Control of load frequency in a power system with multiple areas in the presence of a V2G scheme

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Abstract

In today's power systems, the widespread use of electric vehicles (EVs) and the integration of renewable sources (RSs) have advanced from a luxury to a necessity. This is due to the public's awareness of the benefits of switching to green energy and the sharp rise in demand for electric power. These RSs and EVs, on the other hand, have a negative effect on the load frequency (LF), which is in addition to changes in system parameters and load fluctuations. A LF control for a contemporary multi-area power system with photovoltaic (PV) and electric vehicle (EV) chargers is presented in this work. Within contemporary power systems, the proposed controller primarily makes use of EV chargers. The advantage of this strategy is that it uses components that are already in place rather than introducing new ones. The integral controller (I) and the ecological optimization approach (ECO) are included in the proposed controller. The autonomous vehicle-to-grid (V2G) devices for which these components are intended are designed. The V2G plan is in Area-1 of a three-area power system, where the proposed control method is used. The proposed (I+ECO+V2G) controller's ability to control the LF is evaluated by taking into account changes in load, PV power generated, and system parameters. A comparative analysis is carried out to compare the proposed I+ECO+V2G system's performance with that of the standard I-controller and the I+ECO system. When compared to the standard I-control strategy, the simulation results demonstrate that the implementation of the I+ECO and the proposed I+ECO +V2G strategies results in increased system stability and decreased LF fluctuations. In addition, it was discovered that the suggested control strategy I+ECO+V2G achieves steady state values more quickly than the I+ECO control method. The outcomes demonstrate that the proposed controller is both reliable and efficient at reducing the system's effects from load disturbances, uncertainties, and nonlinearities. These reproductions were performed utilizing MATLAB/ SIMULINK. An experimental setup with a real-time dSPACE DS1103 connected to another PC via a QUARC pid_e data acquisition card was used to verify the simulation results. The simulation results regarding the I+ECO+V2G methodology's superiority over to have been confirmed by the experimental results.

1. INTRODUCTION

Nonlinear loads, such as EV chargers, will often introduce power quality (PQ) issues within distribution circuits, which can have detrimental effects on system components. PQ encompasses several specific concepts such as harmonic distortion, DC offset, phase imbalance, and voltage deviations, among others, and these are quantified in myriad ways. Power quality (PQ) is a measure of the fitness of electrical power from the utility to the electrical customer. Low PQ is of concern because it can cause variations in voltage magnitude, issues with continuity of service from utilities, and transient voltages and currents. Harmonic distortion is a primary culprit in the causation of reduced power quality. Our research is focused on investigating three hypotheses. One, we hypothesized that, because EV charge controllers are nonlinear loads and because EVs demand a large amount of power, the PQ issues presented by EV charging could have an impact on distribution feeders. Two, we also hypothesized that the total harmonic distortion (THD) of the current drawn by an EV charge controller would change as a function of time as the charge controller moved through various phases of the charging cycle. And third, we hypothesized that the cumulative effects of multiple charge controllers on the same feeder would result in distortion greater than that of any one charge controller, thereby setting an upper bound on the maximum number of EV charging stations that could be connected to a single feeder. As specified by IEEE 519.1992, that impact is a function of the size of the distribution feeder, as measured by the ratio of the short circuit current available at the point of common connection to the maximum fundamental load current, and quantified by the quantity total demand distortion (TDD). The perpetually escalating demands for energy and the finite nature of the fossil fuel supply, accompanied by global warming and climate change are the main concerns of environmentalists and researchers in the 21st century. The CO2 emissions from the transportation sector are one of the main causes of global warming and climate change.

Researchers have stressed the positive impact of replacing Internal Combustion Engine (ICE) driven vehicles with Electric Vehicles (EVs) to minimize the greenhouse gas contributions of the transport sector. The paradigm shift from conventional vehicles to EVs has many environmental and economic advantages. The increasing number of EVs is however accompanied by a rise in charging demand. The establishment of charging stations imposes an additional burden on the power grid, as the high charging loads of fast EV charging stations will degrade the operating parameters of the distribution network. The degradation of voltage profile, increase in peak load, harmonic distortions are some of the consequences of the uncoordinated charging of EVs. Many references demonstrate the adverse impact of EV charging loads on different parameters of the distribution network like voltage profile, harmonics and peak load.

