Microgrid Frequency Control Using Electric Vehicles and Battery Storage system through Adaptive and ANN based PI Control Strategies

Gholam Sarwer
Assistant Professor
Department of Electrical and Electronics Engineering
Rashtrakavi Ramdhari Singh Dinkar College of Engineering
Begusarai,Bihar, India
gholamsarwer001@gmail.com

Md Irshad Alam
Assistant Professor
Department of Electrical Engineering
Sitamarhi Institute of Technology, Sitamarhi,

Gosainpur, Sitamarhi, Bihar, India

Abstract: The integration of renewable energy sources (RES) into traditional power systems is a key element of global efforts to shift toward more sustainable and eco-friendly energy sources. Utilizing electric vehicles and battery storage systems within an isolated microgrid can enhance the system's inertia. Electric vehicles have become increasingly cost-effective, and vehicle-to-grid (V2G) technologies have garnered significant interest. Combining electric vehicles and energy storage systems can effectively manage frequency fluctuations and ensure the efficient operation of the microgrid. This paper examines an isolated microgrid that includes, renewable sources such as wind and solar power systems, and prosumers including electric vehicles and Battery storage systems (BSS). The Adaptive Droop and Proportional-Integral (PI) controllers aim to address frequency regulation issues in the isolated microgrid by effectively managing the Battery storage system (BSS) and electric vehicles (EVs). The PI controller parameters are optimized through Artificial Neural Network (ANN). The proposed model is developed in MATLAB/Simulink, applying the aforementioned control method. Additionally, three case studies are conducted to validate the performance of the PI controller in regulating frequency in the isolated microgrid.

Keywords: Electric Vehicle (EV), PI Controller, Adaptive Droop control (ADC), Battery Storage System (BSS), Isolated Microgrid, Prosumers.

I. INTRODUCTION

Integrating renewable energy sources is essential for addressing the urgent issues of climate change and resource depletion while also establishing a sustainable energy future for coming generations. Increasing the use of renewable energy is necessary to achieve the greenhouse gas reduction targets set by international environmental organizations. For the efficient operation of power systems, maintaining frequency control is a critical challenge, as noted by (Kundur P 1994). Electric vehicles (EVs) act as energy storage units that can charge from and discharge to power grids using vehicle-to-grid (V2G) technology, as suggested by (Rehman H U et al. 2021). In countries such as the United States, Italy, the United Kingdom, and Germany, the future power potential from EVs could surpass domestic electricity consumption by 6.8–10 times, according to (Iqbal S et al. 2022). The projected rise in EV adoption presents an opportunity to implement advanced Load Frequency Control (LFC) systems, which will help ensure grid stability amid changing energy demands.

In the study by (Ota Y et al. 2012), electric vehicles (EVs) are managed to provide frequency regulation in a decentralized manner, while also adhering to the charging schedules set by vehicle users. In the work of (Yang H et al. 2013), EVs are utilized for primary frequency control (PFC) through distributed signal acquisition via limited communication channels. (Liu H et al. 2013) propose a decentralized vehicle-to-grid (V2G) control method for plug-in electric vehicles (PEVs) to participate in PFC, taking into account charging demands from PEV customers.

Maintaining power balance between generation and demand is one of the most challenging tasks in an electrical power system. This balance is partially supported by the inertia inherent in the system, primarily provided by the rotating mass of synchronous generating units—essential components of traditional power systems, as discussed by (Rehman H U et al. 2020). In the event of a failure of a generating unit, a substantial drop in generation can lead to an observable power imbalance. In response, other generators in the system will naturally increase their power output to compensate for the loss. The kinetic energy stored in the rotor of the generator helps the system restore its frequency and balance the power imbalance. However, modern electrical power systems are experiencing a decline in overall inertia due to the increased integration of renewable energy sources (RESs). This shift towards RESs introduces challenges related to frequency and voltage instabilities, as described by (Fernández-Guillamón A et al. 2019). RESs, such as photovoltaic (PV) systems, typically have minimal or no inertia and require converters for grid integration. As RES penetration in the power grid rises, system inertia decreases, as discussed by (Zheng C et al. 2020), which compromises the power grid's ability to manage power imbalances. This issue is further intensified by the intermittent nature of RESs.

