WEB OF SYNERGY:
International Interdisciplinary Research Journal
Volume 2 Issue 7, Year 2023 ISSN: 2835-3013
https://univerpubl.com/index.php/synergy

Microgrid Impact on Frequency Stability

Ahmed Yahia Yaseen
Southern Technical University, Iraq

Article Information

Received: May 03, 2023
Accepted: June 04, 2023
Published: July 30, 2023

Keywords: *Frequency Stability, System Inertia, Microgrid, Renewable Energy Resource, Photovoltaic, Wind turbine, Battery, Supercapacitor.*

ABSTRACT

Increases in the level of electricity generated by Renewable Energy Sources (RES) in Microgrids (MG), which have almost low moment inertia because of using power conversion devices, might be dangerous to the power system's ability to run under reliable and stable conditions. Numerous solutions to the stated above problem were presented in this study. The goal of this research is to evaluate the technical viability of supplying an inertial response to MG with high Photovoltaic (PV) and wind turbine power penetration by utilizing energy storage devices based on batteries and supercapacitors. Batteries and supercapacitors are recommended in this study to improve frequency stability and response. The study was carried out using the voltage source inverter design with a droop control technique to improve the frequency response. A detailed model of the provincial MG is built using MATLAB/Simulink to assess the effects of the high level of RES penetration on frequency stability in MG.

I. Introduction

One of the main challenges to implementing an MG based on RES is reducing the system inertia [1]. The frequency variation from the set values under disturbances in traditional generating units less than in the RES because of the net system inertia found of these units, which is principally linked to the rotating mass of synchronous machines [2]. Because the RES is linked to the MG via a power electronic converter device and there aren't any rotating machines that are capable of storing the moment of inertia, the bulk of RES sources are devoid of any inherent inertial support [3]. Both PV and wind turbine systems based on Permanent Magnet Synchronous Generators (PMSG), for example use many stage power conversion forms; this will reduce the system's overall inertia and make it more vulnerable to issues with frequency stability. In situations of frequency disruption, the negative effects of a drop in total system inertia become obvious. System inertia must be kept to a minimum during regular operation in order to retain frequency control capabilities. If sufficient regulatory capability is not reserved, this may result in load shedding or even system collapse. System-regulating capacity has decreased as a result of RES integration [4].

In systems that have low inertia, the Rate of Change of Frequency (RoCoF) will widely fluctuate; any disturbance or fault will result in a sudden increase or drop in frequency and a larger frequency variation [5]. During heavy disturbances, RoCoF can activate the under-frequency load-shedding relays to create a balance between the load demand and the available generation to prevent the system shutdown [6]. As the RES increased in the MG instead of the synchronous rotating generators, the system inertia would be reduced, and maintaining the system in stable operation would face a lot of challenges. The amount of attainable inertia in the power system must thus be accurately predicted by system operators and power grid management [7].

There are many technologies that can be used with RES to enhance the system frequency response during disturbances, which are: using the droop control in inverters; using the ESS; inertia emulation; using synchronous condensers; managing the demand response; and in the worst cases, the protection relays should be used for load shedding and making a balance with available generation [8]. These ESS technologies provide a reliable and efficient solution for managing frequency fluctuations in converter-based systems [9]. By integrating batteries and supercapacitors into the frequency control functions, the system can respond rapidly to frequency disruptions, improving its overall stability and reliability [10, 11]. Additionally, these ESS technologies offer flexibility in terms of scalability and modularity, allowing for easy integration into existing power systems.

In this work, an MG based on PV-Wind-Battery-Supercapacitor systems is simulated by utilizing the MATLAB/SIMULINK program to evaluate the frequency response during disturbances. The impact of the ESS on frequency response in MG will be explained in this work, in addition to the comparison between using a battery or supercapacitor to improve the frequency response. As the ESS levels increase in the MG, the RoCoF will be reduced, and the frequency variation will also be reduced. This will be simulated by using the MATLAB-SIMULINK program. The proposed wind turbine is based on the PMSG, and the droop control of the three-phase inverter is utilized to improve the frequency response.

II. Frequency Response Control Phases during Disturbances

When exposed to frequency disruptions, high rates of RES integration cause longer recovery times and larger frequency deviations, which have a detrimental effect on the stability of system operations. Direct load shedding results from protective mechanisms being engaged if system frequency differs too far from its rated value and the RoCoF exceeds permitted limitations. In dire circumstances, the system may fail. In light of RES integration, it is crucial to comprehend system frequency management. The frequency of the system departs from its rated value when it is disturbed (a discrepancy between supply and demand). The frequency control steps during disturbance at t=0 sec. are shown in Figure (1) [12].

Frequency variation is restricted in the first phase by inertia and load dampening. The second phase involves modifying prime mover inputs to regulate generator outputs. The first two phases, which are caused by maximum frequency variation and the period of frequency recovery, stabilize system frequency. Automatic Generation Control (AGC) gives the generator unit a new required point to restore frequency to its standard value. Unit commitment is required for subsequent control at the final phase [13]. The frequency nadir, or lowest frequency point, as illustrated in Figure (1) depends on the inertia of the RES [6, 12].

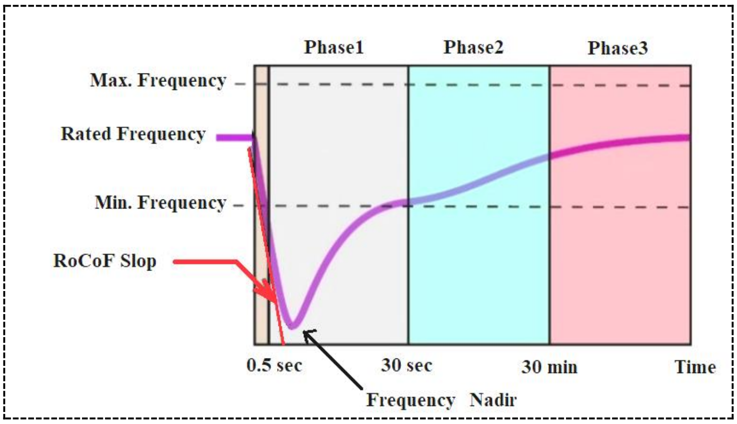

Figure (1): Frequency response during a disturbance at t =0 sec.

