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***Abstract*—The concept of vehicle-to-grid (V2G) has been applied to residential microgrids (MGs) to play an essential role in regulating terminal voltage and system frequency. For this purpose, a power system stabilizer (PSS) has been selected, which is added to the excitatory system to enhance the dynamic and transient stability performance and to offer damping characteristics adequate for V2G regulation. In this work, three interconnected areas powered by diesel generators are investigated to measure the effectiveness of the proposed V2G scheme with PID-PSS controller that is adapted in a direct manner compared to the conventional MGs without the V2G scheme. The studied islanded residential MGs are consisting of diesel generators that are used as main generation sources, residential loads, and EVs aggregator. The performance of the proposed scheme is examined under the effect of a 3-∅ short circuit fault between areas 1 and 3. The final findings emphasize the superiority of using V2G with adaptive PSS compared to the conventional system without both PSS and the inclusion of V2G in terms of over/undershoot and settling time 'stabilizing faster'.**

Keywords—Vehicle-to-grid, residential microgrids, power system stabilizer, voltage regulation, frequency regulations.

I. Introduction

Nowadays, a lot of efforts are made to maintain a reliable operation of the power system to keep stable electricity from the generators to the customers [1]. One of the fit solutions is to use electric vehicles (EVs) as a source of power during contingencies and the term vehicle-to-grid (V2G) starts to appear for several ancillary services that are provided to large and small power systems. Therefore, it becomes more promising worldwide for domestic transportation.

Two sides should be clarified to understand the benefits of using the V2G smart scheme during the plug-in period which is pre-scheduled by car owners to keep their conveyance. First, car owners can save about 13.6 % on charging costs due to discharging their excess stored energy back to the grid during the time of high electricity prices. Second, for the grid side, V2G in the power system can deal with the problem of load changes or the irregular nature of renewable energy, which leads to frequency and voltage stability issues [2]–[4].

Several challenges during the incorporation of EVs into the MG such as absorption of high energy, increased peak demand, and issues of power quality, as well as the unpredictability of the dynamic behaviors, are reviewed.in [5]. On the other hand, different works have been made for EV integration, where the most important is using the V2G scheme that is used for voltage and frequency regulation services. Thus, the concept of V2G gives useful means of interactions between EVs and MGs, with EVs treated as DGs that can supplement the grid for stability conditions [6]–[8]. In addition, the V2G command can help in spinning reserve, and assuaging rapid spikes in grid loads [9].

The controlling process of frequency and voltage in microgrids (MGs) is a major challenge to keep them at their standard values. To alleviate the instability issue, a new shape of control strategy using soft techniques based on the direct adaptive concept (as an adaptation mechanism) has recently been applied to regulate the system frequency and voltage as further discussed in [10]–[11]. Early surveys on adaptive control were conducted by researchers since the 1950s. In addition, contributions to control theory emphasized the importance of expanding the concept of adaptive control are discussed. Initially, three main schemes were discussed: self-tuning regulators, model reference control, and gain scheduling. After that several methods start to emerge over time in various applications including theoretical approaches and machine learning [12]-13]. Furthermore, principles underlying those

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adaptation schemes that now find their path into products and applications were described early on [12].

The main contributions and features of this work are the inclusion of a V2G scheme to supply power to the grid while parking and to assist stabilize frequency and voltage at peak load periods with the help of a PID-PSS controller. Furthermore, to improve the stability and reliability during peak loads. For this purpose, we focused on how the presence of a V2G scheme can help in solving the frequency and voltage stability issues for three-interconnected areas of residential MGs. The addition of the PID-PSS controller in the aspect of the V2G aims to enhance the dynamic and transient stability performance of the studied residential MGs system and to provide suitable damping properties to reset the output steady-state offset. This paper proposes an adaptation mechanism as a secondary control loop in MG1 and MG3 to adaptively tune the PID controller's gains using the change in rotor speed as an input-sensing signal for the PSS within the excitatory system of the synchronous generator.

The remainder of this paper is outlined as follows: Section II presents an overview of the suggested V2G control scheme. In section III, the proposed three-area interconnected residential MGs system configuration is described. The final findings and simulation based on the time domain are discussed in section IV. Section V concludes the work.