Frequency in power systems is a dynamic parameter that indicates the balance between power generation and demand, playing a crucial role in maintaining grid stability. System operators work to keep the frequency within safe, predefined limits, which vary across different regions (e.g., 50 Hz in Asia and Europe, and 60 Hz in North and South America). In China, the acceptable frequency range is particularly narrow (49.8-50.2 Hz), which is more stringent compared to other regions like France and Great Britain, where the permissible range is 50 Hz ± 0.5 Hz, as noted by (Luo X et al. 2018). This tight frequency band in China necessitates robust measures when integrating renewable energy sources (RESs), often requiring Battery storage systems (BSS) to maintain grid stability and facilitate the implementation of microgrids and smart grids. These BSSs can help manage fluctuations in power supply from RESs, smoothing out inconsistencies and contributing to a stable and reliable power system.

Battery storage systems (BSS) are adaptable solutions that can handle load fluctuations and absorb excess power from the grid, thereby effectively countering the intermittency of renewable energy sources (RESs) such as solar and wind, as highlighted by (Nieto A et al. 2016; Jan M U et al. 2021). Integrating various BSS technologies offers a holistic approach to addressing challenges in microgrid management. Electric vehicle (EV) batteries, which serve as mobile battery banks, can be a complementary addition to BSS by helping manage their load. Vehicle-to-grid (V2G) systems enhance microgrid functionality by providing benefits such as frequency regulation, spinning reserve, load demand matching, and reactive power compensation, as detailed by (Banol Arias N et al. 2019; Iqbal S et al. 2020). Frequency regulation in multi-area power systems, particularly those with plug-in electric vehicles (PEVs), must account for communication delays, as demonstrated by (Fan H et al. 2016). Moving away from the traditional dependence on large synchronous generators for frequency regulation, employing BSS and EV fleets offers a more flexible and efficient approach through precise control strategies for battery charging and discharging, as suggested by (Bai Y et al. 2020). As BSS and EVs become more common, controlling the frequency of isolated microgrids (MGs) becomes increasingly complex. Various control strategies have been developed to address these challenges.

This study examines frequency regulation in an isolated microgrid (MG) composed of distributed generation (DG) based on renewable energy sources (RESs) and prosumers. Two specific control methods, Proportional-Integral (PI) and Adaptive Droop Control (ADC), are employed to address power imbalances within the MG by managing energy storage systems and the charging and discharging of electric vehicles (EVs). These control strategies effectively stabilize MG operations, preventing collapse during significant RES integration or fluctuations in load demand. Furthermore, ADC enables EVs to sustain desired power levels for potential future use.

II. MICROGRID MODEL

Researchers have created various dynamic models to validate frequency control within microgrids (MGs), as discussed by (Rehman H U et al. 2021; Fan H et al. 2016). These models incorporate renewable energy sources (RESs) like wind power plants and solar photovoltaic (PV) systems. Additionally, the models integrate prosumers such as electric vehicles (EVs) and battery storage systems (BSS), along with residential loads as power consumers. **Figure 1** illustrates the components of the MG system. Equation (1), suggested by (Jan M U et al. 2021), presents the dynamic model of the isolated MG used for frequency control.

$$\Delta P_{PV} + \Delta P_{wind} + \Delta P_{DG} \pm \Delta P_{EV} \pm \Delta P_{ESS} - \Delta P_L = (Ms + D)\Delta f \quad (1)$$

Where, M, D and Δf represents the system inertia, damping factor and the system frequency deviation respectively.

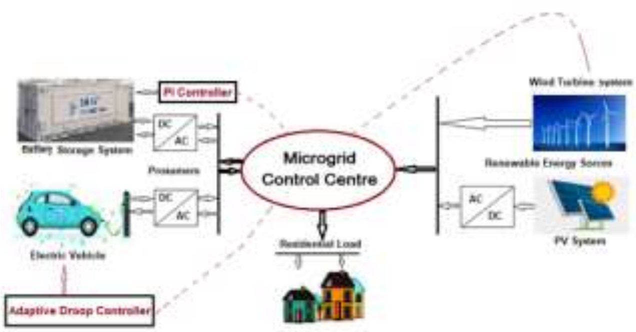


Figure 1 Isolated microgrid dynamic model.

2.1 Renewable Energy Sources (RES)

Solar photovoltaic (PV) systems and wind power systems (WPS) are widely utilized for power generation across the globe, capitalizing on the widespread availability of sunlight and wind energy.

2.1.1 Solar PV Model

Solar panels consist of photovoltaic (PV) cells, which are used to convert sunlight into direct current (DC) power. DC-to-AC converters are needed to transform the DC voltage into the required alternating current (AC) voltages, as illustrated in (Fan H et al. 2016). Equation (2), proposed by (Jan M U et al. 2021), can be used to calculate the output power of the PV system (ΔP_{PV}).

$$P_{PV} = \psi.\varphi.S.\left(1-0.005\left(T_A - 25\right)\right) \quad (2)$$

Where ϕ, ψ, S and T_A denotes the conversion efficiency, solar irradiance and total effective area of the solar panel and the ambient temperature respectively.