The potential impact of EV charging station loads on the voltage profile of distribution networks has been investigated by a number of researchers. In analyzed the impact of the EV charging station loads on a low voltage distribution network in Europe for different EV penetration scenarios. It was concluded in that the network was robust enough to support a low intake of EVs 1–2%. However, it was observed that the voltage profile of the node where multiple charging stations were placed degraded to some extent and the high loads of EV charging stations caused degradation of the voltage profile of the weak buses of the system. In examined the impact of EV charging loads on a 13 node distribution network for different EV penetration scenarios. In analyzed the impact of EV charging loads on a standard distribution network with 14 buses. It was concluded that the transient voltage stability index degraded for high penetration of EVs. The impact of EV charging loads on the voltage stability of distribution network was also analyzed. From the findings of it is observed that most of the distribution networks could withstand the penetration of EVs up to a certain level. However, networks designed a decade ago are not equipped to withstand any large-scale integration of EVs. Harmonics being a crucial outcome of EV integration have been analyzed in depth by researchers in recent years. In investigated the effect of EV charging loads on the harmonic voltages of distribution system by applying statistical analysis. The authors classified the chargers based on the total harmonic distortion (THDI) produced and concluded that even with 45% EV penetration there was negligible harmonic distortion during summer. The effect of non-linear EV charging loads on power quality of the distribution system was analyzed in where it was reported that the lifecycle of distribution network assets was reduced by the harmonic distortion produced by the EV loads. In that the EV battery charging loads caused harmonic distortion of even 50% in the most extreme cases. In simulated the harmonics caused by Plug-in Hybrid Electric Vehicle (PHEV) chargers by a probabilistic Monte Carlo approach considering the uncertainties. It was concluded that residential Level 1 chargers (1.8 kW) had a severe impact on the power quality. In recent years researchers have concentrated on quantifying the variation of peak load demand after the placement of EV charging stations in the distribution network. In examined the effect of the PHEV loads on the metropolitan distribution network of Australia, concluding that with uncoordinated charging and 100% PEV penetration 43% peak load shifting was required to enable smooth operation of the distribution network. In analyzed the effect of the uncontrolled EV charging on the daily load profile.

The improvement in load profile by incorporating coordinated charging was also illustrated. In concluded that disorderly charging would increase the peak load demand and recommended tariff based charging. In analyzed the impact of EV charging on daily load demand in the parking lots and devised an optimal strategy for controlling the charging activities in the parking lots. In analyzed the impact of fast EV chargers on a retail building's load demand and concluded that 38% of the PHEV load demand could be absorbed by demand management and photovoltaics. In proposed a two stage demand response model to control the increase in peak load due to the charging of EVs.

2. System dynamic model

This section of the manuscript describes the model of a multi-area LFC-PS considering the tieline power signal. Fig 1 illustrates a generalized PS with N-control areas. A turbine produces mechanical power for the generator unit, which converts it into electrical power [35, 36]. Due to the difficulties of storing large amounts of electrical power, a balance between the total power generated and the total load demand should be achieved. The PS dynamic model could be described in the subsequent state space model as indicated in the following equations [36].

$$\begin{bmatrix} \Delta\dot{P}_{gi} \\ \Delta\dot{P}_{mi} \\ \Delta\dot{f}_i \\ \Delta\dot{P}_{tie,i} \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_S} & 0 & -\frac{1}{R_i T_{gi}} & 0 \\ \frac{1}{T_{ti}} & -\frac{1}{T_{ti}} & 0 & 0 \\ 0 & \frac{1}{2H_i} & -\frac{D}{2H_i} & \frac{1}{2H_i} \\ 0 & 0 & 2\pi \sum_{j=1,j\neq i}^{N} T_{ij} & \end{bmatrix} 0 \begin{bmatrix} \Delta P_{gi} \\ \Delta P_{mi} \\ \Delta f_i \\ \Delta P_{tie,i} \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ -\frac{1}{2H_i} & 0 \\ 0 & 2\pi \end{bmatrix} \begin{bmatrix} \Delta P_{Li} \\ \Delta P_{vi} \end{bmatrix} + \begin{bmatrix} \frac{1}{T_S} \\ 0 \\ 0 \\ 0 \end{bmatrix} \Delta P_d \quad (1)$$

The V2G smart grids are built on exploiting the EVs during the periods of its plug-in, as illustrated in Fig 2. Without interfering with the EV users' ability to charge their vehicles; this can be done following a pre-scheduled agreement. V2G is mainly applied in the PS to treat the problems of F-deviations and load changes that result from the presence of RESs like PV. So, the V2G arrangement will improve the response of the system, especially throughout the fluctuations periods in RESs. illustrates the battery output power of the V2G arrangement. The slope of the battery output power is negative in the charging period and positive in discharging period as a result of the F-violation value and sign ($\Delta f = factual{-}freference$). The relation between the V2G power and the F-deviation can be defined as described in the following equation [20]. shows the EVs battery SOC balance control considering V2G power, and indicates the values of V2G control parameters.