II. V2G Control Scheme

Several countries located in Europe embolden their people to use EVs with various regulations (i.e., Denmark, Norway,….) to ban gas and diesel-powered vehicles by 2025. Therefore, it is expected to reach 20 million cars by the end of 2030 [14]. EVs have two main key functions when connected to MG, the first is acting as loads (charging mode or MG as G2V). Second, they can be used as storage units (regulation mode or MG as V2G) to give supplementary services for regulating the frequency and voltage. The instant EV battery charging state is defined as:

$$P_{EV}^{t} = P_{EV}^{max}\left(1 - e^{\left(\frac{at}{tmax}\right)}\right) + P_{EV}^{C} \qquad (1)$$

where P_{EV}^{C} and P_{EV}^{max} mean battery status and maximum EV power capacity, $tmax$ is the maximum time for charging. Similarly, the discharging state of EV battery is expressed as:

$$P_{EV}^{t} = P_{EV}^{C}.e^{\left(\frac{at}{tmax}\right)} \qquad (2)$$

Considering an autonomous distributed V2G, the unbalance in power between the supply and load demand can be detected from the deviations in frequency at the home outlet [15]. EV charging scenario has been completed in two shapes, as follows. First, is keeping the battery's state of charge (SOC). Second, is adjusting its energy level. These shapes ought to be combined in defining the V2G power regulation as [16]:

$$\begin{cases} P_{j,k+1}^{up,1} = \sum_{i=1}^{N_j^1}\left(P_{max}\,k_{i,k}^{up}\right) \\ P_{j,k+1}^{down,1} = \sum_{i=1}^{N_j^1}\left(P_{max}\,k_{i,k}^{down}\right) \end{cases} \qquad (3)$$

where $k_{i,k}^{up}$ and $k_{i,k}^{down}$ are the regulation up (discharging) and down (charging) droops of i[th] EV at time k and calculated for all SOC scenarios in [16]. The correlation between EVs and V2G power is given as:

$$P_{max} = P_{j,k+1}^{up,1} + P_{j,k+1}^{down,1} \qquad (4)$$

The total V2G power required at each EVs charging station can be calculated as:

$$\begin{cases} P_{j,k+1}^{up,1} = P_{j,k+1}^{up,1} + P_{j,k+1}^{up,2} + \cdots \\ P_{j,k+1}^{down,1} = P_{j,k+1}^{down,1} + P_{j,k+1}^{down,2} + \cdots \end{cases} \qquad (5)$$

where $j = 1, \ldots..p$, and the total V2G power including the power uploaded by CSO is defined as follows:

$$\begin{cases} P_{j,k+1}^{up,1} = \sum_{j=1}^{p}\left(P_{i,k+1}^{up}\right) \\ P_{j,k+1}^{down,1} = \sum_{j=1}^{p}\left(P_{i,k+1}^{down}\right) \end{cases} \qquad (6)$$

This means that the regulation up/down demonstrated a negative SOC-dependent correlation of the battery as stated in [16].

III. MG System Configuration

In this study, three residential interconnected areas powered by diesel generators were investigated. The proposed MGs system consists of residential loads and two fleets of EVs with 230 cars added to MG 1 and 3 as shown in Fig. 1. The nominal parameters of the considered MGs and EV's initial profiles are introduced in [17], and EVs' fleets and system nominal power data are stated in Table I.

TABLE I. Initial Parameters Of The Proposed Residential MGs System.

Parameter	Capacity
Number of EVs fleet in area 1	100 cars (4 MW)
Number of EVs fleet in area 3	130 cars (5.2 MW)
Diesel generator for area 1	15
Diesel generator for area 2	15
Diesel generator for area 3	15
Loads in area 1	10
Loads in area 2	5
Loads in area 3	5
Transmission line between areas 1 and 2	80 km
Transmission line between areas 2 and 3	35 km
Transmission line between areas 3 and 1	50 km

