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The Role of Electric Vehicles Aggregation in the Provision of Ancillary Services

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ABSTRACT

The rapid increase of the renewable energy affects the power system in such way that could reduce the reliability of the system. The replacement of fossil fuel driven vehicles with electric vehicles (EVs) would also change the underlying demand and make the stabilization of the system frequency to become more difficult. This paper addresses the availability of electric vehicles for the provision of frequency response at different time of the day. A low frequency response is provided by stop charging the domestic EV batteries where applicable. Simulation results indicates that EVs are good elements for the provision of frequency response if a proper design of a control scheme is implemented considering the EV's charging behaviour.

Keywords: demand side response; dynamic load control; electric vehicles; smart grids; charging control algorithm

1. INTRODUCTION

Many countries have taken several measures to facilitate the entry of clean energy sources into the electric power grid. According to the Committee on Climate Change, the electric energy generated from clean energy sources is expected to reach around (30- 45) % of the total electrical energy in the UK in 2030 [1]. This change in the power grid does not include only sources of power generation, but also sources of consumption such as the use of electric vehicles (EVs) instead of fossil fuels driven vehicles.

Nonetheless, the large-scale electrification of the transport sector necessarily means an increase in the overall load capacity. Thus, the sudden and rapid chances in loads will be greater, which may cause problems that could violate the grid reliability requirements. Therefore, the electrical power system is requiring new capabilities and control manners to maintain the fundamental levels of reliability, including frequency and voltage response [2-5]. Many studies have been conducted to find out how an appropriate response can be provided for any rapid power mismatch between the demand and generation without relying on response services from the generation side. Recent studies have shown great interest in the subject of demand side response, as industrial and domestic loads can be exploited for the purpose of controlling the power mismatch between the generation and demand [6]. That is, the grid operator can control the energy consumption behavior of some types of loads (such as thermal loads) and also control the charging and discharging behavior of some energy storage batteries (such as the batteries of EVs) in order to stabilize the system frequency. This can be accomplished by motivating the consumers to change their energy consumption pattern as required, or through a commercial contract between the network operator and companies (aggregators) that are responsible for collecting the load response and selling it to the operator.

The studies in [7-10] dealt with the use of a range of thermal loads to reduce the deviation in the frequency of the system, given that renewable energy units replace a large portion of the fossil fuel generation sources. The conclusion of the previous piece of works were that the residential and industrial load can provide frequency and voltage response the same way as the peak loaded generators provide.

On the other hand, energy storage systems are witnessing continuous and rapid interest, where the context here revolves around the energy storage systems (ESS). It is expected that these systems will play a large role in the power system, especially in accommodating the increasing impact of the wind power.

In [11-14], several scenarios have been adopted in the use of ESSs to smooth the volatile output power generated by wind energy sources. In the area of the grid frequency improvement, the response obtained from the aggregation of thousands of storage units can be used to inject active power to manipulate the power mismatch between the generation and demand almost immediately after a frequency event [15-17]. From these studies, it has been concluded that a group of small-size ESSs could provide large rate of primary frequency response and inertial response.

It is also important to mention the increasing number of EVs and their direct impact on the electric power system from the technical and economic prospects. The number of electric vehicles is expected to dominate the streets by 2030 [1]. The EVs can be exploited as a flexible energy sources for grid frequency control as they are interfaced with the grid through power electronic devices. EVs have the capability of charging/stop-charging and charging/discharging their power

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very quickly responding to an operator's requests almost instantaneously. Thus, EVs can be considered as controllable load which may contribute to the ancillary services of frequency response. Dynamic control of EVs, using V2G mode, was studied in an islanded system, providing primary and secondary frequency response [18]. Reference [19] considered the design of general dynamic EV frequency control strategy taking the travelling behaviour of the EV users into account. Also, a droop control method was used to regulate the EV charging power, offering frequency response with the presence of high level of renewables.

This main contribution of this paper is to provide a simplified frequency control model based on EVs which could offer a scope for a detailed model to control the EVs in a dynamic way. In this work, the frequency response drawn by EVs will be obtained by disconnecting the charging EVs according to a signal from the operator. The method of disconnecting the charging EVs, in this paper, is from now on called VHG (Vehicle Help Grid) method.