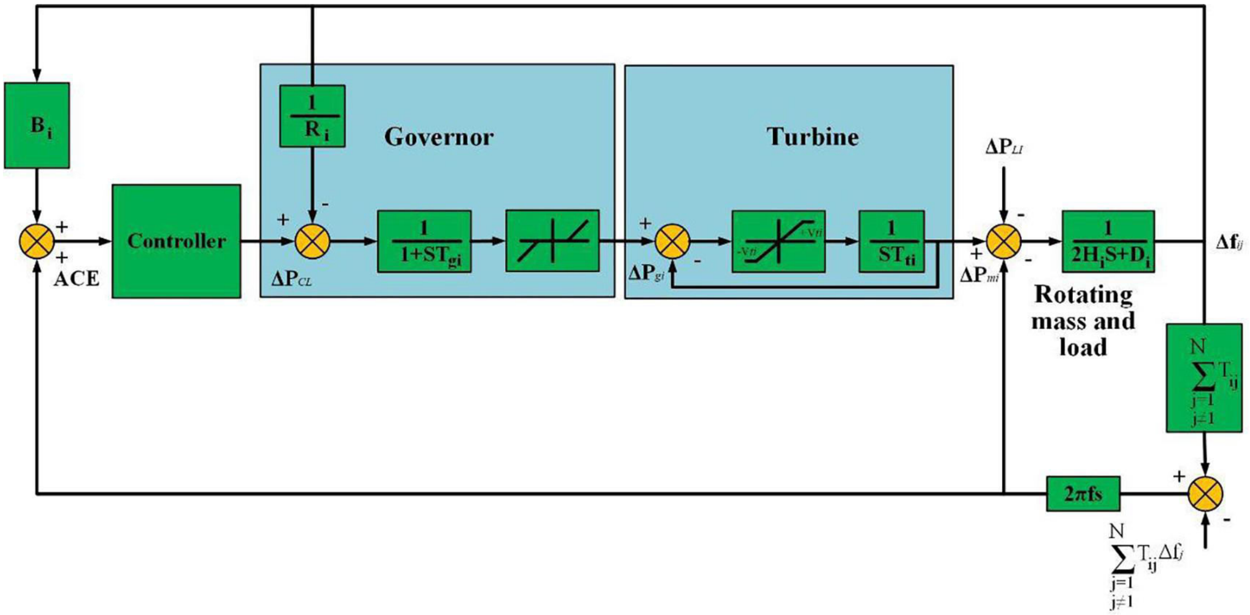

Fig 1. Configuration of the interconnected power system.

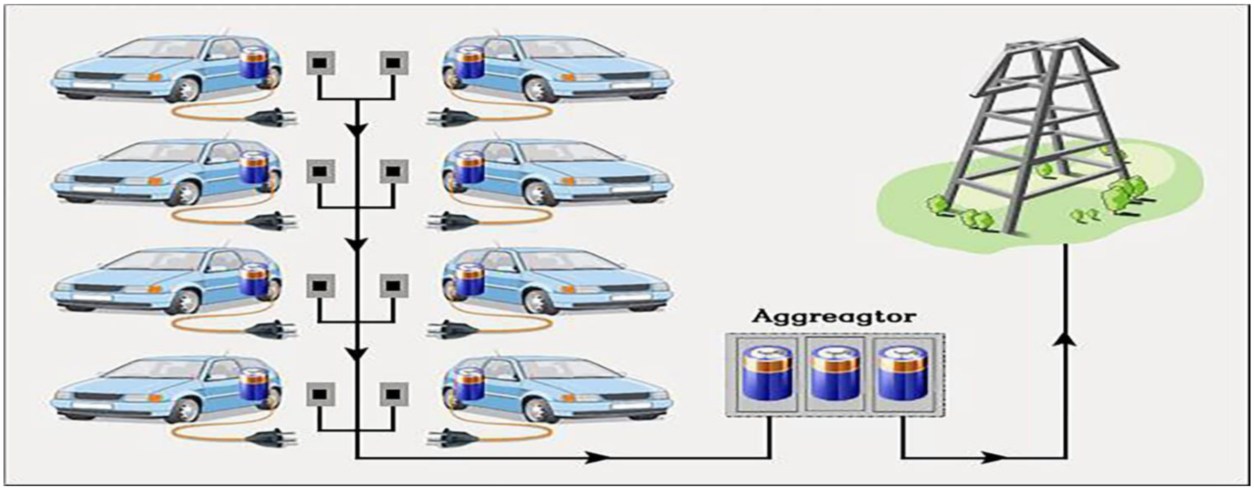

Fig 2. V2G smart scheme.

3. Results and discussions

The ecological controller is executed on a three-area interconnected power system by finding its state space model. MATLAB/Simulink as a simulation tool has been exploited to confirm the accomplishment of the suggested control scheme. Fig 3A shows the three-are controlled power system interconnected together for this purpose. demonstrates the simulation parameters for each area used in the studied system [37]. In addition, illustrates the block diagram of the proposed three-area interconnected power system. In addition, only in Area-1, a 12MWV2G system (300 cars with detailed parameters listed in is considered in the studied cases. As a prescheduled agreement, all vehicles should be plugged in from 11 pm until 7 am by their owners. In the simulation studied cases, the GRC and the maximum dead band value of the governor are set as

10% per minute and 0.05 p.u. for every area, respectively [45, 46]. These values are used with the proposed control method.