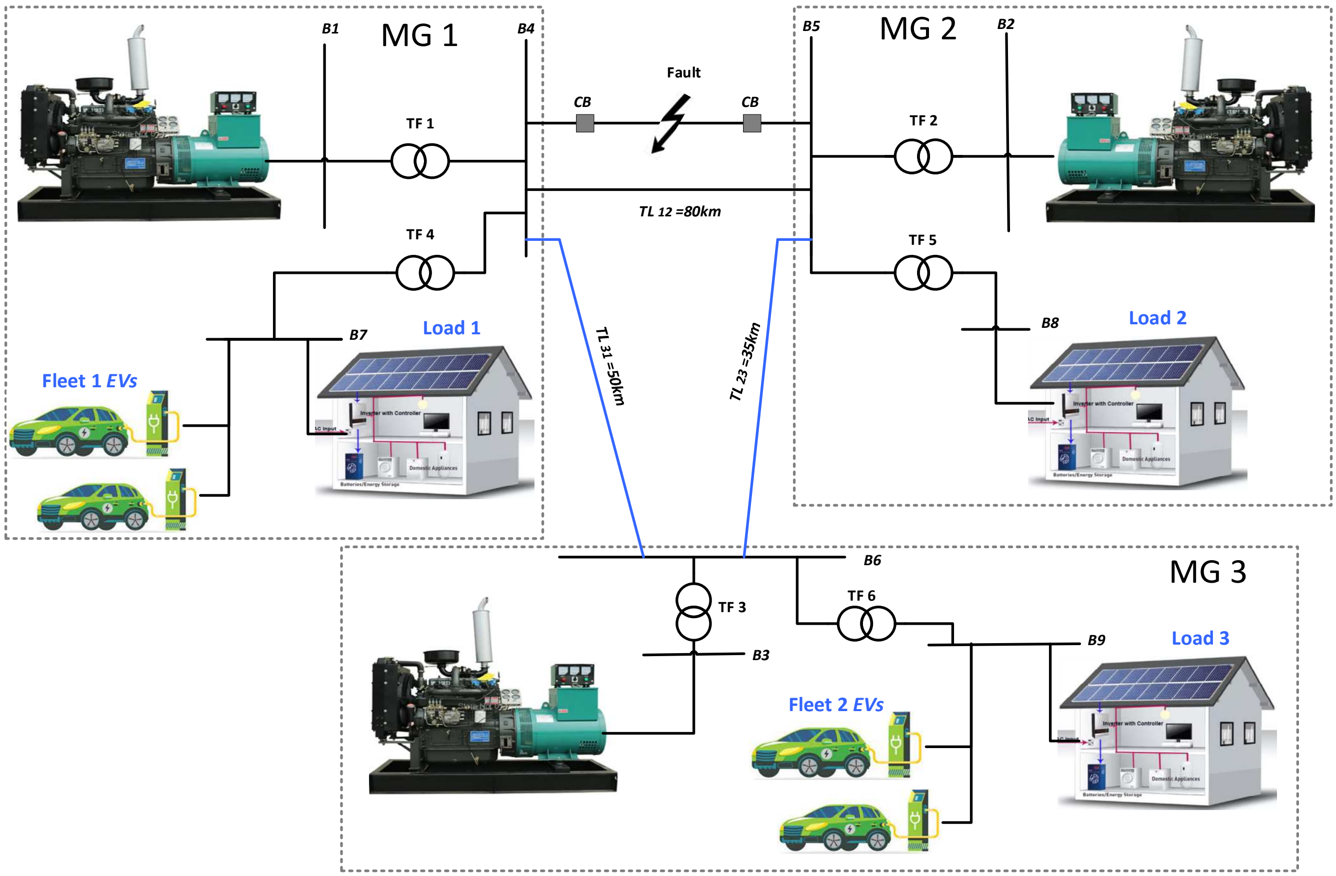

Fig. 1. A simplified three-area interconnected residential MGs.

The V2G scheme is linked with area 1 on bus No. 4, and area 3 on bus No. 5. The studied residential areas are connected by three transmission lines (there are two series of symmetric lines linked between areas 1 and 2 for protection purposes each 80 km in length). In addition, each area has a step-down transformer, which is used to connect to the residential load demand.

The dynamic behavior of the power system is given by the following set of nonlinear equations as follows [18]:

$$\dot{\omega} = \frac{(T_m - T_e)}{M} \tag{7}$$

$$\dot{\delta} = \omega_o\, \omega \tag{8}$$

$$\dot{E_q'} = \frac{-(E_q - E_{fd})}{T_{do}^{'}} \tag{9}$$

$$E_{fd} = \frac{1}{T_E}\left[-E_{fd} + k_E(V_{ref} - V_t)\right] \tag{10}$$

where δ rotor angle; ω_o , ω synchronous and angular speed; M is the inertia constant; T_m, T_e are mechanical and electrical torques; E_q field flux emf; T_{do}' d-axis time constant field circuit in d-axis; E_{fd} field voltage; k_E, T_E are gain and voltage regulator time constant; V_{ref}, V_t reference and terminal voltages, respectively. Also, Eqs. (7-10) can be constructed in a state-space frame in case of a small disturbance using the Heffron-Phillips model [18].