First Phase of Frequency Control: system inertia can be considered as first stage in frequency control technique; because of the conventional generators have the ability to They store the kinetic energy among their revolving components, the system's initial frequency capability is enhanced when the stored energy is rapidly released or absorbed after a disturbance [14]. Whenever there is a generation-demand mismatch, there is going to be a discrepancy in the torques acting on the generators' rotors, which will result in acceleration or slowing.

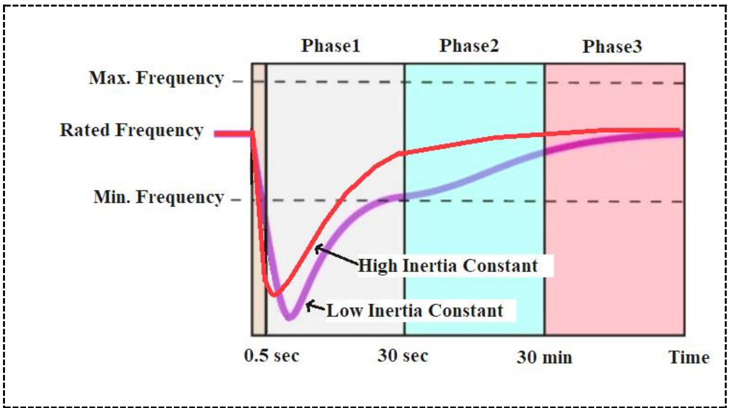

Figure (2): Impact of increasing the inertia on the frequency response

The stored kinetic energy of a generator is typically expressed as a ratio of its VA rating (H) using the inertia constant. It may be stated as the time, and it given in sec., required for a machine to regain its kinetic energy when operating at the output power and speed that are specified in its specifications. Figure (2) explain the effect of the different value of the inertia constant on the frequency response during disturbances. The swing equation gives the following explanation of the relationship among the power dynamic, inertia coefficient [15]:

$$\frac{2H}{w_0}\frac{dw}{dt} = P_m - P_e - K_d\,\Delta w \quad \text{... (1)}$$

For investigations of short periods of time, such as the period following of disturbances, the damper factor K_d is typically ignored. Consequently, the equation (1) can be given as [15]:

$$\frac{2H}{w_0}\frac{dw_m}{dt} = P_m - P_e = \Delta P \quad \text{... (2)}$$

Where w_0 and w_m stand for the nominal and mechanical speeds in rad/sec, the mechanical and electrical powers are (Pm) and (Pe), of the machines correspondingly, in p.u. The inertia constant (H), which is expressed in a sec, is equal to the stored kinetic energy over the specified machine rating in VA.

Second Phase of Frequency Control: the principal control, which is represented by the governor's response, is the governor's immediate response to any changes in system frequency. Shortly after the deviation, frequently within 30 seconds, the governor reduces the frequency deviation and ensures the stability. The frequency is kept within acceptable bounds as long as the second control mechanism is not engaged. The second frequency control system is used only in the region of the disturbance, and it is represented as a PI controller in modeling. The intention is to reset the system to its nominal frequency [16]. It begins following the deviation for a period of around 30 seconds and lasts for a few minutes.

Third Phase of Frequency Control: during the third frequency control phase, the produced units' delivered power is manually altered between tens of minutes and a few hours after a disruption. During this manually regulated procedure, the primary and secondary reserves are supposed to be restored [17].

III. Virtual Inertia

A persistent off-normal variation in frequency may damage equipment, impair load performance, overload transmission lines, and activate protective devices, which can all have an impact on the

ISSN: 2835-3013

running, stability, dependability, and effectiveness of the power system [18]. Increasing the virtual inertia of such a grid is one way to stabilize it. By employing energy storage, a power inverter/converter, and an appropriate control mechanism, virtual inertia may be created for RESs. A virtual synchronous machine (VSM) or virtual synchronous generator (VSG) is the term used to describe this idea. Then, when operating, the generating units will behave like synchronous generators (SGs), showing the inertia and damping characteristics of typical synchronous machines. As a consequence, the virtual inertia notion may serve as a foundation for continuing to use a significant amount of RES in future networks without affecting system stability [19].

There are many benefits when the virtual inertia power grid is used, such as, minimizing the frequency's nadir and variation from its rated frequency, quickening of the transient or reaction times and a reduction in overshoot, the RoCoF will have a less extreme gradient, and lastly, shorter period of time is required to resume the regular frequency. As seen in Fig. (3-a), the VSG is made up of three essential parts: a source of energy, an inverter, and a control system [20]. A major energy source and the grid are connected through the VSG. A dynamic formula that is comparable to the SGs' swing equation is often integrated into the VSG control block and calculates the output power depending on grid readings and their rate of change. Figure (3-b) displays a VSG-controlled inverter with a three-phase connection diagram [21]. Line-to-line voltages and currents are measured, and pulse width modulation signals are evaluated in the VSG control. Power transformer is used between the grid and inverter filter to measure voltage, while the inductor current prevents overcurrent. The system current at the source side is the difference between the filter capacitor and inductor current, with the inductor current equal to the system current. In this work, VSG three phase inverter based on droop control technique is used to evaluate the frequency response during disturbances.