2. ELECTRIC VEHICLES PARAMETERS

Every electric vehicle needs battery on-board to store energy so that it can be easily converted into electrical energy. At present, batteries are the most preferred system for storing energy, especially lead-acid and lithium ion batteries, due to their high energy density which is typically 50-200Wh/kg [20, 21]. Also, the study assumed a power of 6kW for domestic charging. The charging profile for home EVs, between 0%-100%, is shown in Fig. 1 [22]. The EVs can be part of ancillary services of the power system during the time of charging. The home EVs are plugged to the charging point almost in the evening and lasts to the morning. As shown in Fig. 1, every EV required 7hr for complete charging. This is the only time where the EVs can participate in the frequency control by disconnecting the charging where requested, and hence reducing the power of demand.

3. FRAMEWORK OF EV FREQUENCY CONTROL

Fig.2 shows the framework of the EV control algorithm. The control algorithm is divided into two parts. The first part is the state of charge control algorithm which is in charge of controlling the charging state of the EV battery (soc) based on the EVs' state of charge level. The frequency controller is the second part of the control algorithm which is responsible for controlling the frequency of the grid by disconnecting the charging EVs based on a frequency signal. Two frequency set-points are used; the Min and Max frequency set-points Min_{freq} and Max_{freq} respectively. These setting points can be adjusted by the operator according to the contract code [8]. However, (59.985-59.5) Hz and (60.015-60.5) Hz are used as low and high frequency set-points, where 60 Hz is the nominal grid frequency. Controlling the grid frequency beyond these frequencies' settings will offer fast frequency control. For example, for a frequency event, if the frequency drops lower than 59.985Hz, the frequency controller will disconnect the responsive EVs to reduce the power of demand. Similarly, if the frequency increases more than 60.015Hz, the frequency controller will charge the responsive EVs to increase the power of demand.

This research did not ignore the importance of EV users' comfort. The comfort of the EV users is ensured by conducting the following techniques. I) threshold limit (10%) for soc levels is given, i.e. when the soc is less than 10%, the charging controller is prioritized. II) Linear relationship between the batteries' soc and the frequencies set-points was adopted. That is, during and after the frequency event, EVs are disconnected linearly from the highest to the lowest state of charge.

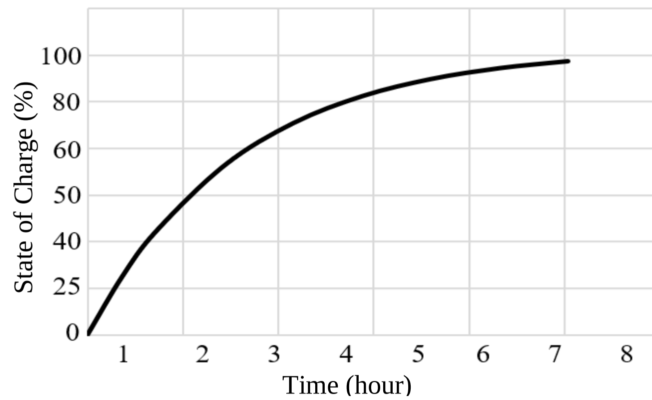

Fig. 1 Charging profile for lead acid battery

4. SIMULATION RESULTS

The IEEE 9-bus modified test system model was used to assess the proposed control scheme of EVs. The schematic diagram of this system model is shown in Fig. 3. It consists of 3 synchronous (G1-G3) generators with IEEE type-1 exciters. The model contains 9 buses, 6 transmission lines, 6 transformers and 3 constant loads. The total load demand is 315 MW [23]. The nominal grid frequency is 60Hz.

The frequency control algorithm of EVs was integrated to the test system by using DigSilent- Power Factory. The simulation results were obtained by connecting different number of aggregated houses EV models. Aggregated EV models were assumed to be allocated at bus bar 8. The residential EVs are often plugged into the house charging point during the night and sleeping time (between 07:00-06:00am). Therefore, the charging state of the population of EVs were randomised between 0% to 100%. The frequency control algorithm adjusts the EVs charging state throughout VHG method, i.e. disconnecting the EV charging based on a frequency signal.

4.1 Case Study 1

This case study was undertaken by connecting 100 controllable EVs to the test system. The power consumption of each EV's battery was assumed 6kw. An increase of 9MW in