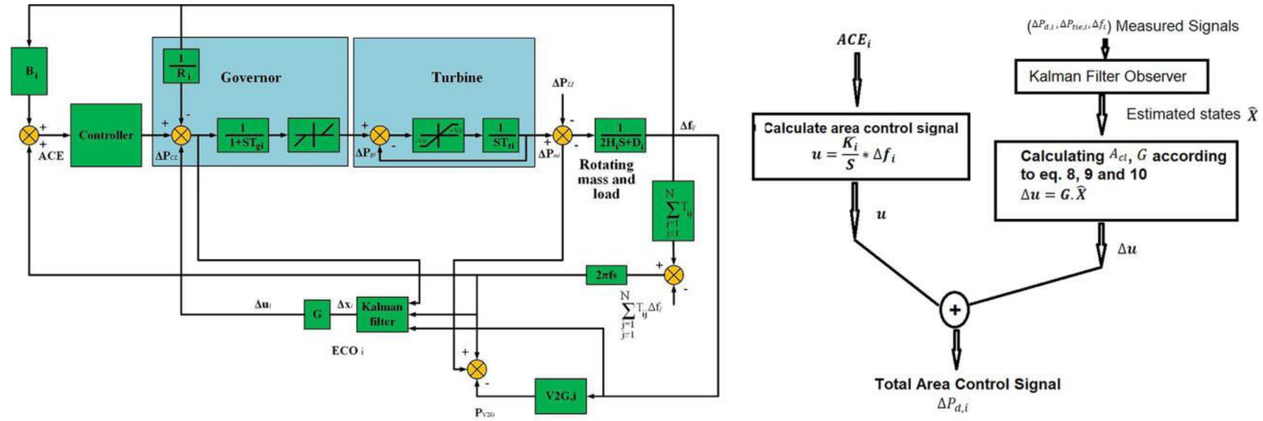

Fig 3. (a) Interconnected power system involving the suggested (I + ECO +V2G) scheme. **(b)** the flow chart of the proposed control method.

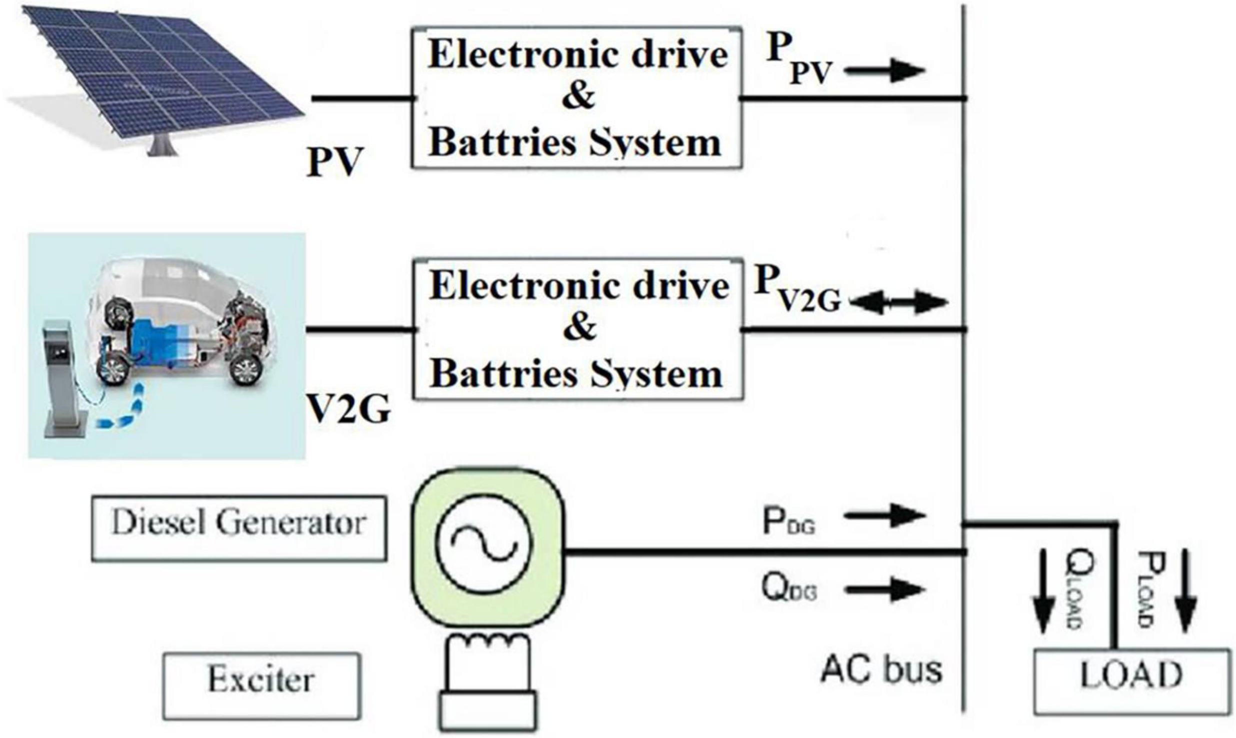

Fig 4. A schematic of the proposed model with power flow.