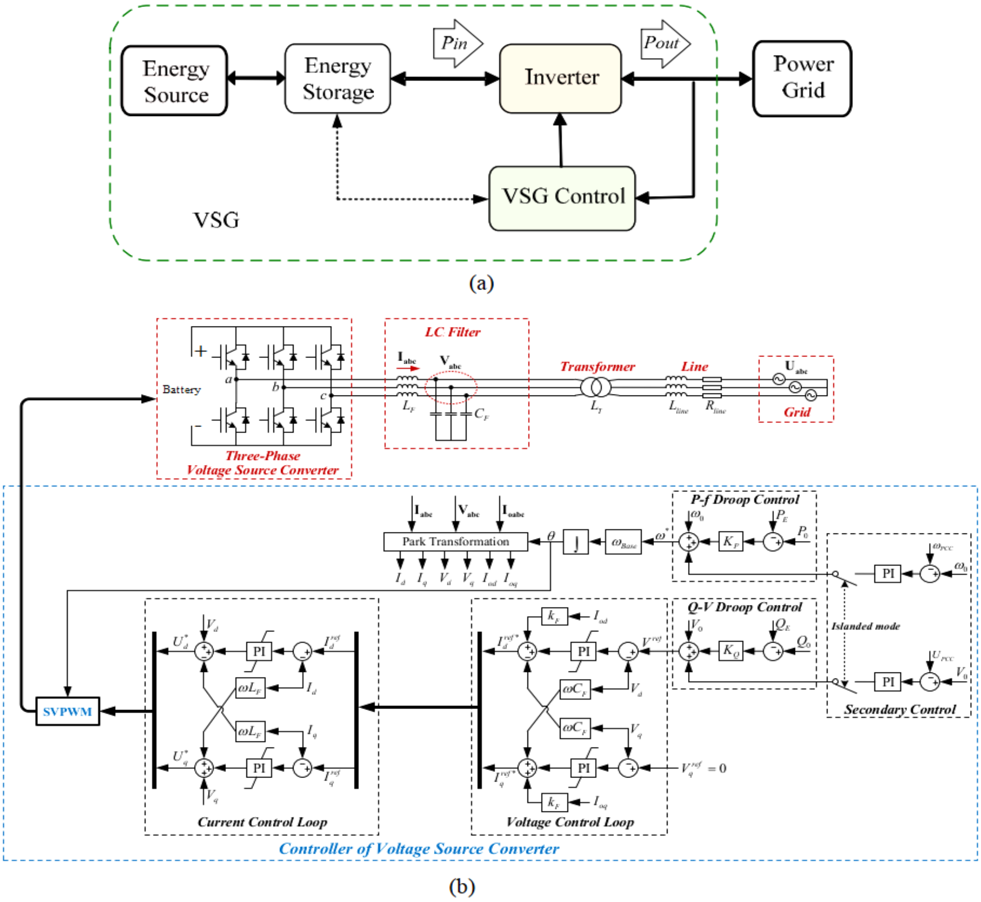

Figure 3: (a) VSG's basic design, (b) detailed design of a three-phase inverter base on VSG

Droop control is essentially the voltage source inverter voltage-controlled technique, which regulates the transferred power by changing the voltage's amplitude and their angle. Active power in an inductive transmission line is mostly influenced by the power angle. The voltage differential determines the reactive power [22]. The droop control approach mimics the droop functions of conventional generation units in the microgrid by adjusting the resulting amount of active (P) and reactive power (Q) to regulate the frequency (F) and voltage (V). This allows the microgrid system to work on maintaining voltage places during island operation mode. Furthermore, it differs less from the voltage in network operation. The switchover is seamless, ensuring that the load continues to operate as usual. The P-F and Q-V droop curves are displayed in the image below together with frequency [23].

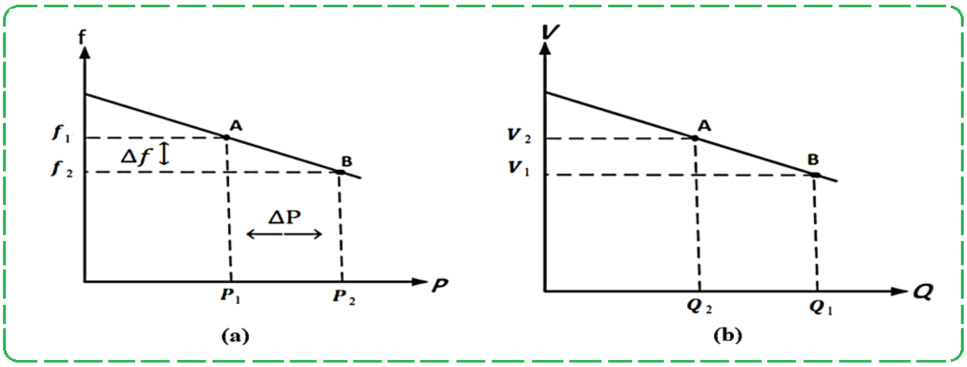

Figure 4: (a) (P-f) droop relationship curve, (b) The block diagram of the (P-f) droop control

In case of the system operates at point (A), with (F1, P1), the increasing in load demand will reduce the frequency and the system will operate at point (B), with (F2, P2) as shown in Figure (4-a) Similarly, when the system operates at point (A), with (V2, Q2), the increasing in reactive power load will reduce the voltage and the system will operate at point (B), with (V1, Q2) as shown in Figure (4-b).

