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Reactive power support managing charging park of PHEV

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ABSTRACT

Due to the extensive influence of hybrid vehicles in recent years, the presence of these components as a part of a smart distribution network seems inevitable. Plug-in Electric Vehicles (PEV) participates in electric power transmission to the network in certain hours of a day within a smart distribution network framework. The major PEV's feature is to reinforce the reactive power of the smart distribution system of the power supply. However, utilizing PEVs under any circumstances cannot have positive effects. For example, unscheduled and random charging may cause voltage fluctuations, increased blackouts due to network overload, very large peaks in power consumption thus deteriorating the reactive power. Therefore, this article examines the reactive power reinforcement in distribution networks as well as alleviating sever voltage fluctuations and overload by adjusting EVs charging. It is shown that a proper strategy for Smart Parks, like STATCOM, can be employed to properly compensate the reactive power and eliminate the voltage fluctuations.

1. Introduction

Due to the increasing tendency to EVs, it is anticipated that a large number of EVs will be used in next few years. The Electric Power Research Institute (EPRI) has stated that by 2050 up to 62% of the transportation system in United States will belong to PHEVs (Mallette and Venkataramanan, 2010).

Since these vehicles require batteries with high-capacity energy storage, uncoordinated and unplanned recharge of batteries on a large scale imposes a large load on the system. Thus, application of EVs has a large influence on the load curve, performance and design of power system (Mohammad and Hajforoosh; 2011- Kempton and Tomi, 2005).

One way to reduce the negative effect of the vehicle battery is charge management; i.e. plug-in batteries in low-load hours. Connecting the battery to EV at peak times to transmit electric power to the network can also have positive effects, such as reactive power reinforcement.

Studies conducted on drivers' behavior have shown that they park their cars 22 hours a day (Emadi and Joo Lee, 2008). For EVs, a long park time makes the energy in the batteries unused. If these vehicles can be connected to V2G network, the energy stored in batteries can be used to provide ancillary services such as reducing the peak power and network reactive power reinforcement (Kramer, Chakraborty and Kroposki, 2008).

Therefore, for successful implementation of EVs interacts with the electricity distribution network some issues must be specified including time and number of EVs participating in plan, and charge and discharge time and location. With the increasing number of vehicles, charging management control systems become more complex. This is where the need to optimal planning and management of EVs charging in the smart network to fulfill the objectives such as network reactive power reinforcement is more evident.

Charge adjusting can be done remotely to shift the demand to low-load periods thus avoiding larger peaks in power consumption. Smart network technology, which is currently being developing, is seeking for power network modernization to deal with the increasing energy demand in the future. Although smart networks details and standards should be finalized, it is clear that a high-speed two-way communication network is essential. This provides a general framework for fast monitoring and control of transmission, distribution, and end consumers for effective coordination and utilization of existing energy sources (Mohammad and Hajforoosh, 2011).

2. Smart park model

The Smart Park model discussed in this paper is shown in Fig. 1 as a battery with a bi-directional

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three-phase inverter. The inverter generates a 208rms three-phase voltage (line to line) passing through a 208V/22KV multiplier and then connecting to the Smart Park bus. A small inductance (0.5mH) is mounted between the converter and transformer. Smart Park controls (inverters) are designed so as to be able to exchange the 30 MW power with the network. Since the average power exchange in EVs is about ±30 kW, each Smart Park is considered containing approximately 1,000 EVs to supply the 30MV power.