The linearized model of the synchronous generator including the excitation system with PSS is shown in Fig. 2 supported by the adaptation mechanism as a secondary control loop to tune the gains of the PID controller. For PID-PSS, it has been added in a direct adaptive manner as presented in [19] to extract the stabilizing voltage signal and added to the automatic voltage regulator (AVR) inside the excitation system to offer a suitable damping property for V2G regulation of the studied MG systems as shown in Fig. 2. The nominal parameters of the PID-PSS controller are chosen from our work in [19].

The desired objective function is a function of the on-time value of $\Delta\omega_r$, and it is based on maximum over/undershoot M_P, settling time T_s, and steady-state error e_{ss}, which is identified as follows:

$$J_{objective} = min\, f(M_{P,}\, T_s, e_{ss}) \tag{11}$$

In order to determine these indices, the Heffron-Philips's mode [20] is suggested for our case study which is simplified as:

$$G_{plant}(s, m, h) = \frac{\Delta\omega_r(s)}{\Delta V_{ref}(s)} = \frac{-ms}{h_4 s^4 + h_3 s^3 + hs^2 + hs + h_0} \tag{12}$$

Where $m\ and\ h_{0-4}$ are functions in k_{1-6} , $inertia\ M$ and exciter gain and time constant, more details provided in [20].

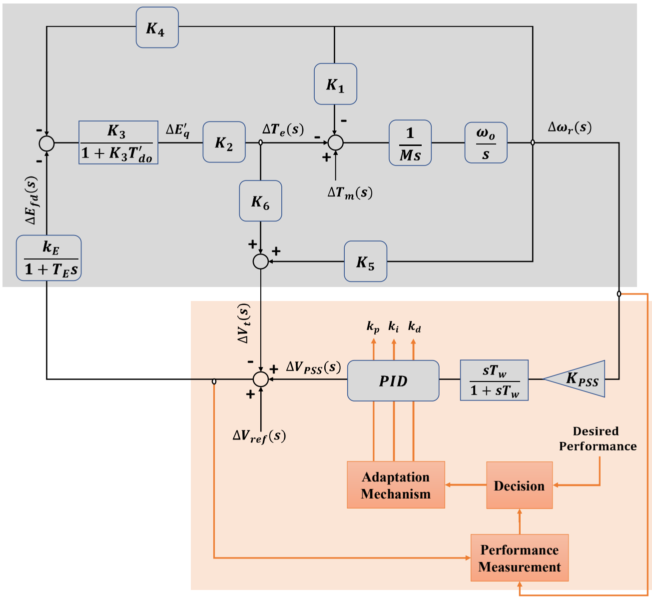

Fig. 2. A linearized model of the synchronous machine-based adaptive PID-PSS controller.

It is noted from Eq. (13) that the closed system order is four, so we need to factorize the denominator to second-order using following m-file code in Eq. (14):

$$G_{CL}(s,m,h)=\frac{-[m_{11},m_{12}]s}{\begin{array}{c}[h_{41},h_{42}]s^4+[h_{31},h_{32}]s^3+\\ [h_{21}+m_{11}k_d,h_{22}+m_{21}k_d]s^2+\\ [h_{11}+m_{11}k_p,h_{12}+m_{21}k_p]s+\\ [h_{01}+m_{11}k_i,h_{02}+m_{12}k_i]\end{array}} \tag{13}$$

Pseudo code:

$$\begin{aligned}sys=tf\big(-[m_{11},m_{12}],[\,[h_{41},h_{42}]\ [h_{31},h_{32}]\ [h_{21}\\ +m_{11}k_d,h_{22}+m_{21}k_d]\ [h_{11}\\ +m_{11}k_p,h_{12}+m_{21}k_p]\ [h_{01}\\ +m_{11}k_i,h_{02}+m_{12}k_i]\big)\end{aligned} \tag{14}$$