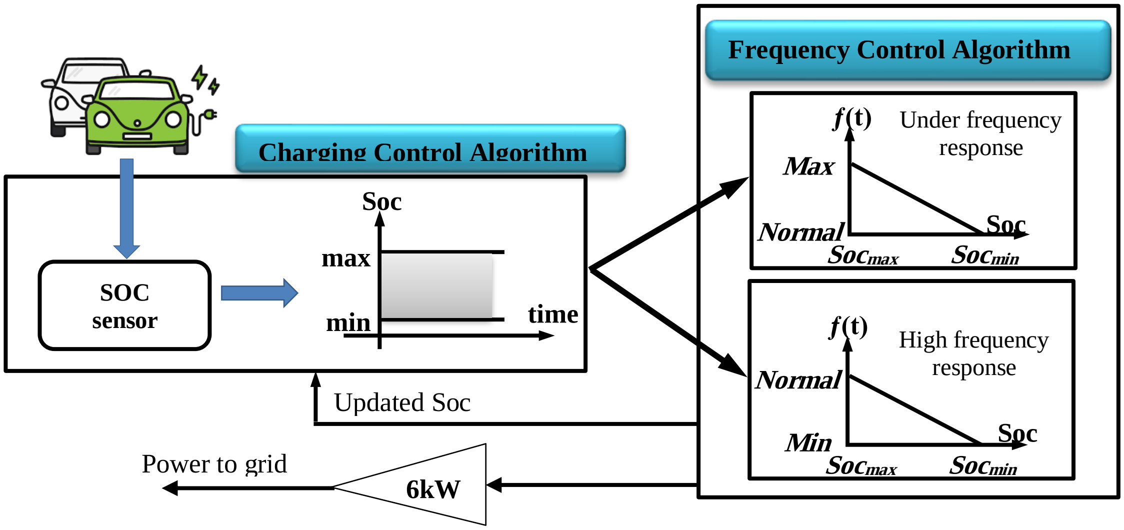

Fig. 2 Framework of EV frequency control system

power of load at bus-6 was injected at time 10sec, as a frequency incident. Fig. 4 shows the grid frequency during and after the frequency incident without EV controller. The figure also shows the power increase of generation unit at bus bar 2 following the frequency event. Fig. 5 shows the grid frequency with the controllable EVs. As a consequence of frequency incident at time 10 sec, the frequency controller has disconnected the charging of 100 EVs throughout VHG control method saving a 0.3 MW of total load power. Within the first two seconds, the frequency control algorithm has reduced the frequency deviation from 59.87 Hz (without EVs control system) to 59.91 Hz (with the frequency control system). After 50 sec, the frequency deviation has been decreased to 58.65 Hz from 58.60 Hz. The increasing power drawn by G2 unit has been reduced slightly after using the VHG method as shown in Fig. 5.

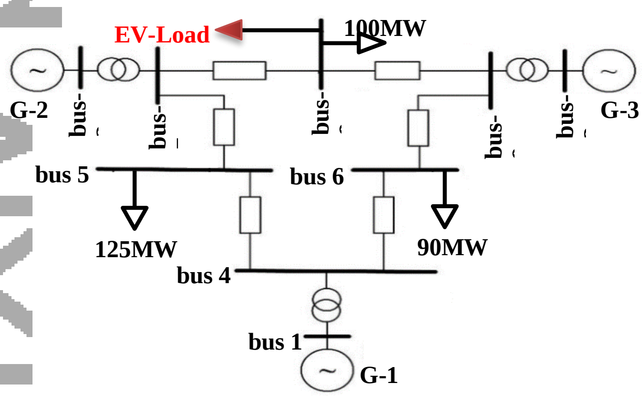

Fig. 3 IEEE 9-bus modified test system

4.2 Case Study 2

This case study was carried out by connecting 1,000 responsive EV models to the grid. The same incident of 9MW low frequency response was considered at time 10sec. Following the frequency event, 3 MW of EVs' charging power has been reduced using VHG mode almost instantaneously as shown in Fig. 6. In first two seconds following the incident, the frequency deviation has been reduced to 59.914 Hz (using frequency controller) from 59.87 Hz (without the frequency control system). After five seconds, the frequency deviation has been reduced to 59.82 Hz from 58.60 Hz. At time 60 sec, the frequency deviation has been driven back to 59.15 Hz (with frequency controller) from 58.60 Hz (without frequency controller). The generation G2 unit has showed a noticeable reduction in its generation power (Avg reduction= 0.5 MW) thanks to the frequency controller.