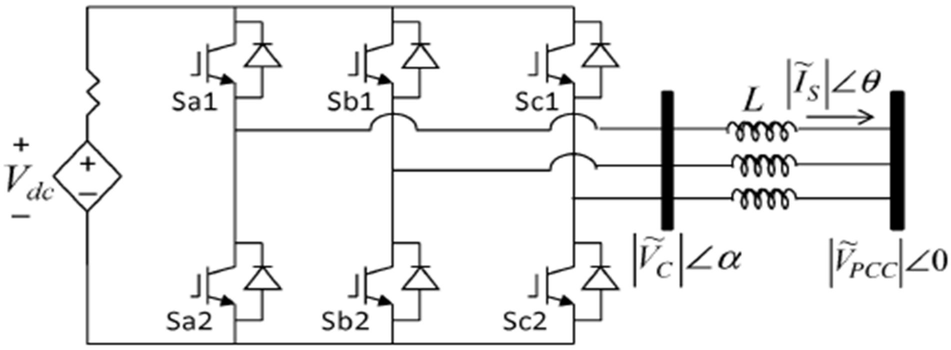

Fig. 1: PEV as a dc voltage source and inverter

Control strategy for Smart Parks is shown in Fig. 2.

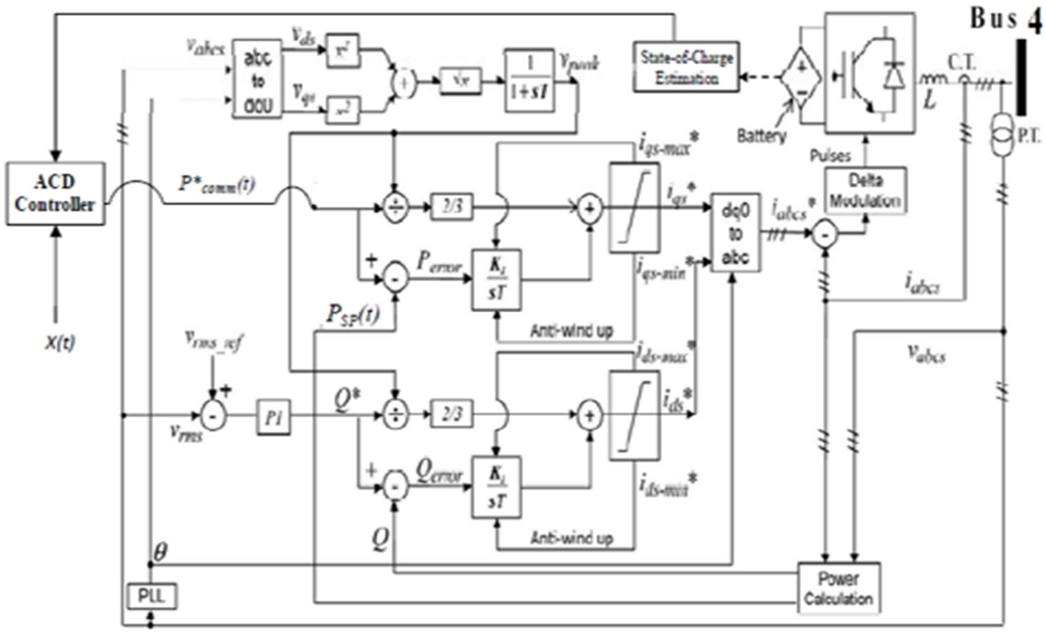

Fig. 2: current Control strategy for Smart Parks (reactive power control)

In d-g reference frame, the outpour active and reactive power of the inverter is as follows (Krause et al., 2002):

$P = \frac{3}{2}(v_{qs}.i_{qs} + v_{ds}.i_{ds})$ P: Output active power of the inverter (1)

$Q = \frac{3}{2}(v_{qs}.i_{ds} + v_{ds}.i_{qs})$ Q: Output reactive power of the inverter (2)

In a synchronous rotating reference frame, the line-to-neutral voltage falls on q axis and is $v_{ds} = 0$. Therefore, the function of control system is to command the currents corresponding to the reference power which can be expressed as follows:

$i^*_{qs} = \frac{2P^*}{3\sqrt{2}v_{peak}} + \frac{K_i}{s}(P^* - P)$ i^*_{qs}: reference current in q reference frame (3)

$i^*_{ds} = \frac{2Q^*}{3\sqrt{2}v_{peak}} + \frac{K_i}{s}(Q^* - Q)$ i^*_{ds}: reference current in d reference frame (4)

The first term in Eq. 3 and 4 are based on Eq.1 and 2 from power equations. v_{peak} is the filtered line-to-neutral peak voltage. This term causes rapid response to sudden changes in the demand power. So, the integral term will eliminate the steady-state error. As shown in Fig. 2, a constraint is set on the command current to prevent large currents flowing in the inverter and battery during network transmissions.