2.1.2 Wind Power System Model

Wind energy is most prevalent in coastal areas, plains, and high-altitude regions where wind speeds are consistently high. A wind power system (WPS) generally consists of a wind turbine that drives an induction generator. The system's governor controls the power output by adjusting the pitch angle (β) of the turbine blades. The turbine inputs in a wind power system (WPS) include the mechanical speed (ω) and wind speed (V) of the connected turbine. The change in output power (ΔP_{wind}) of the WPS, with T_w representing the turbine time constant and ±δw indicating the ramp limits, is discussed by (Rehman H U et al. 2020). The output power of the wind power system (P_{wind}) generally depends on various technical parameters outlined in the equation provided by (Jan M U et al. 2021).

$$\Delta P_{wind} = \frac{1}{2} C_p\left(\lambda, \beta\right) A\eta\rho_a V^3 \quad (3)$$

Here, C_p stands for the wind turbine's capturing efficiency, λ for TSR, and β for blade pitch angle. Moreover, efficiency, air density, wind speed, and V are represented by the values of A, η, ρ_a, and V, respectively.

1.2 Prosumers

Prosumers can generate more electricity than they consume, enabling them to either store the surplus for later use or feed it back into the grid. This two-way flow of electricity allows prosumers to actively engage in the electricity market and support grid stability and resilience. This article employs two types of prosumers—electric vehicles and energy storage systems—for frequency regulation.

2.2.1 Electric Vehicle Model

Modeling the electric vehicle (EV) battery is essential for understanding its role in frequency regulation, which is achieved through the provision of vehicle-to-grid (V2G) services via battery charging and discharging. EV batteries (EVBs) offer three key advantages within microgrids (MGs): EVBs effectively stabilize MG frequency by adjusting their stored energy in response to fluctuations in system load. This dynamic adaptability helps maintain consistent frequency levels. EVBs augment MG storage capacity, minimizing the need for additional energy storage systems and associated costs. This efficient use of existing resources can lead to cost savings. Also EVBs can generate financial benefits for owners by selling excess power to the MG during peak demand periods. This practice not only supports the grid but also provides an additional revenue stream for EV owners as outlined in (Rehman H U et al. 2021; Jan M U et al. 2021).

Electric vehicle (EV) batteries are connected to the microgrid through a DC-AC converter, as shown in **Figure 1** and described by (Fan H et al. 2016). Charging the EV battery is crucial for meeting customers' transportation needs and providing additional frequency control. The dynamic model of the EV, illustrated by (Fan H et al. 2016), demonstrates how changes in EV power output (ΔP_{EV}) are regulated by frequency variations (Δf), as shown in equation (4).

$$\Delta P_{EV} = \frac{K_{ev}}{T_{ev}s+1}.\Delta f \quad (4)$$

2.2.2 Battery Storage System (BSS)

Battery storage systems are in high demand for providing frequency regulation services in isolated microgrids due to their rapid response time and flexible operation. BSS can inject a substantial amount of electricity into the grid quickly, effectively acting as virtual inertia, as described by (Bai Y et al. 2020). Unlike traditional generation units that are typically kept online for primary frequency regulation, BSS offers both upward and downward control by adjusting power injection or absorption in response to grid needs. BSS typically maintains its state of charge (SOC) between 20% and 90%, as the output power of BSS (ΔP_{BSS}) changes linearly within this SOC range in response to frequency fluctuations. Below is the transfer function for the Battery Storage System (BSS), as suggested by (Rehman H U et al. 2021).

$$\Delta P_{BSS} = \frac{1}{T_{bss}s+1}.\Delta f \quad (5)$$

III. THE PROPOSED CONTROL SYSTEM MODEL

To examine the impact of electric vehicles (EVs) and battery storage systems (BSS) on microgrid (MG) frequency regulation, this study examines an isolated MG, as shown in Figure 2. A Proportional-Integral (PI) controller manages the regulation of the BSS output in response to system frequency deviations, while the Adaptive Droop Control (ADC) method controls the electric vehicle battery (EVB).