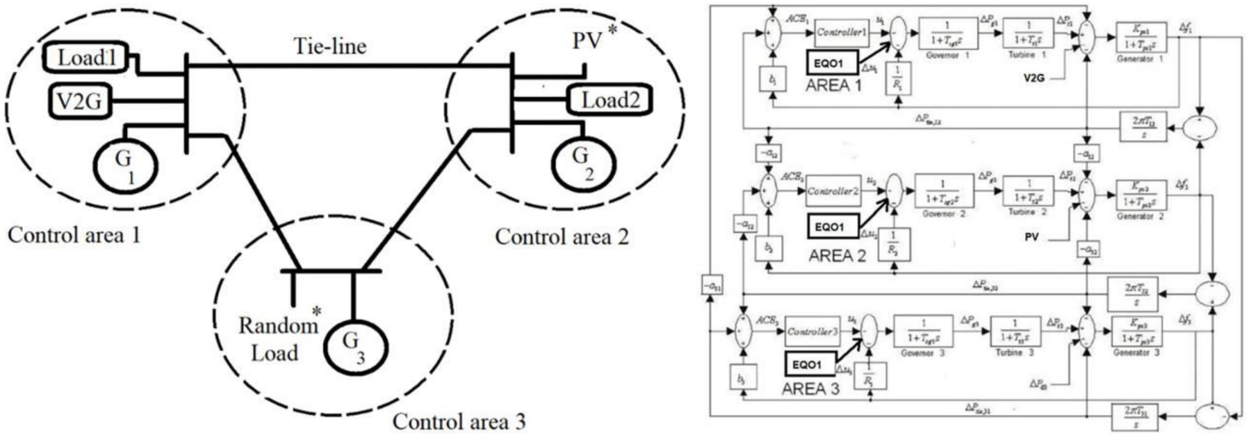

Fig 5. Studied interconnected systems.

This design can be applied to large-scale systems with multiple RES using the same past steps by determining the dimensions of the system matrix, the value of *Acl*,*i* and *Gi* can be determined. First, this research will examine the effects of plugging in V2G on the load frequency without any control and to charge only. Then the proposed controller will be used to regulate the frequency using the E2V technique. The ability of the (I+ECO+V2G) control scheme to support the load frequency during these disturbances will be evaluated using three test cases. Those are step changes in the load, variations in the system parameters, and random changesin the load with variations in the amount of PV power generated.

(a) Impact of plugging V2G on the frequency

The impact of plugging an EV into the power system on the load frequency profile will be explored in this case. The total V2G unit used in past cases has been divided into three small units; each unit has 4MW(100 cars), the time plane of plug-in/plug-out of each unit is shown in Fig 6. The load frequency areas 1 and 2 show ripples of 5%. In contrast, the third area shows ripples of 10%, as depicted in Fig 7. This discussion showed that the V2G will negativelyaffect the system load frequency if it is not controlled.This study aims to provide an I + ECO + V2G controller scheme for load frequency control a three-area power system with a PV system in one area.