When employing the Smart Park in the voltage-control mode, an additional voltage-control loop is used in control strategy which is like a personal car inverter. In the voltage-control mode, the rms voltage of the bus is first compared with the reference voltage; the error is then passed through a PI controller to send the reactive power command to Smart Park.

3. The studied power system

Single-line diagram of the discussed power network is shown in Fig. 3.

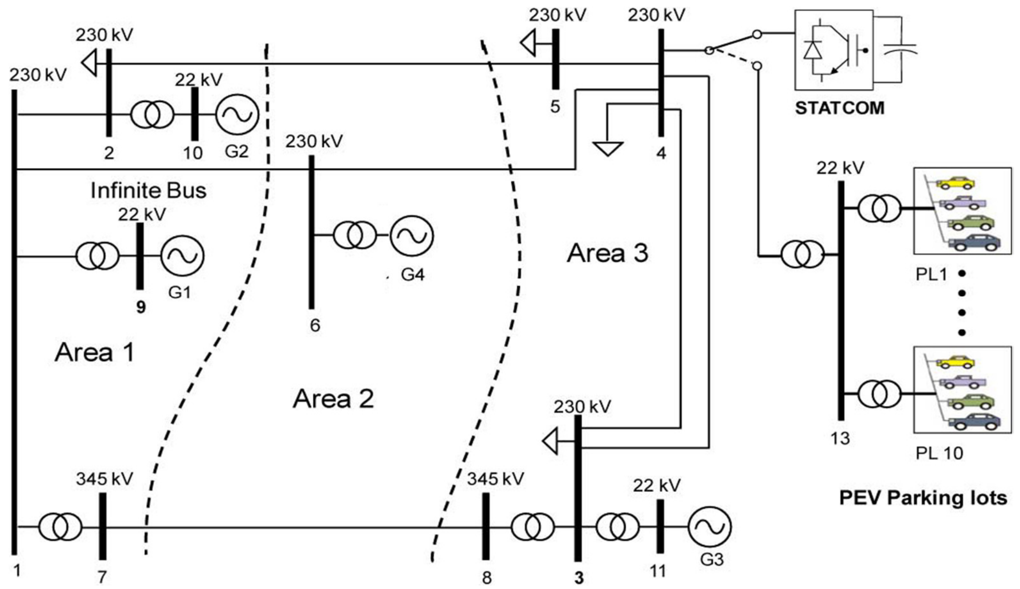

Fig. 3: Single-line diagram of the discussed power network

The 12-bus network (six 230kV, tow 345kV, and four 22kV buses) are working at a frequency of 60 Hz. The test network covers three geographical regions (Zones I, II, and III). Zone I generally consists of water generators. Zone II is considered as a transition system between the sources mounted at zone I and the load (zone III). Some sources are also mounted in the load zone. However, they lack enough capacity to supply the load. Zone II has also a limited capacity to generate energy. The generated energy must pass through the 230kV transmission network. Apart from the connection between zones I and III which is modeled by a 345kV transmission line between buses 7 and 8 (Jiang et al., 2006) zones II and III use parallel capacitors to preserve the voltage. In order to accurately compensate the reactive power of the network, 10 Smart Park units (PL1 to PL10) are integrated in the bus 4 (Jiang et al., 2006). Normally, bus 4 has the least voltage. Result of voltage-control obtained from this set is compared with results from the STATCOM mounted in the system. To control STATCOM, the reference strategy (Qiao et al., 2009) is applied.

4. Simulation

Here, the results of two case studies are presented. In the first one, the voltage of bus 9 is changed and the voltage regulations by Smart Park and STATCOM in bus 4 (the weak bus in the network) are compared and evaluated. In the second case study, a three-phase short circuit happens in bus 6 then the voltage controls and reactive power compensations by Smart Park and STATCOM on bus 4 are compared.

