K., Ai, Q., Wang, S., Ni, J., Lv, T. (2016). Analysis and optimization of droop controller for microgrid system based on small-signal dynamic model. IEEE Trans. on Smart Grid, 7(2), 695-705.

[32] Song, Y., Hill, D.J., Liu, T., Zheng, Y. (2017). A distributed framework for stability evaluation and enhancement of inverter-based microgrids. IEEE Trans. on Smart Grid, 8(6), 3020-3034.

[33] Rey, J.M., Rosero, C.X., Velasco, M., Martí, P., Miret, J. Castilla, M. (2019). Local frequency restoration for droop-controlled parallel inverters in islanded microgrids. IEEE Trans. on Energy Conversion, 34(3), 1232-1241.

[34] Kim, J., Guerrero, J.M., Rodriguez, P., Teodorescu, R., Nam, K. (2011). Mode adaptive droop control with virtual output impedances for an inverter-based flexible ac microgrid. IEEE Trans. on Power Electronics, 2(3), 689-701.

[35] Behera, M.K., Saikia, L.C., Ramoji, S.K., Dekaraja, B., Bhagat, S.K. (2022). A novel decentralized FO voltage and current control scheme for voltage and frequency regulation in inverter dominated islanded microgrids using improved droop control. IFAC-PapersOnLine, 55(1), 679-684.

[36] Salem, A., Khang, H.V., Robbersmyr, K.G., Norambuena, M., Rodriguez, J. (2021). Voltage source multilevel inverters with reduced device count: Topological review and novel comparative factors. IEEE Trans. on Power Electronics, 36(3), 2720-2747.

[37] Zarei, S.F., Mokhtari, H., Blaabjerg, F. (2021). Fault detection and protection strategy for islanded inverter-based microgrids. IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(1), 472-484.

[38] Hmad, J., Houari, A., Trabelsi, H., Machmoum,M. (2019). Fuzzy logic approach for smooth transition between grid-connected and stand-alone modes of three-phase DG-inverter. Electric Power Systems Research, 175, 105892.

[39] Bouzid, A. M., Sicard, P., Chaoui, H., Cheriti, A., Sechilariu, M., Guerrero, J. M. (2019). A novel decoupled trigonometric saturated droop controller for power sharing in islanded low-voltage microgrids. Electric Power Systems Research, 168, 146-161.

[40] Dizioli, F.A.S., Barra, P.H.A., Menezes, T.S., Lacerda, V.A., Coury, D.V., Fernandes, R.A.S. (2024). Multi-agent system-based microgrid protection using angular variation: An embedded approach. Electric Power Systems Research, 220, 109324.

[41] Roslan, M.F., Hannan, M.A., Ker, P.J., Mannan, M., Muttaqi, K.M., Mahlia, T.M.I. (2022). Microgrid control methods toward achieving sustainable energy management: A bibliometric analysis for future directions. Journal of Cleaner Production, 348, 131340.

[42] Jadhav, H.T., Roy, R. (2013). A comprehensive review on the grid integration of doubly fed induction generator. International Journal of Electrical Power and Energy Systems, 49, 8-18.

[43] Kumar, D., Zare, F., Ghosh, A. (2017). DC microgrid technology: System architectures, ac grid interfaces, grounding schemes, power quality, communication networks, applications, and standardizations aspects. IEEE Access, 5, 12230-12256.

[44] Fayazi, H., Moazzami, M., Fani, B., Shahgholian, G. (2021). A first swing stability improvement approach in microgrids with synchronous distributed generators. International Transactions on Electrical Energy Systems, 31(4), e12816.

[45] Ortiz, L., Orizondo, R., Aguila, A., Gonzalez, J.W., Lopez, G.J., Isaac, I. (2019). Hybrid AC/DC microgrid test system simulation: grid-connected mode. Heliyon, 5(12), 1-21.

[46] Seyed-Beheshti-Fini, S.A., Shariatmadar, S.M., Amir, V. (2023). Frequency control in multi-carrier microgrids with the presence of electric vehicles based on adaptive neuro fuzzy inference system controller. Journal of Intelligent Procedures in Electrical Technology, 14(55), 27-42.

[47] Lyu, Z., Yi, J., Song, J., Liu, B. (2023). Coordinated optimal control and dispatching operation of grid-connected AC/DC hybrid microgrid group. Electric Power Systems Research, 221, 109430.

[48] Fayazi, H., Moazzami, M., Fani, B., Shahgholian, G. (2023). Coordination of protection equipment in synchronous generator-based microgrids with regard to maintaining first swing stability. Journal of Intelligent Procedures in Electrical Technology, 14(53), 1-14.

[49] Abbasi, M., Nafar, M., Simab, M. (2022). Management and control of microgrids connected to three-phase network with the approach of activating current limitation under unbalanced errors using fuzzy intelligent method with the presence of battery, wind, photovoltaic and diesel sources. Journal of Intelligent Procedures in Electrical Technology, 13(49), 55-66.

[50] Bidram, A., Davoudi, A., Lewis, F.L., Qu, Z. (2013). Secondary control of microgrids based on distributed cooperative control of multi-agent systems. IET Generation, Transmission and Distribution, 7(9), 822-831.

[51] Uudrill, J.M. (1968). Dynamic stability calculations for an arbitrary number of interconnected synchronous machines. IEEE Trans. on Power Apparatus and Systems, PAS-87(3), 835-844.