The expression that follows able to be used to get the gradient of the P-F characteristics (m) for both values of P and F [24]:

$$m = -\frac{f_2 - f_1}{P_2 - P_1} = -\frac{\Delta f}{\Delta P} \quad \dots (3)$$

In similar way, the next expression is used to get the gradient of the Q-V characteristics (n) for both values of Q and V [25]:

$$n = -\frac{V_2 - V_1}{Q_2 - Q_1} = -\frac{\Delta V}{\Delta Q} \quad \dots (4)$$

IV. The Proposed Midrogrids

Figure (5) shows the proposed grid connected to MG Based on RES and ESS, the PV system is linked to the DC bus via a DC-DC boost converter, and the PMSG wind turbine is linked to the DC via a three-phase rectifier and a DC-DC boost converter. The Maximum Power Point Tracking (MPPT) for the PV and wind turbines is achieved by using the perturbation and observation (P&O) algorithm. Battery and supercapacitor devices are used in this work as ESS; they are linked to the DC bus via a DC-DC bidirectional converter, which is used for charging and discharging purposes. A three-phase VSG inverter based on the droop control technique is used in this work to emulate the inertia of the system during disturbances and improve the frequency response by reducing the RoCoF variation. The ESS units are also utilized to improve the system inertia and frequency stability. For ESS, two scenarios are proposed in this work: one with a battery system and another with a supercapacitor system. When compared to other ESS, the supercapacitor has many benefits, including a high power density, a prolonged lifespan and a longer shelf life (four to five years), environmental safety, no carbon dioxide emissions, the ability to stop storing energy when it reaches full charge, and the inability to explode in the event of an unintentional direct short connection [26].

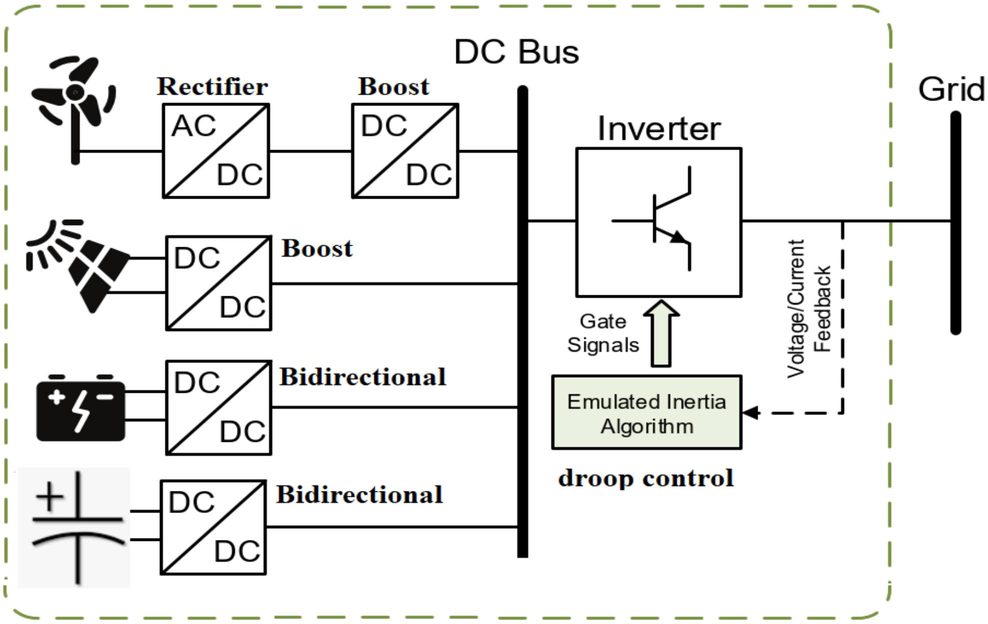

Figure 5: The proposed MG based on RES and ESS

These benefits for hybrid PV-Battery-supercapacitor systems are examined. The two different energy storage devices of a MG based on ESS are frequently connected to a main AC or DC bus. For RESs-based off-grid microgrids with an ESS, connecting via a shared DC bus is the best option for several uses. First off, most common RESs (PV, Fuel cells, etc.) and ESS components operate at DC voltage. Second, the DC bus doesn't require synchronization, which greatly reduces the complexity of the controller and the whole system [26]. The proposed system used the DC bus system connection configuration as explained above.

V. Simulation and Results

According to the proposed MG system shown in Figure (5), the implementation of this system utilizing the MATLAB/SIMULINK program is illustrated in Figure (6). To conduct and evaluate the frequency response in MG in such systems that have RES (PV and wind turbine) energies and ESS, different cases are needed to be studied for this purpose. The generation of the PV system is about 60 kW at 1000 w/m2 irradiation, and the wind turbine generates 27 kW when the wind speed is 11 m/sec. The variable load proposed in this work varies from 35 to 70 kW. The ESS (battery and supercapacitor) is used to supply the required energy when the load demand is greater than the production of the RES and can store the energy when the production of the RES is greater than the load demand. As described in this work, the ESS supports the system with inertia in case of disturbances; this inertia can be increased if the ESS level is increased in the MG. Only the battery system shown in Figure 6 will be replaced with a supercapacitor with the same bidirectional circuit in the case of evaluating the impact of the supercapacitor on the frequency response. The power balance according the proposed energy management system is shown in Figure (7).