4.1. Voltage control

The Smart Park's performance in voltage control when connected to bus 4 is compared with a STATCOM (Fig. 5). The voltage of G1infinite bus changes as shown in Fig. 4. Without compensation, reactive power of bus voltage has sever fluctuations. To eliminate the fluctuations, Smart Parks are connected to bus 4. A similar experiment was performed with a STATCOM with a power of 300 MVAR and the performances are compared. Fig. 5 shows the voltage range for bus 4. As obvious, Smart Parks act almost similar to a real STATCOM with 300MVAR power.

Fig. 6 compares the reactive power injection for ten Smart Parks with STATCOM.

As shown in the above figures, in voltage-control study, a similar reactive power is injected or absorbed. Fig. 5 and Fig. 6 suggest that for load control in a power system, Smart Park inexpensive systems can act as expensive FACTS devices.

4.2 Voltage control through a three-phase to earth fault

In this study, a three-phase to earth fault is applied on bus 6 for 4 cycles. In case no compensation is done, voltage fluctuations are first sever in bus 4 and then slowly alleviate after a long time.

Fig. 8 shows the reactive power injection of STATCOM during the compensation.

As seen in Fig. 7, Smart Parks has a good performance just like STATCOM in compensation of reactive power and eliminating the voltage fluctuation. Fig. 9 shows the injection power of Smart Parks.

As you can see, the reactive power injections for STATCOM and Smart Park are similar.

5. Discussion

Using the strategies applied to utilize the power lies in the smart parks of EVs, the reactive power can be compensated without installing expensive FACTS devices. In a smart network, the information exchange capabilities can be employed to avoid overloads due to uncoordinated vehicle charging. Hybrid electric vehicles and Smart Parks are used not only to supply the network but can prevent the pollutions caused by common vehicles with the support of government. With the development of Smart Parks all over the city, the energy contained in Smart Parks can be used anywhere in the network.