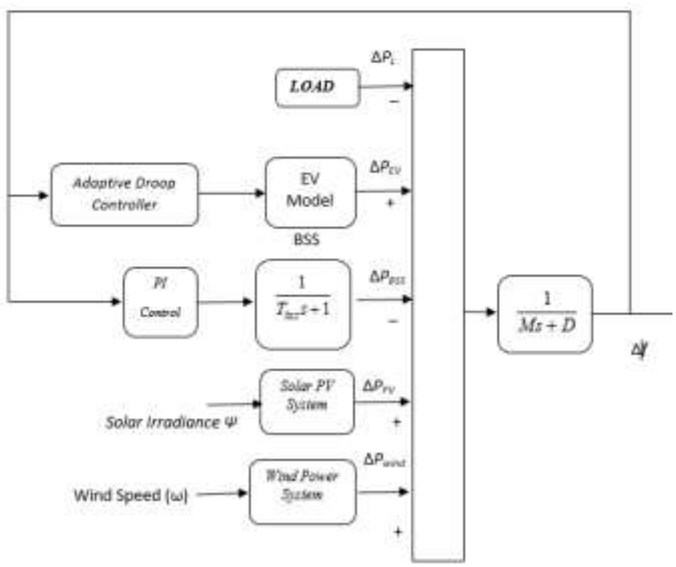


Figure 2 Dynamic Model of the Proposed microgrid

3.1 Modelling of ADC For Electric Vehicle

The overall power of electric vehicles (EVs) is determined by the combination of the total power supplied by electric vehicle batteries (EVBs) during discharging and the power they consume during charging. This relationship is represented by the series of equations, as proposed by (Jan M U et al. 2021). Individual EV controls the SOC of the batteries by charging/discharging current I_{ch} with the help of the equation (6), It is computed using the following factors: total plugin time (t_i^p), rated capacity (C_{EV}) and the difference between SOC^d and SOC^{in}.

$$I_{ch-i} = \frac{SOC_i^d - SOC_i^{in}}{t_i^p}.C_{EV} \tag{6}$$

The primary objective is to charge electric vehicle batteries (EVBs) to the desired state of charge (SOC^d) for future transportation use, while also providing additional support to the isolated microgrid (MG). According to the equations provided, the adaptive droop controller (ADC) manages the variables K_{ev}^d and K_{ev}^c, as suggested by (Jan M U et al. 2021).

If $SOC^{in} < SOC^{\min}$,

$$then \begin{cases} K_{ev}^c = K_{\max} \\ K_{ev}^d = 0 \end{cases} \tag{7}$$

If $SOC^{\min} < SOC^{in} < SOC^d$, then

$$\begin{cases} K_{ev}^c = 0.8K_{\max}\left(1+\sqrt{\dfrac{SOC^d - SOC^{in}}{SOC^{in} - SOC^{\min}}}\right) \\ K_{ev}^d = 0.2K_{\max}\left(1-\sqrt{\dfrac{SOC^d - SOC^{in}}{SOC^{in} - SOC^{\min}}}\right) \end{cases} \tag{8}$$

If $SOC^d < SOC^{in} < SOC^{\max}$

$$\begin{cases} K_{ev}^c = 0.5K_{\max}\left(1+\sqrt{\dfrac{SOC^{in} - SOC^d}{SOC^{\max} - SOC^{in}}}\right) \\ K_{ev}^d = 0.5K_{\max}\left(1-\sqrt{\dfrac{SOC^{in} - SOC^d}{SOC^{\max} - SOC^{in}}}\right) \end{cases} \tag{9}$$

Where SOC^{in}, SOC^d, SOC^{min}, SOC^{max} and SOC^{rated} are the initial, desired, min, max, and rated SOC of the EVB, respectively. The state of charge of EVB is divided into four different tiers for effective operation as $SOC^{min} < SOC^d < SOC^{max} < SOC^{rated}$. These zones are important, since the SOC of EV batteries exhibits a linear behavior between SOC^{min} and SOC^{max}, which is set at 20 % and 90 %, respectively. In addition, SOC^d is added to protect the EVBs from deterioration and to maintain their health. The SOC^d is the point at which the EVB SOC must be maintained in order to use the EV for transportation in the future. The ADC controls the power of the EVBs based on the frequency change (Δf) in the microgrid and the SOC^{in} of the EV batteries using the equations (7-9).

IV. RESULTS AND DISCUSSION

The values for the microgrid parameters/constants are shown in Table-1, and an isolated microgrid (MG) is modeled using MATLAB/Simulink (R2023a). Three distinct scenarios, each involving different combinations of generating sources, are employed to test the proposed controllers. Initially, the battery storage system is considered using a proportional-integral (PI) controller. The PI controller's parameters are optimized through Artificial Neural Network (ANN), resulting in final values of $K_P = 1.92$ and $K_I = 2.78$. In the second scenario, the BSS and wind power system (as a renewable energy source) are included. In the final scenario, the combination of electric vehicles (EVs), ESS, and the wind power system (WPS) is analyzed, and the adaptive droop control (ADC) algorithms are tested.