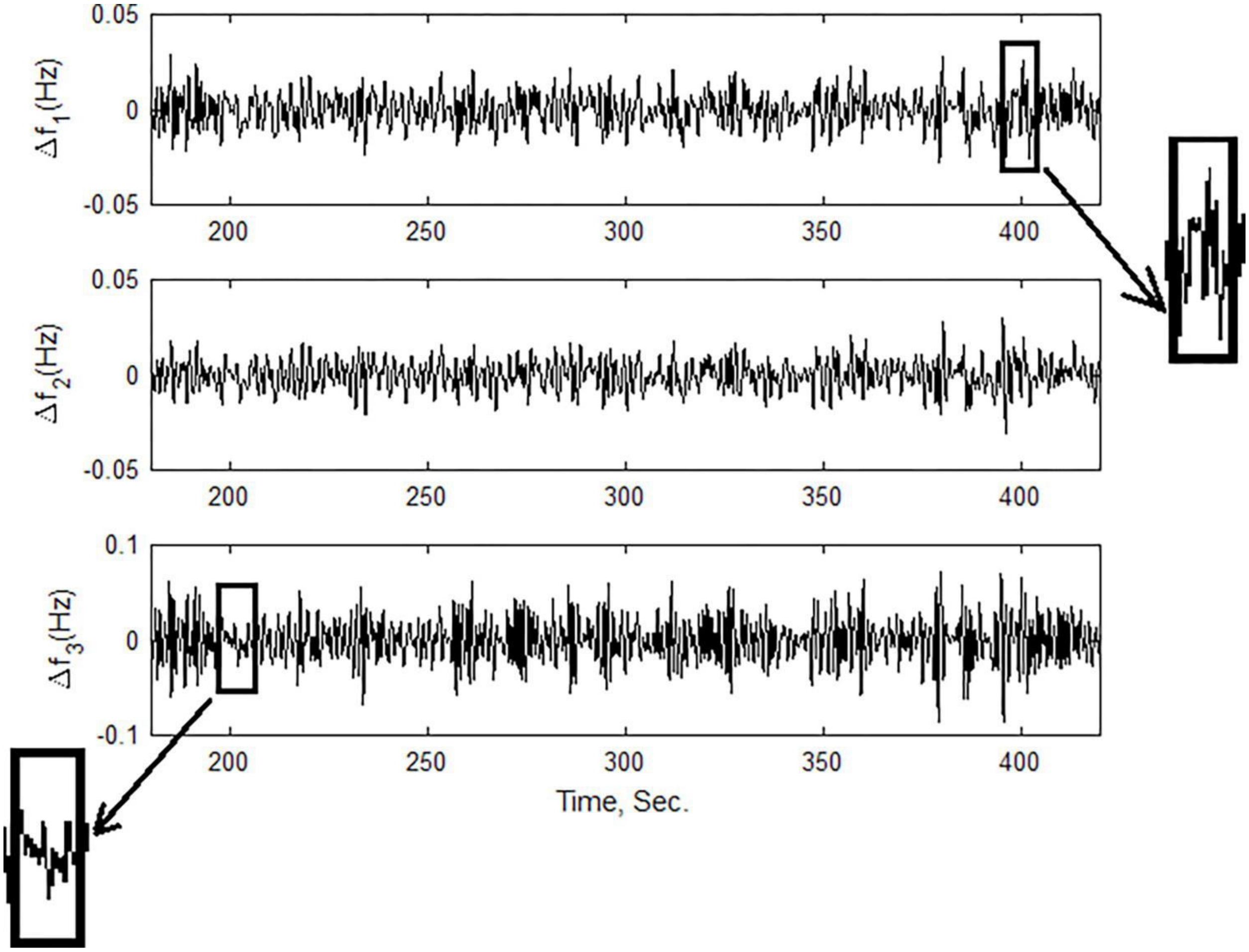

Fig 6. Frequency responses when plugging V2G.

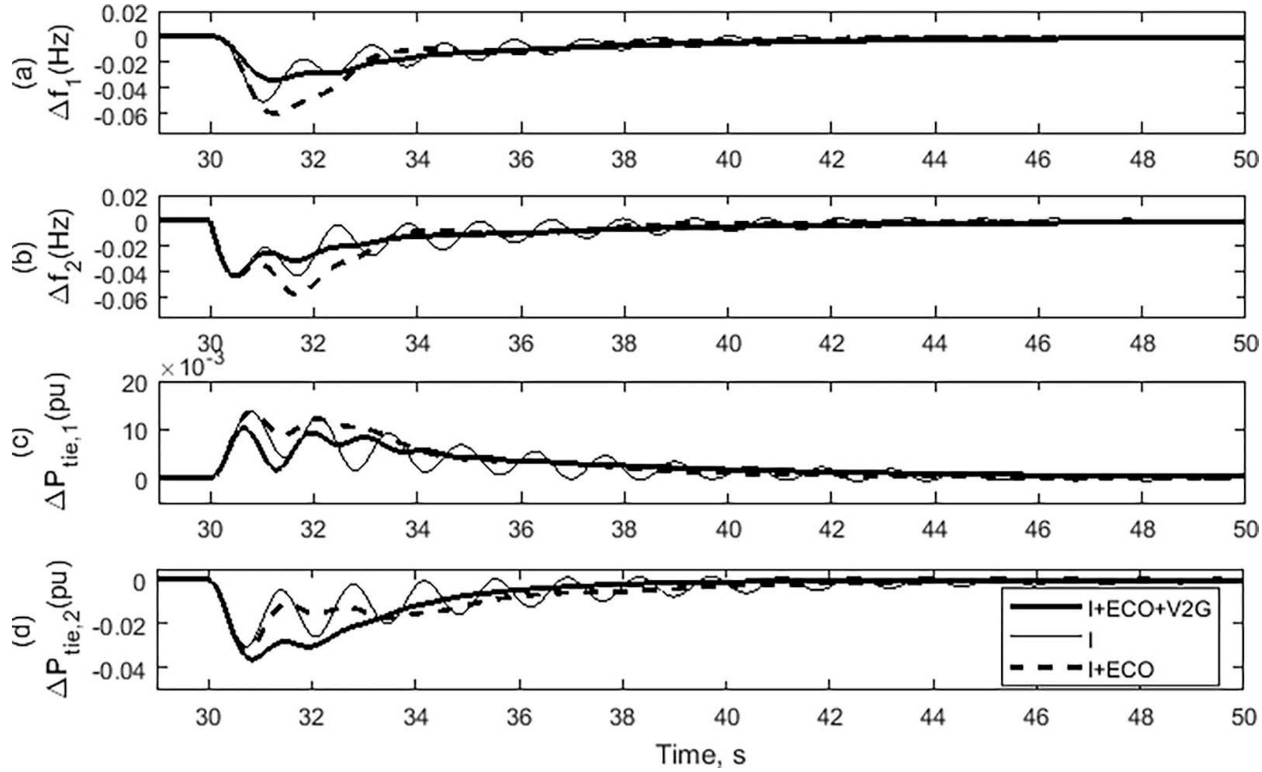

Fig 7. System response of the examined power system in case 1.