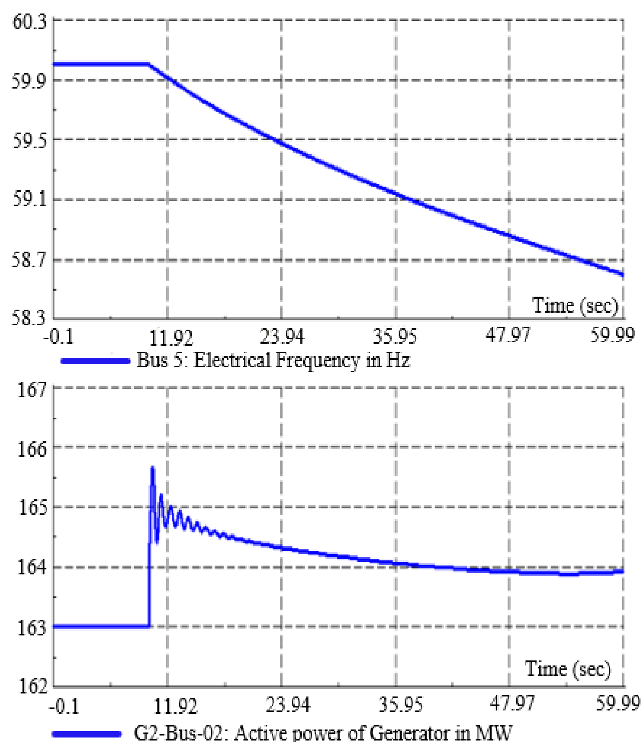

Fig. 4 Grid frequency and power of G2 generation unit (no frequency controller)

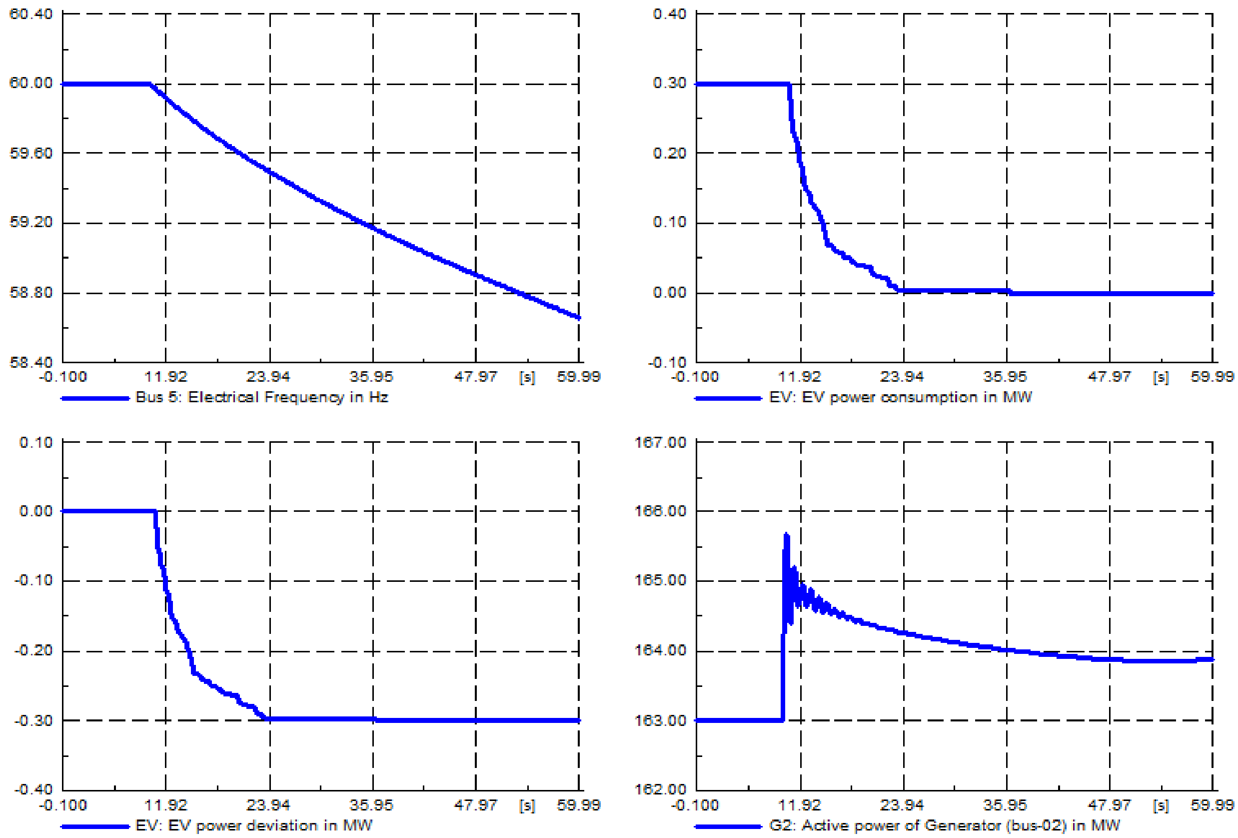

Fig. 5 Grid frequency, and power of EVs and G2 unit using frequency controller for 100 EV models