Table 1 Microgrid Parameters/Constants

Parameters	Value	Parameters	Value
BSS rated capacity in MW	3	Wind Turbine Time Constant T_w(s)	0.5
PV rated capacity in MW	3	EV Gain K_{EV}	1
Battery capacity of EV's in kWh	100	EV Battery time Constant T_{EV}(s)	1
Damping Constant D in pu/Hz	1	EV Plug-in Time t_p(Hours)	5
Droop coefficient R in Hz/pu	0.05	BSS time constant T_{bss} (s)	0.08
System Inertia M (s)	10	SOC^{min}, SOC^{max}	0.2, 0.9
Wind Turbine Inertia Constant M_w(s)	2	SOC^d	0.6

Case Study- I

In the first case, as illustrated in Figure 3(a), load disturbances (ΔP_L) are imposed at different instants (t = 10s, 50s, 120s, 150s and 180s) to examine the performance of the proposed PI controller. The proposed model is simulated with the battery storage system (BSS) taken into account. Figure 3(b) shows the output power of the BSS (ΔP_{BSS}). Figure 3(c) shows the frequency control (Δf) of the isolated MG by using PI controller. The control signals (U_{BSS}) that govern the BSS is shown in Figure 3(d).

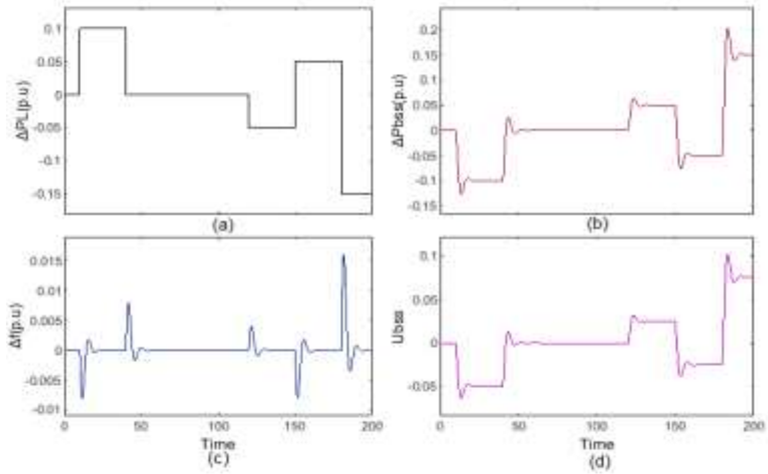


Figure 3 The simulation Outcomes of BSS using PI Controller under Load variation. (a) Load variation in p.u. (b) The power output of the BSS. (c) The frequency response (d) The control signal of BSS.

Case Study- II

Here, a Wind Power system (ΔP_{wind}) is taken into consideration to illustrate how well the proposed PI controller works. Additionally, as illustrated in Figure 4(a), the unit step load ΔP_L are imposed at different instants. The input U_{BSS} to the BSS under this variable load is displayed in Figure 4(b), which controls the BSS output power as shown in Figure 4(e) in accordance with system requirements. Figure 4(c) shows Δf restoration of the system utilizing PI controller. The frequency minimization performance, settling time, and overshoot are all under the permissible range, even though the controller manages to restore the Δf to its optimal value. The wind power varies with the wind speed as shown in Figure 4(d) and Figure 4(f) shows the wind speed variation with time.

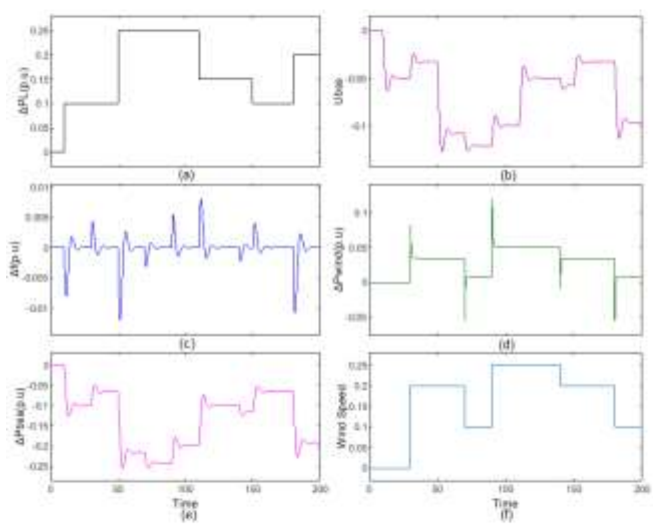


Figure 4 The simulation outcomes for BSS using PI controllers for variations in load and RESs penetration. (a) The load variation in p.u. (b) The control signal of BSS. (c) The frequency variations (d) The output power of WTS (e) The output power of the BSS (f) The Wind speed variation.

