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Utilizing Electric Vehicles on Primary Frequency Control in Smart power Grids

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Abstract. Micro grids as one of the most significant parts of smart grids must be able to maintain their stability following likely disturbances by optimal handling of their existing resources. In large power systems, frequency distortions are covered suitably due to sufficient spinning reserve all over the grid. But in micro grids because of either the limitations of generation resources and uncontrollability of the most part of them, occurring a relatively large disturbance will result in a significant oscillation of frequency. In this article, the participation of electric vehicles (EVs) in primary frequency control (PFC) of micro grids is evaluated and it has been shown that the increasing of the penetration of EVs has significant impact on PFC of smart grids. EVs are recognized for their improving effect on PFC due to their capability of swift response to large disturbances because they are so quick to change their power output in accordance with the size of disturbances. The above-mentioned issues are verified according to simulation on a test system.

Keywords: Electric vehicles, micro-grid, power system, primary frequency control (PFC), smart grid.

1. Introduction

Most power systems tend to be large and interconnected and therefore when these systems are subjected to disturbances, all generating units react to the disturbances. In the case that disturbances are large, it will result in disintegration of the whole power system and as a result, the power system will break into smaller systems which are referred to as micro-grids. These micro-grids must be able to maintain their own stability and be capable of providing the required power of their own systems without having any unintentional loss of load by protection devices [1].

Due to the presence of spinning reserve, power systems usually don't suffer frequency instability but when they are subjected to large disturbances it is possible to divide into various micro-grids [2]. As a result, in this case, the frequency control issue including governor and frequency sensitive loads response must be accurately taken into account. Available electric vehicles (EVs) could act as a electric power producer in the network when the system needs further generation while loads are increased. When load shedding must be performed to enhance the system security, EVs can be easily disconnected from the system to act as a load shedding measure.

In this paper, electric vehicles are introduced as one of the most significant resources for frequency control. Indeed, the impacts of EVs on Primary Frequency Control (PFC) have not been evaluated so much. When the frequency tends downwards, EVs could inject power to the grid by discharging their own batteries and act as a power producer to prevent further dropping of frequency. On the other hand, in case, frequency tends upwards, EVs could absorb power from the grid by charging their own batteries and act as a power consumer to prevent further rising of frequency.

The proposed method consists of three steps which are described separately as follows.

1- PFC considering static load is studied for a reduction of generated power from one of the generating units and the frequency behaviour of all generating units are assessed.

2- EVs are taken into action for their flexible capability in PFC enhancement and their impacts on performance of the other generating units are evaluated.
3- The penetration of EVs is increased to evaluate the effect of EVs' penetration index in the grid on PFC.

Finally, the results are compared and the correlation between them is characterized in detail.

The remainder of the paper is organized as follows. In section 2, a brief description of coordination of EVs is presented. The principles of PFC are reviewed in section 3. Section 4, introduces the EVs aggregator. Numerical results are demonstrated in section 5. Section 6 concludes the paper.

2. Concept of Coordination of Electric Vehicles

Most published articles within this area of study predominantly have addressed the general concept and description of electric vehicles' coordination [3-5]. Some articles have presented the applications of EVs in near future [6].High efficient power system can be achieved by joining the renewable resources and EVs [7, 8]. Also, EVs could be used to provide ancillary services such as frequency regulation [9] or spinning reserve [10].

The stored energy in the EVs could be consumed in different aims. e.g. peak clipping, load curve smoothing, reduction of the output power fluctuation of renewable energy resources (i.e. wind and photovoltaic), provision of ancillary services (i.e. voltage and frequency control, spinning reserve) [11].

In this paper, the Effect of EVs on PFC has been addressed. Indeed, due to the ability to swiftly altering the consuming power, flexible operating mode and being distributed throughout the network, EVs are suitable resources for PFC.

3. Primary Frequency Control

When load and generation are balanced, the frequency of power system remains constant and uniform, but when a disruption occurs, the generating units respond to the mentioned disruption differently based on their own characteristics until the load and generation is balanced again and this new operating point indicates the new steady state of power system. The above mentioned concept is known as PFC [12].

Those units which participate in primary reserves must be able to regulate their output power up to 5% of their nominal power. The stages at which the units contribute to PFC are as follows.