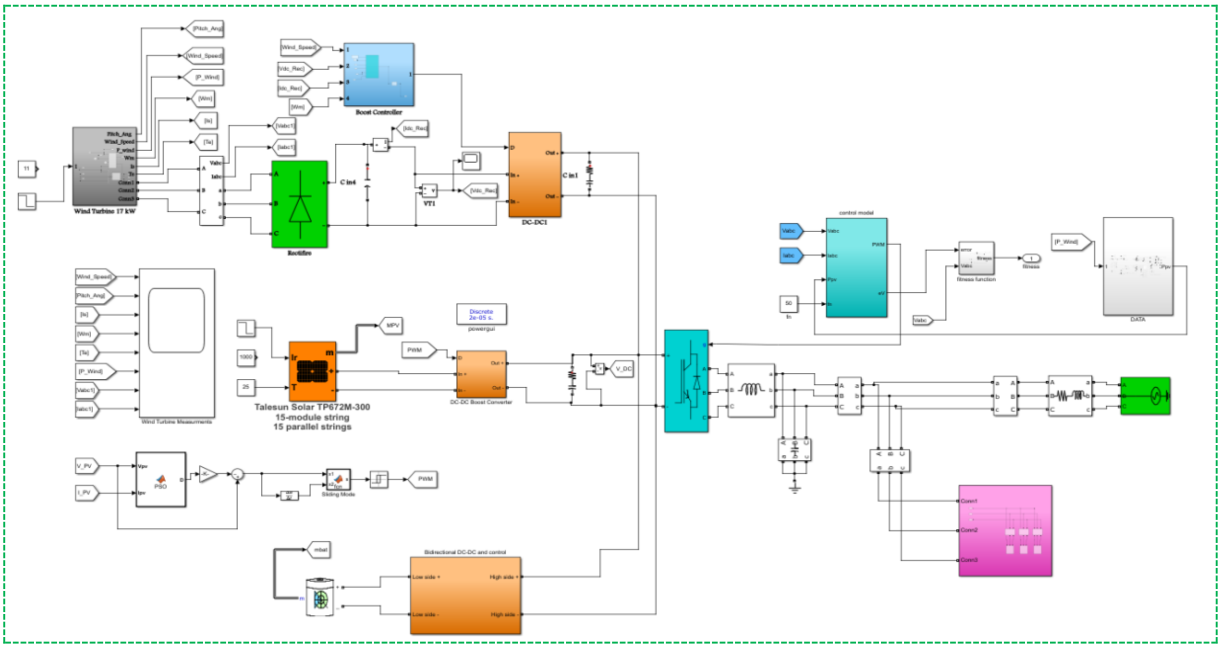

Figure 6: The implementation of the proposed system by MATLAB/SIMULINK program

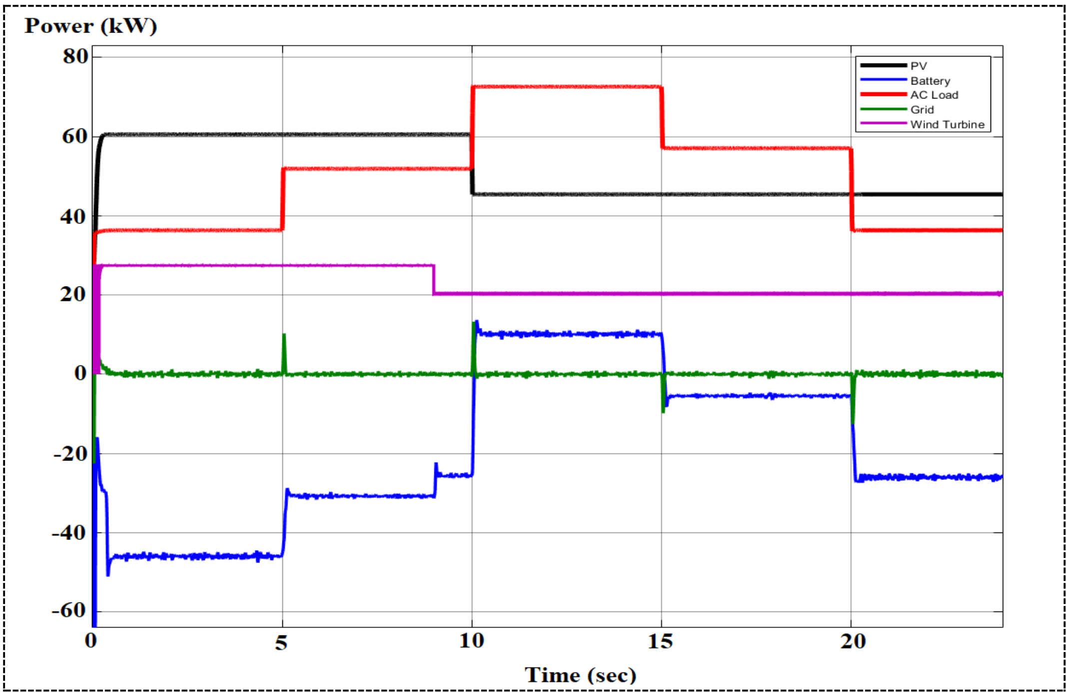

Figure 7: Power balance according to the proposed energy management system

Referring to Figure (7), the maximum disturbance can be present at t=10 sec, when the load increased and the PV generation decreased, the maximum variation in frequency response can be present in this time. In case of there is no ESS, the frequency response at t=10 sec can be shown as in Figure (8), it clear to show that the frequency nadir is (49.84) Hz.