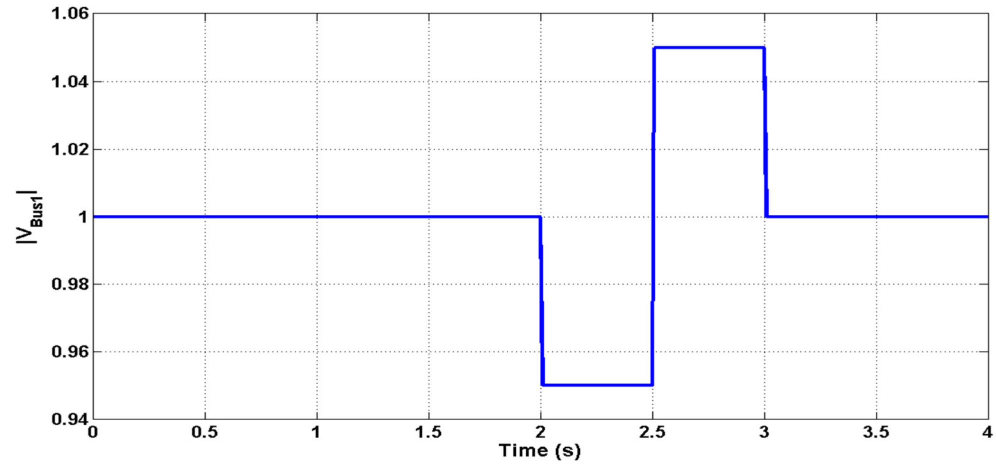

Fig. 4: The G1infinite bus voltage range changes

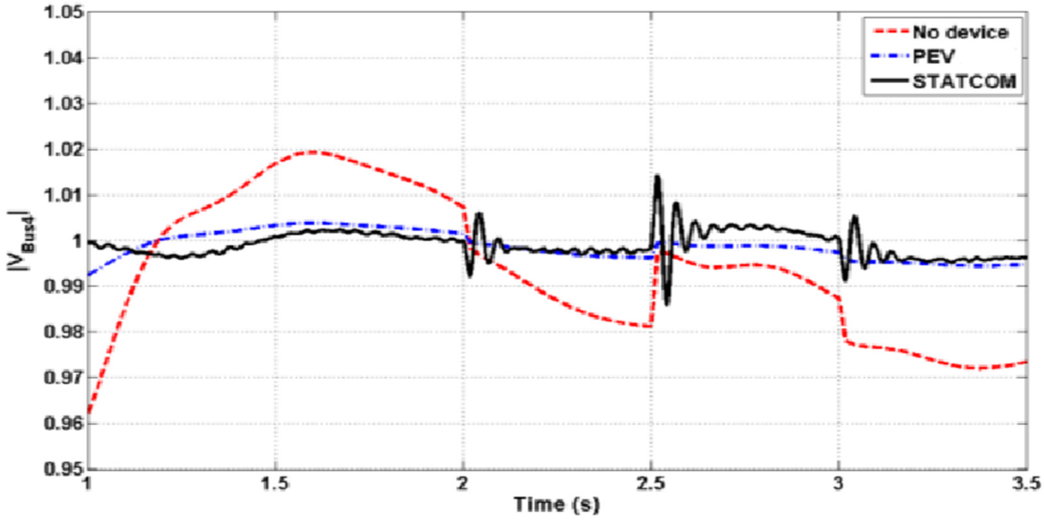

Fig. 5: Performance of STATCOM and Smart Park in bus 4 voltage control

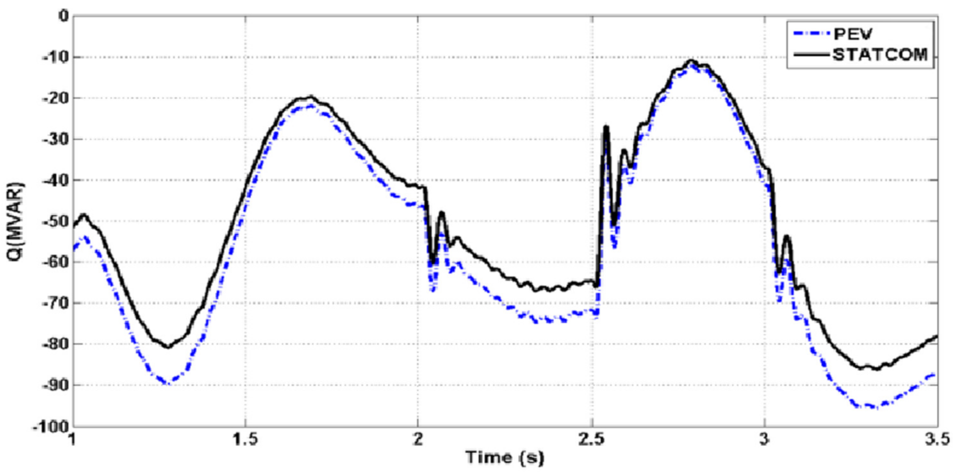

Fig. 6: reactive power of STATCOM and Smart park

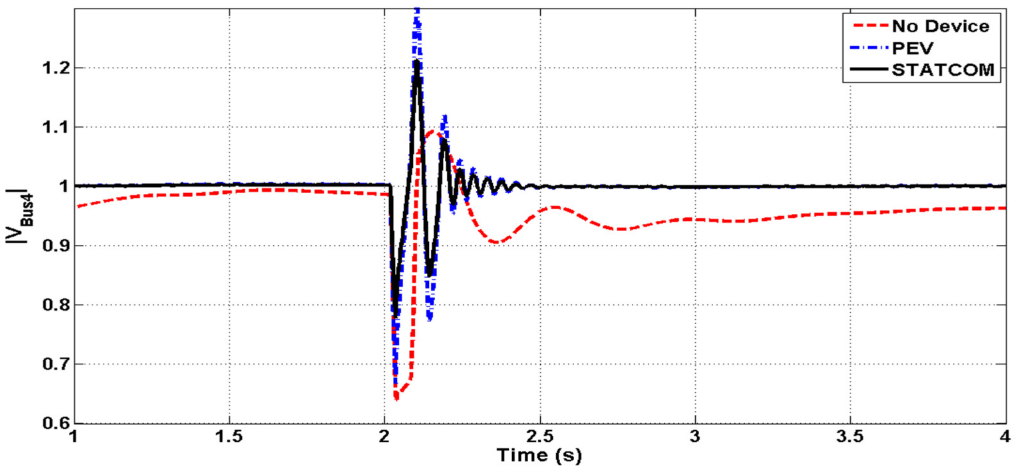