$\Delta f<1.3$ Hz the governor keep the power constant

$\Delta f>1.3$ Hz the governor is switched from the power control to the speed control

Eq. (1) describes the normal condition of the network.

$$\frac{\Delta P_T}{P_L} = -K_T \frac{\Delta f}{f_n} \;\rightarrow\; \frac{\Delta f}{f_n} = -R_T \frac{\Delta P_T}{P_L} \tag{1}$$

where R_T indicates the governor droop and K_T is the effective gain of governor.

In traditional power systems, the frequency dependency of generation response is higher than that of load response but in some grids, the goal is to make the frequency dependency of both generation and load response the same.

The frequency dependency of loads is presented as:

$$\frac{\Delta P_L}{P_L} = K_L \frac{\Delta f}{f_n} \tag{2}$$

where K_L indicates the load sensitivity coefficient.

So as to increase the frequency dependency of loads, EVs are brought into action to act as a frequency dependent loads.

The stiffness coefficient of a power system is presented as K_f which its formula is described as follows.

$$K_f = K_T + K_L \tag{3}$$

The proposed PFC is to change the load and generation simultaneously so that the system reaches to a new frequency equilibrium point. The working of the proposed method is investigated through a numerical study using a test system.

4. EVs Aggregator

An EVs aggregator must be able to encourage the EV owners to enrol in a contract to make all their battery capacities available whenever it is needed.

The objective of the aggregator is to provide a kind of coordination between charging and discharging the available batteries and this could be done only from technical standpoint or economical viewpoint or a combination of both.

Participating in spot markets could be highlighted as one of the common economical objectives. This objective is realized through buying the electricity (charging the batteries) during low price period and selling (discharging the batteries) during high price period.

Also, EV aggregator could participate in ancillary service market by providing the spinning reserve and voltage or frequency regulation.

Technical objectives of utilizing EVs could be reliability enhancement, grid loss reduction, increasing the power quality and improving the network security. EVs are highly appropriate for participating in PFC program for following reasons.

a. The capability of charging their consuming/generating power so quickly.

b. Being distributed all over the network.

c. Being integrated in a particular area.

d. Providing a great capacity of integration which enables them to act like a large mobile power plant.

With respect to the unique characteristics of EVs in the PFC field of study, it is somewhat surprising that EVs have not been given enough attention in the literatures so far.

As it is known, in transient periods of power system, following a disturbance, the frequency is different at different bus bars. On the contrary, in steady state, the frequency remains the same at different bus bars within the micro-grid. So, the aggregators measure the nodal frequency at different bus bars and detect the frequency drop/rise by comparing with the reference frequency.

Detecting the rate of frequency changes, the aggregator must alter EVs mode so that the frequency disturbance is covered through a logical pattern. According to the table 1.

Table 1: EVs' Operational Mode

Initial mode	Alter mode applied from EV aggregator	
	Frequency drop	Frequency rise
Controllable load	Neutral/ Power producer*	Increase consuming power
Neutral	Power producer	Controllable load
Power producer	Increase generating power	Neutral/ Controllable load *

* Depends on the amount of frequency disturbance

To evaluate the effect of increasing EVs participation on the PFC of the network, the participation rate of EVs is described in two scenarios.

a. In the first scenario, 5% of the electrical loads are consist of EVs.

b. In the second scenario, 10% of the electrical loads are consist of EVs.

The aggregator, which is responsible for the charging and discharging the vehicles' batteries, must decide the extent to which the EVs' response rate is used and accordingly determine the optimal frequency response rate. In fact, due to the mentioned fact, in both scenarios tree levels of frequency response are assumed, namely; low, medium and high response rate.

5. Numerical Study

In this section, numerical study on a test system is expressed. As this network [13] is known as a small system, this system is regarded as micro-grid. The single line diagram of the network is shown in the figure 1. For the analysis of the network the DigSilent Power Factory software is used.

This micro-grid is consist of 3 generating units, 3 loads, 9 bus bars and 3 transformers, which the information of generating units are described in [13].