Then finding the poles and zeros as:

$$\text{poles}=\text{roots}(\text{cell2mat}(\text{sys},\text{Den})$$

$$\text{zeros}=\text{roots}(\text{cell2mat}(\text{sys},\text{Num})$$

Therefore, it will be easy to identify the parameter indices using the standard closed loop formula as follows:

$$T.F=\frac{\omega_n^2}{s^2+2\zeta\omega_n s+\omega_n^2} \tag{15}$$

$$\left.\begin{aligned}T_s&=\frac{4}{\omega_n\zeta}\\ M_P&=e^{\left(\frac{-\pi\zeta}{\sqrt{(1-\zeta^2)}}\right)}\\ e_{ss}=\lim_{s\to 0}sE(s)&=\lim_{s\to 0}s\left(\frac{\Delta V_{ref}(s)}{G_{CL}(s,m,n)}\right)\end{aligned}\right\} \tag{16}$$

IV. Validation and Simulation

During disturbances, controlled variables are adversely affected and the process of achieving the desired value is characterized by the required damping if the plant's initial parameter values are known. Thus, the damping response will vary if a sudden change in the plant occurs due to these perturbations. Therefore, a special scenario will be demonstrated to show the importance of adding an adaptation mechanism to the conventional PID-PSS controller. The objective is to achieve the desired damping using the V2G scheme under the effect of a 3-∅ short circuit fault that happened in the transmission line between areas 1 and 2 as shown in Fig. 1.

In this discussion, a tuned PID controller was developed adaptively to extract the stabilizing voltage signal added to the AVR system within the excitatory system. The AVR mainly comprises of four parts, namely the exciter, generator, sensor to sense the terminal voltage, and regulator (amplifier) which is used to amplify the error voltage signal constructed from comparing the reference voltage terminal and the sensed signal used to control the synchronous generator field windings by means of the exciter [11, 19]. The terminal voltage V_t, rotor speed (frequency), and output electric power P_{eo} , mechanical output power P_m, and regulation power P_{reg} provided by V2G in case of fault duration are described as follows:

The performance of the studied residential MGs is validated under the influence of a 3-φ short circuit fault as shown in Fig. 1. The fault started at 50 s and cleared after 0.14 s. The system's dynamic behavior is displayed in Fig. 3. It is seen from Fig. 3, the existence of the adaptation mechanism enhanced the performance indices of the proposed system in terms of M_P, T_s, and e_{ss}. From Fig. 3a-3c, the frequency response of the studied MGs with the conventional control loop still has higher oscillations during the fault period compared to the proposed one. The frequency of the conventional system without V2G and PSS varies between 49.92-50.04 Hz, 49.891-50.036 Hz, and 49.928-50.037 Hz for MG1, MG2, and MG3, respectively. And it ranges between 49.929-50.025 Hz, 49.893-50.05 Hz, and 49.93-50.036 Hz for a system with V2G without PSS, and last for a system with the proposed scheme, it varies between 49.941-50.007 Hz, 49.918-50.009 Hz, and 49.943-50.0092 Hz for MG1, MG2, and MG3, respectively. Moreover, the system-based proposed control scheme stabilizes faster than other conventional schemes after removing the fault by ≤ 2 s compared to the conventional system by 5 s and the system with only V2G when disabled the PSS by 8 s.

On the other side, as shown in Fig. 3f for the generator terminal voltage, it is mandatory to be at 1 pu for all operating conditions. It is found from Fig. 3f, that a significant drop occurred in the terminal voltage around 0.49 pu for the conventional system resulting in excitation loss and usually leading to an Undervoltage and Overcurrent trip if not controlled. For this reason, we added the adaptation mechanism with the PSS inside the excitation system to reduce the drop in the voltage and make the system stable during the fault. The drop in the terminal voltage using the proposed scheme is reduced to 0.74 pu at the start of the fault. In addition, it stabilizes by < 1 s compared to the conventional system, which stabilizes after > 2 s, and the system with only V2G and without PSS by 5 s.