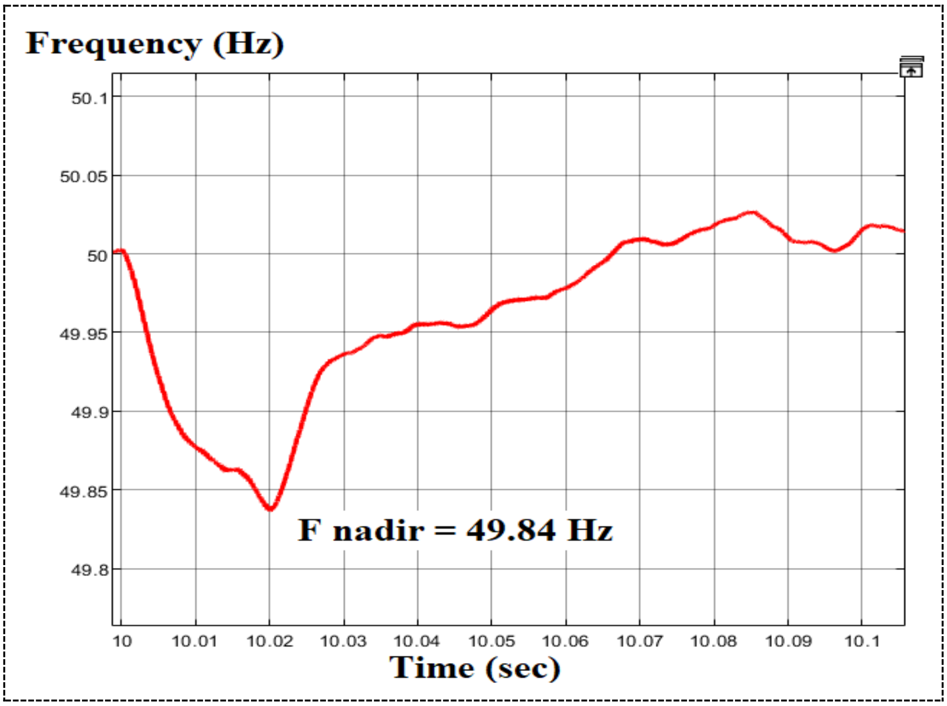

Figure 8: Frequency response without ESS

In case of the battery-ESS is used, the frequency response is improved and deviation from the rated value is decreased, the frequency nadir is about (49.903) Hz as clear in Figure (9).

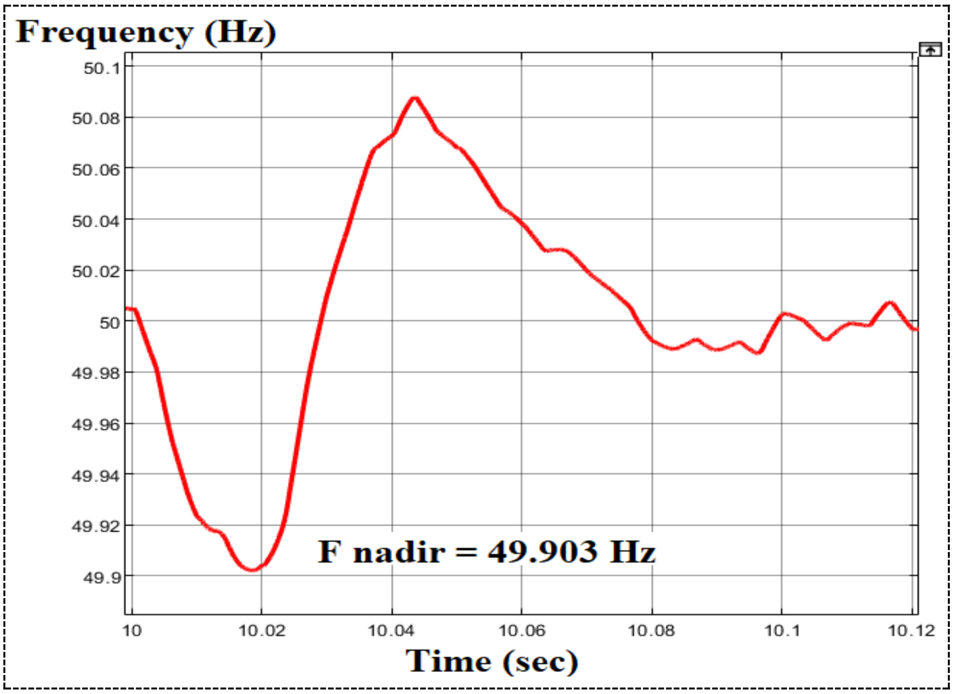

Figure 9: Frequency response with battery-ESS

In case of using supercapacitor-ESS, the frequency response is improved better than when the battery-ESS is used and deviation from the rated value is decreased , the frequency nadir is about (49.919) Hz and also the time to reach the rated frequency is also reduced as clear in Figure (10).

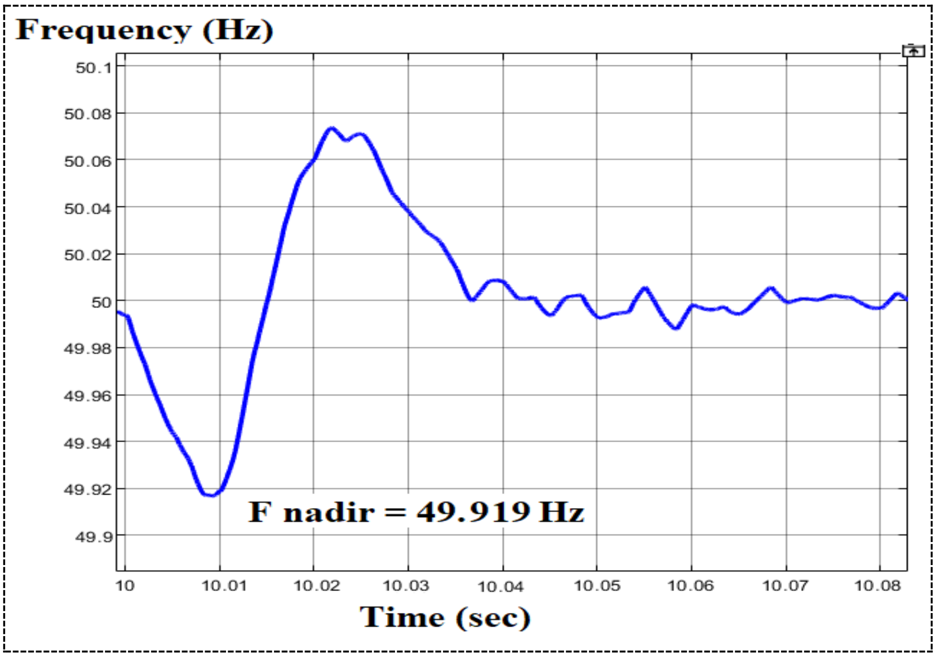

Figure 10: Frequency response with suppercapacitor-ESS

In case of the battery-ESS is doubled, the inertia of the system will be increased, the frequency response in this case will improved and deviation from the rated value is decreased, the frequency nadir is about (49.913) Hz as clear in Figure (11).