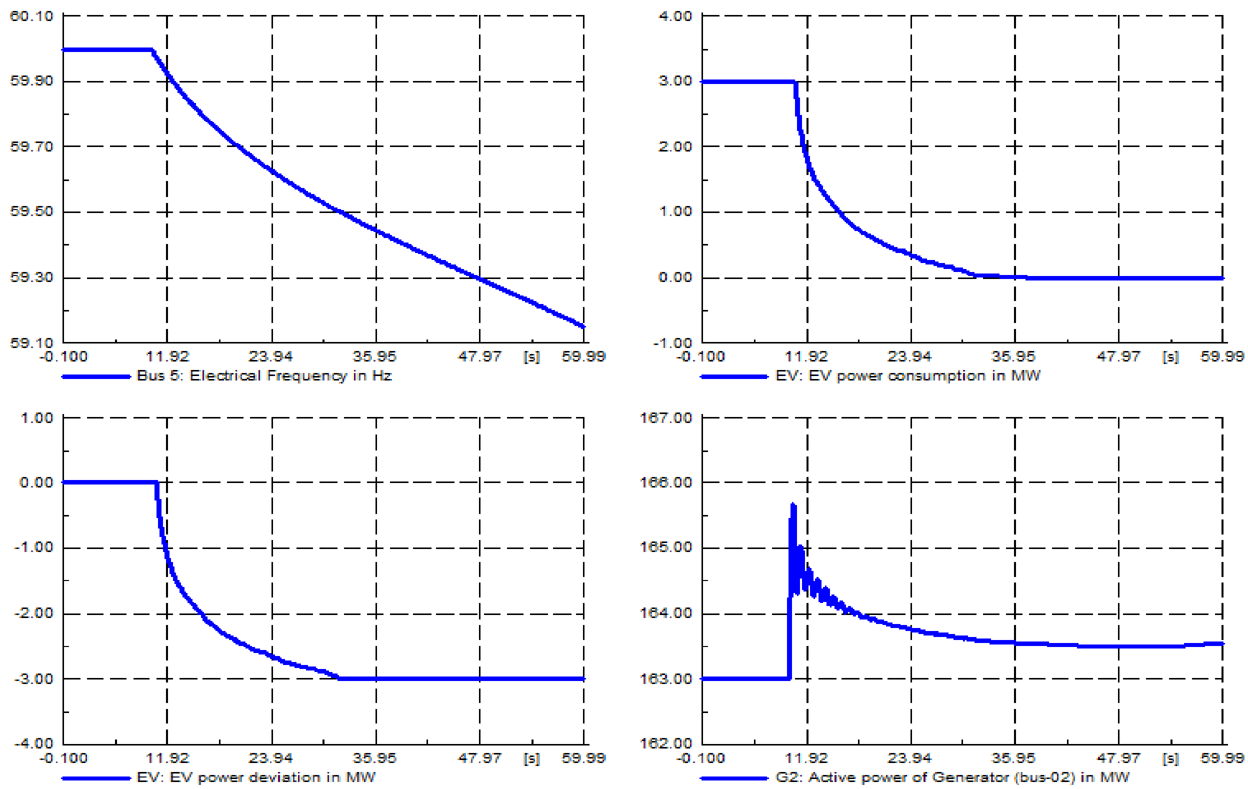

Fig. 6 Grid frequency, and power of EVs and G2 unit using frequency controller for 1,000 EV models

5. CONCLUSION AND RECOMMENDATIONS

This paper addresses the aggregation of EVs to contribute in the ancillary services of the frequency response. A simplified frequency controller was designed to alter the behaviour of the charging EV based on a frequency signal. The frequency controller that was designed in this study has controlled the grid frequency by disconnecting the charging EV according to the frequency signal thoughout a VHG mode. Then, population of controllable EV models were engaged to the IEEE nine-bus modified power system model. It has been shown that the residential EVs can be aggregated to provide low frequency response service in an instantaneous manner.

This study could provide a scope of further studies to enhance the behaviour of charging EVs. Possible paths for future work may involve the following extentions. I) the design of comprehensive dynamic frequency control algorithm, including the VHG and Vehicle to Grid (V2G) models. II) proper assumption for the availability of residential EVs that are ready to take actions when required by the operator should be further investigated .III) Operational constrains such as multiple events, travelling behaviour, compfort of EV owners, load recovering must be well included in the design of the frequency control algorithm. Furthermore, the EVs can be aggregated with different assets (eg. heat pumps, fridges..etc) for the provision of larger frequency and voltage response.

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