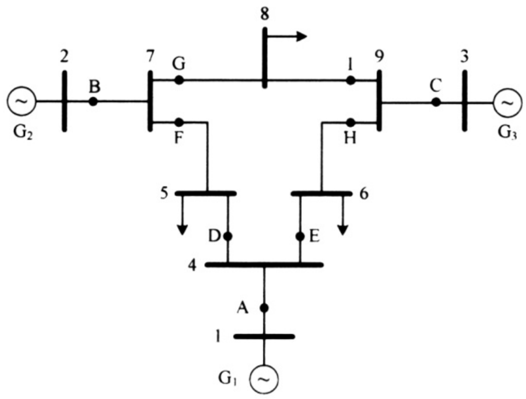

Fig 1: Single line diagram of the test system

Figures 2-a, 2-b and 2-c represent the frequency of power system while the penetration of EVs is 5% and their frequency response rate is low, medium and high, respectively. As it can be seen, in these figures the minimum frequency is increased by increasing the EVs frequency response rate and the steady state frequency has become closer to the reference frequency. Also, from these figures it can be concluded that the frequency distortion damps faster by increasing the EVs' frequency response rate. But, because the EVs' responses get faster the system mode tend to be more oscillatory.

By comparing figures 2-a, 2-b and 2-c with figures 2-d, 2-e and 2-f which represent the frequency behaviour when the EVs' penetration index is 10%, it could be highlighted that by increasing the EVs' penetration in the network, in addition to rising up of the minimum frequency point, the steady state slop of frequency drop has been reduced.

It is so important to notice that in all cases the timing of minimum frequency occurrence is the same which is the reflection of the effect of inertia constant of the generators and other parameters do not have considerable impact.

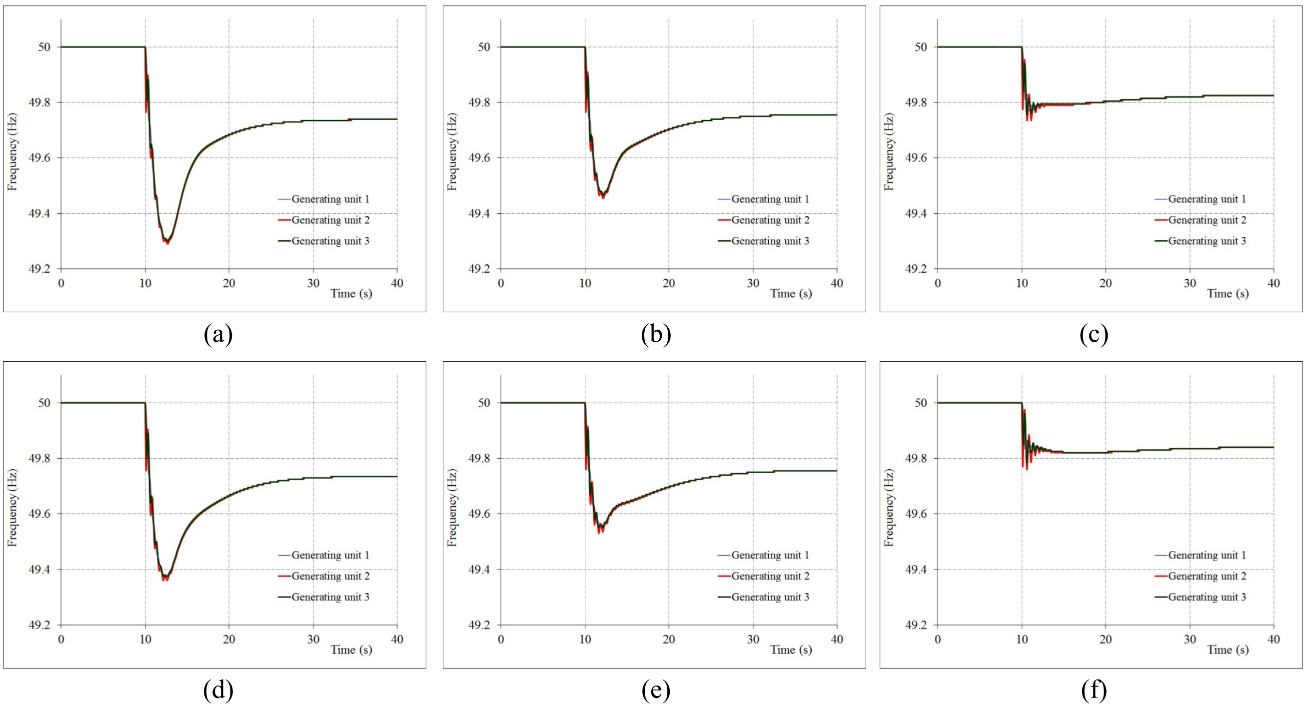

Fig 2. System frequency by different penetration index (PI) and different dependency to the frequency distortion
(a & d have 5% & 10% PI with low dependency, b & c have 5% & 10% PI with medium dependency
a & d have 5% & 10% PI with high dependency)