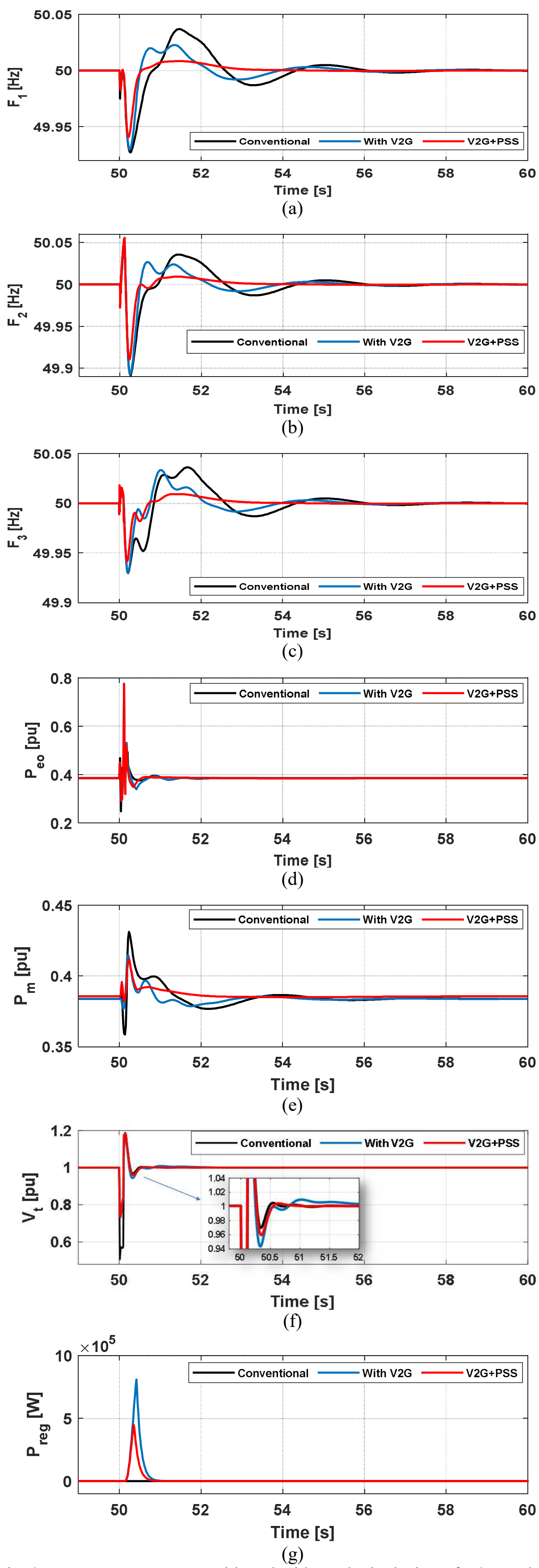

Fig. 3. System response with and without the inclusion of V2G and PSS.

Fig. 4 shows the V2G scheme signals SOC of all EV profiles 1-5. The initial SOC is 90% for units 1-4 (regulation) and 0% for unit 5. Negative values of SOC mean that the cars are still on the road and not plugged in for charging. The output control signal of the adaptive PID-PSS controller gains after 20 iterations with 5 candidate solutions is stated in Fig. 5 in order to achieve the optimal solution as chosen in [11]. Finally, the addition of V2G and PSS schemes provides an effective solution to power regulation and stabilization of the overall MGs system voltage and frequency in terms of M_P, T_s, e_{ss} compared to the conventional system (no V2G and no PSS) and the system with only V2G inclusion (no PSS).

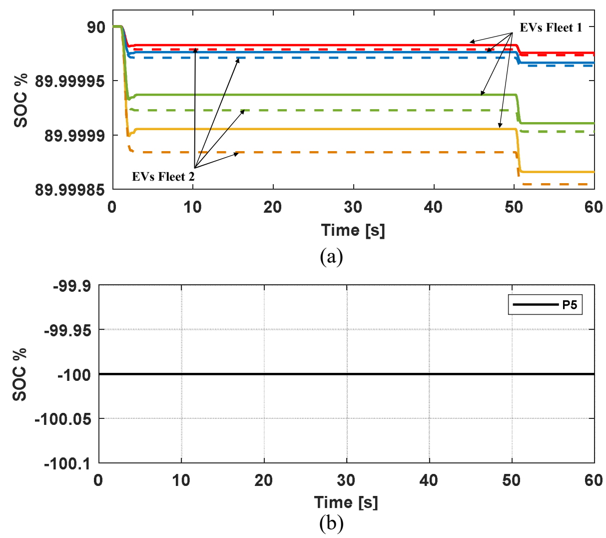

Fig. 4. SOC % for EV fleets 1 and 2 a) Profiles 1-4 b) Profile 5.