(b) Case 1: A step change in the load

In this case study, the effectiveness of the proposed load frequency controller will be assessed by considering the impact of a step change in the load while keeping the system parameters constant. The performance of the suggested control strategy (I + ECO + V2G) is evaluated on the assessed power system by adjusting the load power in Area-2 alone. It will be compared to the performance of the traditional integrator (I) control technique as well as the performance of the (I + ECO) control approach. Fig 7 compares the suggested controller (I + ECO + V2G) and both the I + ECO and the conventional I during a step changing of load power in Area-2 ($\Delta PL2$) of 0.02 p.u. at 30.0 sec. The frequency deviation in Area-1 and Area-2 with all controltechniques are demonstrated in Fig 7(A) and 7(B), respectively. The change in the tie-line power of Area1 and tie-line power of Area-2 are illustrated in Fig 7(C) and 7(D), respectively. It can be noticed that the studied power system is more stable and has fewer oscillations by implementing both the proposed (I + ECO + V2G) and (I + ECO) control techniques compared with the conventional integrator (I) control technique. Also noteworthy from Fig 6, the proposed (I + ECO+ V2G) control method is faster than the (I + ECO) control method to reach the steady state.

(c) Case 2: Changing the system parameters

The present research aims to assess the influence of several system characteristics on the efficacy of the proposed I + ECO + V2G controller in regulating frequency. The time constants of the governor and the turbine have been increased, according to Table 1. In this case, Fig 8 compares the outcomes of the three control techniques utilized in this study with the suggested changes in the governor and turbine time constants. The performance of the examined power system when employing the traditional integrator (I) controller is unstable. Moreover, it has substantially worsened as a result of the changes in the turbine and ' 'governor's time constant parameters for the frequency deviations of Area 1

Areas	T_g (sec) old	T_g (sec) new	Percentage of increasing (%)	T_t (sec) old	T_t (sec) new	Percentage of increasing (%)
Area-1	0.08	0.105	31	0.40	0.785	96
Area-3	0.07	0.150	114	0.3	0.7	133
Area-3	0.07	0.150	114	0.3	0.7	133

and 2, respectively as depicted in Fig 8(A) and 8(B). The frequency fluctuates reaches a value greater than 5%, which was outside of acceptable limits [47]. Compared to I + ECO, the proposed I + ECO + V2G controller stabilized the investigated power system more quickly and with less vibration. The tile line power of Areas 1 and 2 are plotted in Fig 8(C) and 8(D), respectively. The proposed controller exhibited less severe oscillations than the other controllers, almost bringing this power to zero. The V2G batteries provide power to the system when the generator and governor time constants vary. Consequently, the SOC decreases to regulate the system load frequency as indicated in Fig.

(d) Case 3: Random load changes and PV power variation

In this case, the system has been tested under both random load change in Area-3 and fluctuation of the PV power generated (100 MVA PV system in Area-2). The uncertainties of PV are considered, and the combined uncertainty for the module performance ratio module performance ratio (MPR) fig 9 [41, 42]:

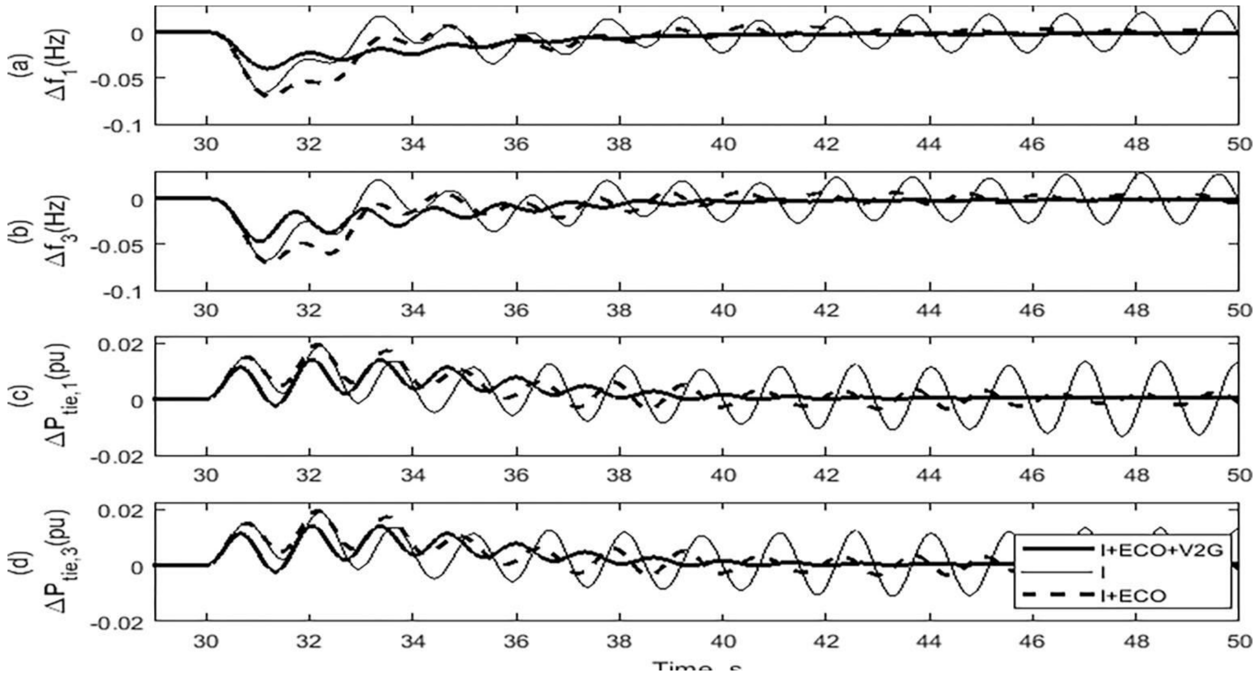

Fig 8. System response of the examined power system in case 2.

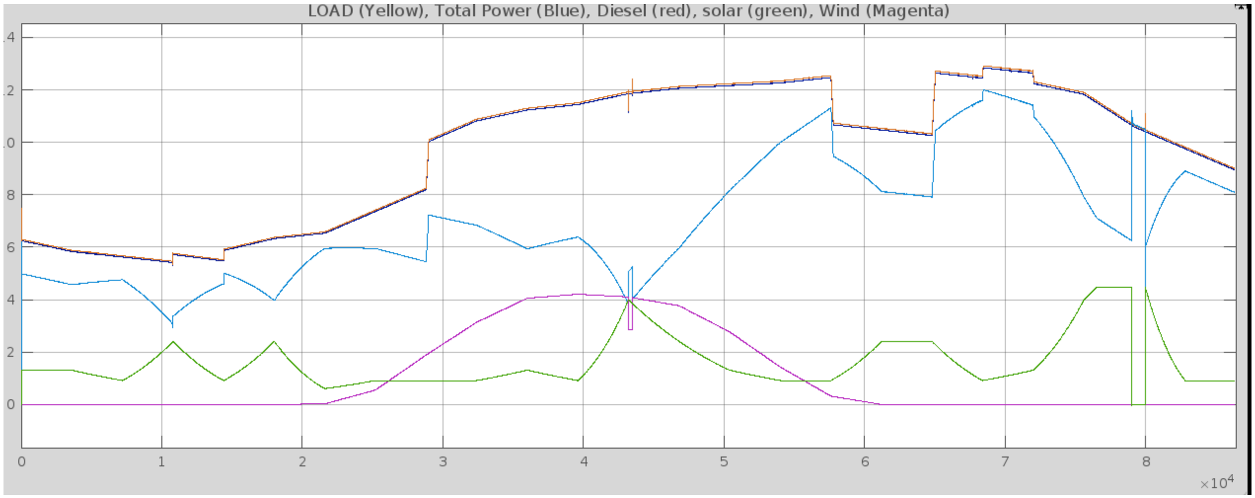

Fig 9. System power and frequency response of the examined power system in case 3.

4. Conclusions

Initially, an examination was conducted to assess the influence of implementing V2G technology on load frequency. The results indicated that, without proper control mechanisms, the implementation of V2G had an adverse effect. Then an I+ECO+V2G control scheme was proposed and used in this article as a load frequency controller for an integrated three-area power system. The effectiveness of the proposed I+ECO+V2G was examined through some changes in the load values, system parameters, and PV power generated. Comparisons between the suggested controller and both conventional integrators and (I+ECO) have been investigated. It has been noted that the proposed (I+ECO+V2G) control scheme gathers the advantages of both the optimal and conventional controllers, besides the simple structure of ECO that is easy to implement. In addition, both MATLAB Simulink and RTS results have demonstrated the efficiency of the suggested (I+ECO+V2G) control technique. It was clear that the power system performance in the case of using the proposed (I+ECO+V2G) controller is more robust in the face of the load and parameters variations and PV fluctuations. In addition, more desirable performance can be achieved using the proposed control scheme compared to the conventional integral control method. Furthermore, the digital results have proved that both (I +ECO) and (I+ECO+V2G) schemes can provide robust responses against load change and parameters uncertainties; but the suggested (I+ECO+V2G) can give better desirable and smooth responses. The future research direction can be presented as follows:

1. Evaluating the impact of integrating additional controllable loads, such as heat pumps, on the system.
2. Investigation of other optimal controllers such as linear quadratic gaussian.
3. Comparing with other recent control methods.
4. Application of a new optimization technique on the addressed system.

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