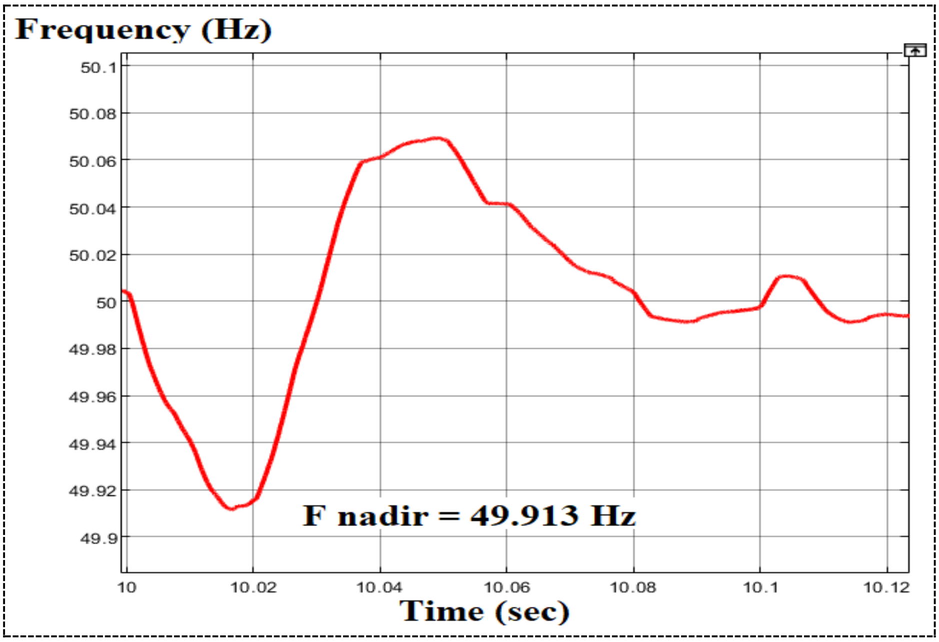

Figure 11: Frequency response when ESS is doubled

VI. Conclusion

This research examines the potential implications of high RES integration on MG frequency responsiveness. In MGs with significant RES penetration, the inertial response and main frequency reserve are reduced, and when a disturbance occurs, the frequency operating limits may be exceeded. ESSs are a viable option for providing inertial response and main frequency reserve for enhancing the frequency response. The MG in this study is made up of PV, wind turbine, and ESS. Battery and a supercapacitor as an ESS are utilized to evaluate the frequency response. The inertia response of batteries and supercapacitors has been provided to increase frequency stability; the findings were obtained in this study by utilizing the

MATLAB/SIMULINK program. The frequency response was investigated using two different ESS values; the RoCof decreased as the ESS size increased, and vice versa. The frequency nadir without ESS is 49.84Hz, while when the ESS is used the frequency nadir is 49.903 Hz. When the battery-ESS increased, the nadir frequency was 49.913 Hz. The supercapacitor-ESS has a faster temporal response than the battery-ESS and can increase frequency stability more effectively than the battery-ESS. To complete this study, droop control of the voltage source inverter model was used to improve the frequency response.

References:

1. Ewais AM, Elnoby AM, Mohamed TH, Mahmoud MM, Qudaih Y, Hassan AM "Adaptive frequency control in smart microgrid using controlled loads supported by real-time implementation" PLoS ONE 18(4): e0283561, 2023, https://doi.org/10.1371/journal.pone.0283561
2. H. Nerkar, P. Kundu and A. Chowdhury,"An Analysis of the Impact on Frequency Response with Penetration of RES in Power System and Modified Virtual Inertia Controller" Journal of Operation and Automation in Power Engineering Vol. 11, No. 1, Apr. 2023, Pages: 39-49, https://doi.org/10.22098/joape.2023.9494.1661.
3. Sahil Mehta and Prasenjit Basak,"A comprehensive review on control techniques for stability improvement in microgrids" John Wiley & Sons Ltd, International Transmission Electrical Energy System. 2021;31:e12822. https://doi.org/10.1002/2050-7038.12822.
4. Raof F. Idana, Ali J. Mahdib, and Thamir M. Abdul Wahab,"Review on Virtual Inertia Control Topologies for Improving Frequency Stability of Microgrid" Engineering and Technology Journal 41 (02) ,2023, P.P: 345- 358, http://doi.org/10.30684/etj.2022.136217.1304 .
5. Alqahtani S., Shaher A., Garada A., and Cipcigan L. "Impact of the High Penetration of Renewable Energy Sources on the Frequency Stability of the Saudi Grid" Electronics, MPI, 2023, 12, 1470. https://doi.org/10.3390/electronics12061470.
6. Shrestha A. and Gonzalez-Longatt F. "Frequency Stability Issues and Research Opportunities in Converter Dominated Power System" Energies, MDPI, 2021, 14, 4184. https://doi.org/10.3390/en14144184.
7. Ha Thi Nguyen, Guangya Yang, Arne Hejde Nielsen, and Peter Højgaard Jensen" Challenges and Research Opportunities of Frequency Control in Low Inertia Systems, E3S Web of Conferences 115, 02001 ,2019, https://doi.org/10.1051/e3sconf/201911502001.
8. Dragozis Romane," Dynamics and control of low inertia power networks with high penetration of renewable energy sources" Master's Thesis, Faculty of Applied Sciences, University of Liège, 2020, available at : https://vdocuments.mx/masters-thesis-dynamics-and-control-of-low-inertia-.html?page=1
9. J. Fang, Y. Tang, H. Li and F. Blaabjerg, "The Role of Power Electronics in Future Low Inertia Power Systems," *2018 IEEE International Power Electronics and Application Conference and Exposition (PEAC)*, Shenzhen, China, 2018, pp. 1-6, https://doi.org/10.1109/PEAC.2018.8590632.
10. Jie Yu, Siyang Liao, Jian Xu, "Frequency control strategy for coordinated energy storage system and flexible load in isolated power system" Energy Reports 8 ,2022, P.P: 966–979, https://doi.org/10.1016/j.egyr.2022.02.133.
11. Md. Nahid Haque Shazon, Nahid-Al-Masood, and Atik Jawad, Frequency control challenges and potential countermeasures in future low-inertia power systems: A review" Energy Reports 8 ,2022, P.P: 6191–6219, https://doi.org/10.1016/j.egyr.2022.04.063.