Fig. 7: Results of STATCOM and Smart Park performance in voltage control for bus 4

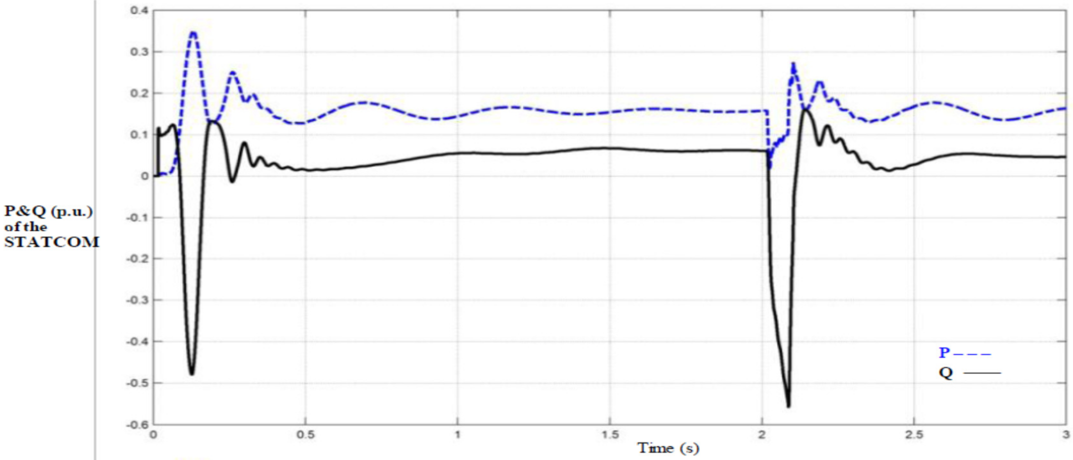

Fig. 8: Reactive power injection of STATCOM during three-phase to earth fault

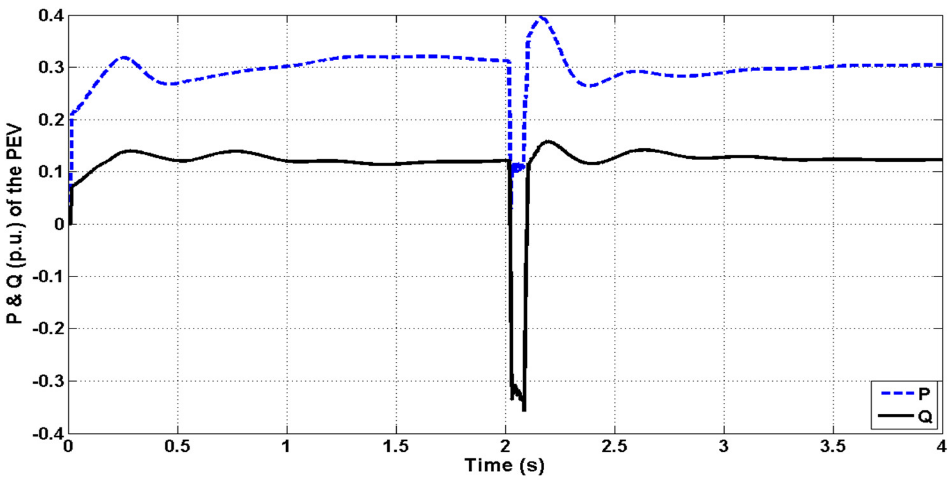

Fig. 9: Reactive power injection of Smart Park during three-phase to earth fault

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