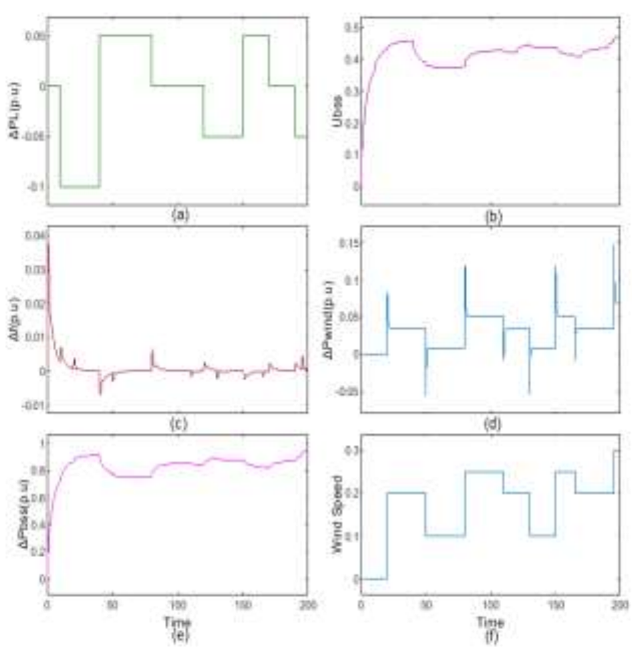
Case Study-3

In this case, the electric vehicle batteries (EVBs) are new power sources as a prosumers is included in evaluating the microgrid frequency stability. The load variation and wind power system generation variation are shown in figure 5(a) and 5(d) respectively. Figure 5(j), 5(g), 5(h), and 5(i) shows the input signal (U_{adc}) that controls the EV's power, current, and SOC respectively. Further, two different situations are discussed:

Situation: A

Here, SOC^{in} (0.15) is set to be lower than the minimum value required SOC^{min} (0.2). In this scenario, the EV do not participate in frequency regulation, which is illustrated in Figure 5(i). The power imbalance are compensated either by RES and BSS respectively as shown in 5(d) and 5(e). EVBs should interact with MG frequency fluctuations only after preserving their desired power, which is their primary objective.

.



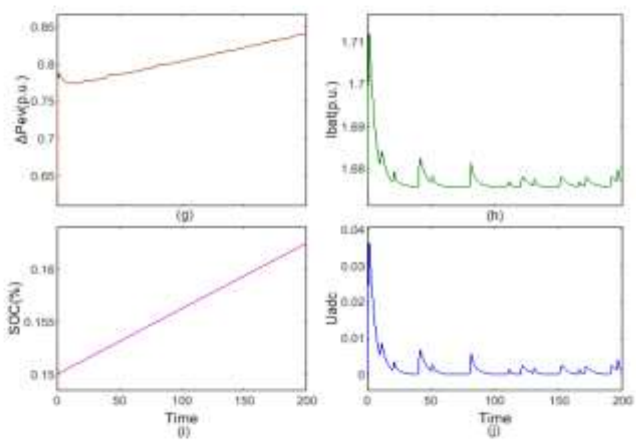


Figure 5 The simulation outcomes for BSS/EV under load variations with RES penetration by PI and ADC controllers in case SOC^{in}=0.15. (a) Load variation in p.u. (b) The control signal of BSS. (c) The frequency response (d) The output power of WTS (e) The output power of the BSS. (f) The wind speed variation. (g) The output power of an EV. (h)The Charging/discharging current of the EV battery. (i) State of Charge of EVB (j) The Control signal of EV.

Situation: B

Here, SOC^{in} (0.78) is set to be higher than the desired SOC^{d}; there is no power imbalance and no change in frequency; the BSS and EV attempt to charge their battery storage prior to imposing a step load shift of -0.1 p.u. When the load decreases and the frequency increases at t = 10 sec, the BSS releases the power, and the connected EVs will continue to charge until they reach the maximum SOC for use in future transportation usage. Again, at t = 40 sec, a step load shift of 0.15 p.u. is applied, the frequency decreases, and EVB starts discharging to supply the increased power demand in support of BSS until the system stabilizes, which is illustrated in Figure 6(i). Again, at t = 80 sec, the frequency increases, i.e., extra power is available, and the EV starts charging. Similar patterns of electric vehicle batteries (EVBs) charging/discharging and frequency restoration amidst load variations and wind power variations can be observed in figures 6(c) and 6(i) respectively.