12. Oladimeji Joseph Ayamolowo, Patrick Manditereza and Kanzumba Kusakana,"An overview of inertia requirement in modern renewable energy sourced grid: challenges and way forward" Journal of Electrical Systems and Inf Technol 9:11, 2022, P.P: 1-27, https://doi.org/10.1186/s43067-022-00053-2.
13. V. Knap, S. K. Chaudhary, D. -I. Stroe, M. Swierczynski, B. -I. Craciun and R. Teodorescu, "Sizing of an Energy Storage System for Grid Inertial Response and Primary Frequency Reserve," in IEEE Transactions on Power Systems, vol. 31, no. 5, pp. 3447-3456, Sept. 2016, https://doi.org/10.1109/TPWRS.2015.2503565.
14. Knap, V., Sinha, R., Swierczynski, M. J., Stroe, D. I., & Chaudhary, S. (2014). Grid Inertial Response with Lithium-ion Battery Energy Storage Systems. In Proceedings of the 23rd IEEE International Symposium on Industrial Electronics, ISIE 2014 (pp. 1817-1822). IEEE Press. https://doi.org/10.1109/ISIE.2014.6864891.
15. Rezkalla, M. M. N., Pertl, M. G., & Marinelli, M. (2018). Electric Power System Inertia: Requirements, Challenges and Solutions. Electrical Engineering, 100(4), 2677-2693. https://doi.org/10.1007/s00202-018-0739-z.
16. Y. Yoo, S. Jung and G. Jang, "Dynamic Inertia Response Support by Energy Storage System with Renewable Energy Integration Substation," in Journal of Modern Power Systems and Clean Energy, vol. 8, no. 2, pp. 260-266, March 2020, https://doi.org/10.35833/MPCE.2018.000760.
17. Alija Mujcinagic, Mirza Kusljugic and Emir Nukic," Wind Inertial Response Based on the Center of Inertia Frequency of a Control Area" Energies, MPDI, 13, 6177, 2020; https://doi.org/10.3390/en13236177.
18. L. Marin, A. Tarrasó, I. Candela and P. Rodriguez, "Stability Analysis of a Droop-Controlled Grid-Connected VSC," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), Portland, OR, USA, 2018, pp. 4161-4167, https://doi.org/10.1109/ECCE.2018.8558126.
19. Xu, W., Wang, B., Liu J., and Li D. "An Improved Droop Control Strategy for Grid-Connected Inverter Applied in Grid Voltage Inter-Harmonics and Fundamental Frequency Fluctuation. Electronics 2021, 10, 1827. https://doi.org/10.3390/electronics10151827.
20. Hassan Bevrani and Jörg Raisch, "On Virtual inertia Application in Power Grid Frequency Control" Energy Procedia 141, 2017, P.P: 681–688, https://doi.org/10.1016/j.egypro.2017.11.093.
21. L. Huang, H. Xin, Z. Wang, L. Zhang, K. Wu and J. Hu, "Transient Stability Analysis and Control Design of Droop-Controlled Voltage Source Converters Considering Current Limitation," in IEEE Transactions on Smart Grid, vol. 10, no. 1, pp. 578-591, Jan. 2019, https://doi.org/10.1109/TSG.2017.2749259.
22. Y. Geng, L. Zhu, X. Song, K. Wang and X. Li, "A Modified Droop Control for Grid-Connected Inverters With Improved Stability in the Fluctuation of Grid Frequency and Voltage Magnitude," in IEEE Access, vol. 7, pp. 75658-75669, 2019, https://doi.org/10.1109/ACCESS.2019.2920312.
23. A. P. N. Tahim, D. J. Pagano, E. Lenz and V. Stramosk, "Modeling and Stability Analysis of Islanded DC Microgrids Under Droop Control," in *IEEE Transactions on Power Electronics*, vol. 30, no. 8, pp. 4597-4607, Aug. 2015, https://doi.org/10.1109/TPEL.2014.2360171.
24. Liu Xia and Liu Hai, "Comparison of dynamic power sharing characteristics between virtual synchronous generator and droop control in inverter-based microgrid," 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia), Kaohsiung, 2017, pp. 1548-1552, https://doi.org/10.1109/IFEEC.2017.7992276.

25. Xiaochao Hou, Yao Sun, Wenbin Yuan, Hua Han, Chaolu Zhong and Josep M. Guerrero,"Conventional P-ω/Q-V Droop Control in Highly Resistive Line of Low-Voltage Converter-Based AC Microgrid" Energies 9, 943; MDPI, P.P:1-19, 2016, https://doi.org/10.3390/en9110943.
26. Ali Almousawi and Ammar A. Aldair, "Control Strategy for a PV-BESS-SC Hybrid System in Islanded Microgrid" Iraqi Journal for Electrical and Electronic Engineering, Vol. 19, Issue 1, June 2023, https://doi.org/10.37917/ijeee.19.1.1.