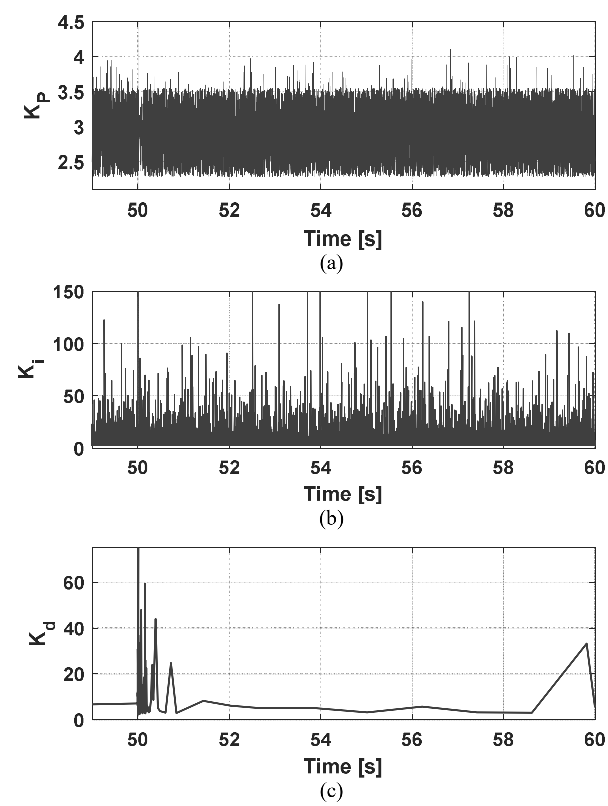

Fig. 5. The output tuned control signal for a) K_P, b) K_i, c) K_d.

V. Conclusion

Ancillary services can be provided using the idea of vehicle-to-grid (V2G). This work highlights the role of the V2G scheme in the presence of PSS for frequency and voltage regulations. Three interconnected residential MGs were implemented to validate the inclusion of EVs supported with PID-PSS controller, which was adaptively added and correlated with the AVR to deliver suitable damping properties and help the V2G scheme achieve objectives. The entire system is examined under the effect of a 3-φ short circuit fault exposed to the transmission line between area 1 at bus No. 4 and area 2 at bus No. 5. The main goal is to regulate the terminal voltage and frequency by supplying additional power during the fault time and to show how the low oscillation in the speed rotor (frequency) can be effectively damped between generators utilized in the power system. In this manner, an adaptation mechanism is added to the excitation system to adjust the parameters of the PID-PSS controller to maintain the desired level of the control system performance and to deal with critical problems in classical systems caused by sudden changes in plant parameters.

A comparison was made between traditional MGs when disabled the V2G and PSS schemes, a system with V2G only (no PSS), and the system with the proposed scheme based on the inclusion of V2G with the adaptive PID-PSS controller under the effect of a 3-φ short circuit fault to demonstrate their superiority in suppressing the unwanted oscillations caused by sudden failure and rapid changes in the system condition. It was found that the presence of an adaptive control loop inside the excitation system assisted to regulate the frequency and voltage well during the fault and boosted in terms of over/undershoot, settling time, and steady-state error as compared to the conventional ones. Accordingly, we can claim that the proposed control scheme can enhance the dynamic stability of all studied MGs and provide resilient and robust features.

References

[1] H. Abubakr, J. C. Vasquez, K. Mahmoud, M. M. F. Darwish, and J. M. Guerrero, “Comprehensive Review on Renewable Energy Sources in Egypt—Current Status, Grid Codes and Future Vision,” in IEEE Access, vol. 10, pp. 4081–4101, January 2022.

[2] S. Vachirasricirikula and I. Ngamroo, “Robust controller design of heat pump and plug-in hybrid electric vehicle for frequency control in a smart microgrid based on specified-structure mixed H2/H∞ control technique,” Appl. Energy, vol. 88, no. 11, pp. 3860–3868, November 2011.

[3] A. Lashab, M. Yaqoob, Y. Terriche, J. C. Vasquez and J. M. Guerrero, “Space Microgrids: New Concepts on Electric Power Systems for Satellites,” in IEEE Electrification Magazine, vol. 8, no. 4, pp. 8-19, December 2020.

[4] H. Abubakr, T. H. Mohamed, M. M. Hussein, J. M. Guerrero, and G. Agundis-Tinajero, “Adaptive frequency regulation strategy in multi-area microgrids including renewable energy and electric vehicles supported by virtual inertia,” Int. J. Electr. Power Energy Syst., vol. 129, pp. 106814, July 2021.