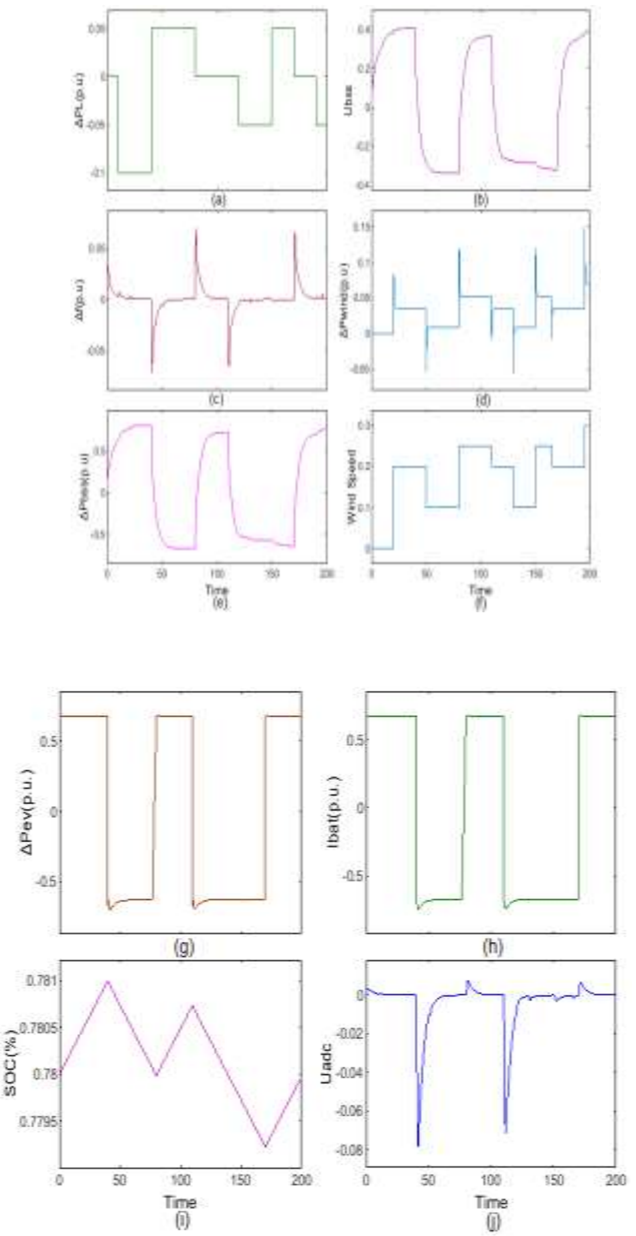


Figure 6 The simulation outcomes for BSS/EV under load variations with RES penetration by PI and ADC controllers in case SOC^{in}=0.78. (a) The load variation in p.u. (b) The Control signal of BSS. (c) The frequency response (d) The output power of WTS (e) The output power of the BSS. (f) The wind speed variation. (g) The output power of EVB. (h)The Charging/discharging current of the EV battery. (i) State of Charge of EVB (j) The Control signal of EV.

V. CONCLUSION

This paper presents control methodologies aimed at effectively regulating the frequency of isolated microgrids (MGs) using Electric Vehicles and Battery storage systems. The proposed control strategy combines a proportional-integral controller (PI) with adaptive droop control (ADC). The study explores a system consisting of electric vehicles (EVs), an battery storage system (BSS), a wind turbine system, a solar photovoltaic (PV) system, and a diesel generator. A PI controller is utilized to adjust the output of the BSS, while ADC is employed to manage the batteries of the EVs. The analysis investigates the impact of load variations on the microgrid frequency. The parameters of the PI controller are carefully tuned using a trial-and-error method to enhance system stability and restore frequency, both under fixed loads and load variations. Additionally, ADC controls the output power of Electric Vehicle Batteries (EVB) in response to frequency deviations (Δf). The coordinated action of ADC and PI controllers aims to minimize frequency deviations by regulating their respective BSS, thus restoring the microgrid frequency to its nominal value. Performance metrics, including frequency restoration, settling time, and overshoot, demonstrate that all parameters remain within acceptable limits. MATLAB/SIMULINK is employed as the validation tool to evaluate the effectiveness of the proposed control methods in regulating the frequency of the isolated microgrid (MG). Simulation results show that the suggested control methods effectively mitigate frequency deviations, returning them to desired levels.