6. Conclusion

The frequency control of the power system (especially in micro-grids) is one of the most important aspects of stability studies. In order to enhance the stability of the power systems, accurate modelling of frequency dependent loads are of great importance. For this reason, in this article, EVs modelling is used for enhancing the stability indices.

With regard to the preformed studies in numerical study section, the usage of EVs in primary frequency control, have produced desirable results such as improvement of minimum transient frequency of power system and system frequency response.

Another advantage of using the EVs is improvement of the steady state frequency in addition to the fact that with more participation of EVs, the frequency response of generating units will be quicker to converge.

The only negative factor that could be mentioned is the reduction of frequency response damping as a fault occurs. Knowing that in practice, system damping is the amount of primary reserve which must be fed into the network following a fault, the negative factor could be disappeared through the reduction of the time of entering the EVs into the network.

7. References

[1] Kundur, P. ,et al, "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions," Power Systems, IEEE Transactions on , vol.19, no.3, pp. 1387- 1401, Aug. 2004.

[2] Horne, J.; Flynn, D.; Littler, T. , "Frequency stability issues for islanded power systems," Power Systems Conference and Exposition, 2004. IEEE PES , vol., no., pp. 299- 306 vol.1, 10-13 Oct. 2004

[3] W. Kempton and J. Tomic, “Vehicle-to-grid power implementation: From stabilizing the grid to supporting large-scale renewable energy,”J. Power Sources, vol. 144, no. 1, pp. 280–294, Jun. 2005.

[4] W. Kempton and J. Tomic, “Vehicle-to-grid power fundamentals: Calculating capacity and net revenue,” J. Power Sources, vol. 144, no. 1,pp. 268–279, Jun. 2005.

[5] W. Kempton and S. E. Letendre, “Electric vehicles as a new power source for electric utilities,” Transp. Res. D, vol. 2, no. 3, pp. 157–175, 1997.

[6] Jasna Tomić, Willett Kempton, “Using fleets of electric-drive vehicles for grid support,” Journal of Power Sources, Volume 168, Issue 2, 1 June 2007, Pages 459-468.

[7] Wehinger, Lukas A.; Galus, Matthias D.; Andersson, Goran; , "Agent-based simulator for the German electricity wholesale market including wind power generation and widescale PHEV adoption," Energy Market (EEM), 2010 7th International Conference on the European , vol., no., pp.1-6, 23-25 June 2010.

[8] Ropp, M.E. , "Similarities between vehicle-to-grid interfaces and photovoltaic systems," Vehicle Power and Propulsion Conference, 2009. VPPC '09. IEEE , vol., no., pp.1221-1225, 7-10 Sept. 2009.

[9] Sekyung Han; Soohee Han; Sezaki, K., "Development of an Optimal Vehicle-to-Grid Aggregator for Frequency Regulation," Smart Grid, IEEE Transactions on , vol.1, no.1, pp.65-72, June 2010.

[10] B. K. Sovacool, R. F. Hirsh.” Beyond batteries: An examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (EV) transition “, Energy Policy, Volume 37, Issue 3, March 2009, Pages 1095-1103.

[11] Robert C. Green II, Lingfeng Wang, Mansoor Alam,” The impact of plug-in hybrid electric vehicles on distribution networks: A review and outlook”, Renewable and Sustainable Energy Reviews, In Press, Corrected Proof, Available online 30 August 2010.

[12] P Kundur, NJ Balu, MG Lauby,” Power system stability and control”, 1994.

[13] P. M. Anderson and A. A. Fouad,” Power System Control and Stability”, vol. 1, Ames, IA: The Iowa State University Press, 1977.