[5] C. H. Dharmakeerthi, N. Mithulananthan, and T. K. Saha, “Overview of the impacts of plug-in electric vehicles on the power grid,” in 2011 IEEE PES Innovative Smart Grid Technologies, pp. 1–8, 16 November 2011.

[6] H. Liu, Z. Hu, Y. Song, J. Wang, and X. Xie, “Vehicle-to-grid control for supplementary frequency regulation considering charging demands,” IEEE Trans. Power Syst. vol. 30, no. 6, pp. 3110–3119, November 2014.

[7] T. H. Mohamed and H. A. Hassan, “Terminal Voltage and Power Regulation Using Vehicle-to-Grid (V2G) Scheme Connected to a Two-Area Power System,” 2018 Twentieth International Middle East Power Systems Conference (MEPCON), pp. 203–208, December 2018.

[8] M. Bayati, M. Abedi, G. B. Gharehpetian, and M. Farahmandrad, “Short-term interaction between electric vehicles and microgrid in decentralized vehicle-to-grid control methods,” Prot. Control Mod. Power Syst., vol. 4, pp. 1–11, February 2019.

[9] J. Meng, Y. Mu, H. Jia, J. Wu, X. Yu, and B. Qu, “Dynamic frequency response from electric vehicles considering traveling behavior in the Great Britain power system,” Appl. Energy, vol. 162, pp. 966–979, January 2016.

[10] H. Abubakr, J. M. Guerrero, J. C. Vasquez, T. H. Mohamed, K. Mahmoud, M. M. Darwish, and Y. A. Dahab, “Adaptive LFC Incorporating Modified Virtual Rotor to Regulate Frequency and Tie-Line Power Flow in Multi-Area Microgrids,” in IEEE Access, vol. 10, pp. 33248–33268, March 2022.

[11] H. Abubakr, J. C. Vasquez, T. H. Mohamed, and J. M. Guerrero, “The concept of direct adaptive control for improving voltage and frequency regulation loops in several power system applications,” Int. J. Electr. Power Energy Syst., vol. 140, pp. 108068, September 2022.

[12] K. J. Åström, “Theory and applications of adaptive control—a survey,” Automatica, vol. 19, no. 5, pp. 471–486, September1983.

[13] J. G. Truxal, “Theory of self-adjusting control,” Proc. 2nd IFAC World Congress, 1964.

[14] Y. Cheng, N. Zhang, B. Zhang, C. Kang, W. Xi, and M. Feng, “Low-Carbon Operation of Multiple Energy Systems Based on Energy- Carbon Integrated Prices,” in IEEE Trans. on Smart Grid, vol. 11, no. 2, pp. 1307–1318, March 2020.

[15] Y. Ota, H. Taniguchi, T. Nakajima, K. M. Liyanage, J. Baba, A. Yokoyama, “Autonomous distributed V2G (vehicle-to-grid) satisfying scheduled charging, ” IEEE Trans on Smart Grid, vol. 3, no. 1, pp. 559–564, October 2011.

[16] S. Iqbal, A. Xin, M. U. Jan, S. Salman, A. U. M. Zaki, H. U. Rehman, M. A. Abdelbaky, “V2G strategy for primary frequency control of an industrial microgrid considering the charging station operator,” Electronics, vol. 9, no. 4, pp. 549, March 2020.

[17] 24-hour Simulation of a Vehicle-to-Grid (V2G) System, MathWorks.

[18] F. P. Demello and C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control,” IEEE Trans. Power Appar. Syst., vol. PAS-88, no. 4, pp. 316–329, April 1969.

[19] H. Abubakr, J. C. Vasquez, K. Mahmoud, M. M. F. Darwish, and J. M. Guerrero, “Robust PID-PSS Design for Stability Improvement of Grid-Tied HydroTurbine Generator,” 2021 22nd International Middle East Power Systems Conference (MEPCON), pp. 607–612, December 2021.

[20] V. Lakshmi A.S.V., S. K., Mangipudi, and R. R. Manyala, “ Control constraint-based optimal PID-PSS design for a widespread operating power system using SAR algorithm, ” International Trans. on Elec. Energy Syst., vol. 31, no. 12, e13146, December 2021.