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose.

REFERENCES

[1] Bai Y, Li J, He H, Santos R C D & Yang Q. (2020). "Optimal design of a hybrid energy storage system in a plug-in hybrid electric vehicle for battery lifetime improvement." IEEE Access, Vol. 8, pp. 142148–142158.

[2] Banol Arias N, Hashemi S, Andersen P B, Traeholt C & Romero R. (2019). "Distribution system services provided by electric vehicles: Recent status, challenges, and future prospects." IEEE Transactions on Intelligent Transportation Systems, 20(12), pp. 4277–4296.

[3] Fan H, Jiang L, Zhang C K & Mao C (2016). "Frequency regulation of multi-area power systems with plug-in electric vehicles considering communication delays." IET Generation, Transmission & Distribution, 10(14), pp. 3481–3491.

[4] Fernández-Guillamón A, Gómez-Lázaro E, Muljadi E & Molina-Garcia A. (2019). "Power systems with high renewable energy sources: A review of inertia and frequency control strategies over time." Renewable and Sustainable Energy Reviews, 115, Art. No. 109369.

[5] Iqbal S, Habib S, Khan N H, Ali M, Aurangzeb M & Ahmed E M (2022). "Electric Vehicles Aggregation for Frequency Control of Microgrid under Various Operation Conditions Using an Optimal Coordinated Strategy". Sustainability, Vol. 14, 3108. https://doi.org/10.3390/su14053108

[6] Iqbal S, Xin A, Jan M U, Abdelbaky M A, Rehman H U, Salman S, Rizvi S A A & Aurangzeb M. (2020). "Aggregation of EVs for primary frequency control of an industrial microgrid by implementing grid regulation & charger controller." IEEE Access, Vol. 8, 141977–141989.

[7] Jan M U, Xin A, Rehman H U., Abdelbaky M A, Iqbal S & Aurangzeb M. (2021). Frequency Regulation of an Isolated Microgrid with Electric Vehicles and Energy Storage System Integration Using Adaptive and Model Predictive Controllers. IEEE Access, 9, 14958–14970. doi:10.1109/access.2021.3052797

[8] Kundur P (1994), Power System Stability and Control, New York: McGrawHill.

[9] Liu H, Hu Z, Song Y and Lin J (2013). "Decentralized vehicle-to-grid control for primary frequency regulation considering charging demands", IEEE Trans. Power Syst., 28, (3), pp. 3480–3489

[10] Luo X, Wang J, Wojcik J, Wang J, Li D, Draganescu M, Li Y & Miao S. (2018). "Review of voltage and frequency grid code specifications for electrical energy storage applications." Energies, 11(5), 1070.

[11] Nieto A, Vita V, Ekonomou L & Mastorakis N E. (2016). "Economic analysis of energy storage system integration with a grid connected intermittent power plant, for power quality purposes." Technology, Vol. 2, 5.

[12] Ota Y, Taniguchi H, Nakajima T, Liyanage K M, Baba J, Yokoyama A (2012). "Autonomous distributed V2G (vehicle-to-grid) satisfying scheduled charging", IEEE Trans. Smart Grid, 3, (1), pp. 559–564

[13] Rehman H U, Yan X, Abdelbaky M A, Jan M U & Iqbal S (2021), "An advanced virtual synchronous generator control technique for frequency regulation of grid-connected PV system", Int. J. Electr. Power Energy Syst, 125, Art. no. 106440.

[14] Rehman H U, Yan X, Abdelbaky M A, Jan M U, Iqbal S, Masood A, Egamnazrova T & Aurangzeb M (2020). "Droop control design based on advanced particle swarm optimization for grid-connected multi PV-VSG." In Proceedings of the 16th IET International Conference on AC/DC Power Transmission (ACDC) (pp. 1–6).

[15] Yang H, Chung C, Zhao J (2013). "Application of plug-in electric vehicles to frequency regulation based on distributed signal acquisition via limited communication", IEEE Trans. Power Syst., 28, (2), pp. 1017–1026

[16] Zheng C, Dragicevic T & Blaabjerg F (2020). "Model predictive control based virtual inertia emulator for an islanded AC microgrid." IEEE Transactions on Industrial Electronics. Advance online publication. https://doi.org/10.1109/TIE.2020.3007105.