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Review

Intelligent control of vehicle to grid power

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ABSTRACT

Vehicle-to-grid (V2G) describes a system in which plug-in electric vehicles (PEV), which includes all electric vehicles and plug-in hybrid electric vehicles, utilize power by plugging into an electric power source and stored in rechargeable battery packs. PEVs significantly increase the load on the grid, much more than you would see in a typical household. The objective of this paper is to demonstrate the use of intelligent solutions for monitoring and controlling the electrical grid when connected to and recharging PEV batteries. In order to achieve this aim, the study examines the distribution of electricity in the power grid of a large-scale city so that PEVs can tap into the system using smart grid electricity. The electricity grid for the large-scale city is modelled, and it can be shown that the vehicle electrification can play a major role in helping to stabilize voltage and load. This developed grid model includes 33 buses, 10 generators, 3 reactors, 6 capacitors, and 33 consumer centers. In addition, the grid model proposes 10 parking servicing 150,000 vehicles per day. The smart grid model uses intelligent controllers. Two intelligent controllers including (i) fuzzy load controllers and (ii) fuzzy voltage controllers have been used in this study to optimize the grid stability of load and voltage. The results show that the smart grid model can respond to any load disturbance in less time, with increased efficiency and improved reliability compared to the traditional grid. In conclusion it is emphasized that smart grid electricity should contribute to PEVs accessing renewable energy. Although the V2G will play a major role in the future portfolio of vehicle technologies, but does not make much sense if the carbon content of the electricity generated by the grid will not be reduced. Thus, the recourse to renewable energy and other alternatives is crucial. The energy is stored in electrochemical power sources (such as battery, fuel cells, supercapacitors, photoelectrochemical) when generated and then delivered to the grid during peak demand times.

Contents

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1. Introduction

Plug-in electric vehicles (PEVs), which include pure electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), provide a new opportunity to deliver fuel consumption and exhaust emission reductions by drawing power from the electric power grid. EVs utilize one or more electric motors and batteries for propulsion, while PHEVs have both an internal combustion engine and batteries for propulsion. However, it is necessary to know when PEVs are connected to the grid, and are available for charging and discharging. Therefore, the Energy Storage System (ESS) of PEVs has to monitor the battery State-of-Charge (SOC). Vehicle to grid (V2G) offers a new possibility for the ESS. V2G can be utilized as an electricity consumer and electricity supplier. In recent years a number of studies have researched the V2G concept under different views: (i) connection to the grid [1,2], (ii) pioneer its new markets [3], and (iii) identify ancillary services [3–6]. Such ancillary services aggregate the important roles in a network controlled to transfer power from where it is generated to where it is utilized. In addition, researchers have shown that aggregator services are needed for frequency regulation and balancing, load leveling, and voltage regulation to deal with PEVs while providing power electricity [7]. Guille and Gross [4] proposed a framework that recognized the central role of the aggregator in V2G and can appropriately accommodate its critical role in “collecting” battery vehicles to form aggregations and dealing with Energy Service Providers (ESPs) and the ISO/RTO for the purchase/provision of energy and capacity services. In addition, the framework provided the means for incorporating the computer/communication/control infrastructure to represent the flows between the ESPs or the ISO/RTO and the individual battery vehicles. Saber and Venayagamoorthy [8] used the Unit Commitment (UC) aggregator for V2G. Regarding a number of gridable vehicles in V2G, they showed that the extended UC with V2G makes the problem even more complicated, and they tried to balance between cost and emission reductions for UC with V2G by using the Particle Swarm Optimization (PSO) method. The optimality was pursued only from the perspective of efficient grid operation rather than that of each vehicle. Thus, it was determined to attract the vehicle owners to join the V2G voluntarily. Moreover, when it came to the regulation, the decision strategy should be entirely revised as the pricing mechanism of regulation was based on the available power capacity, not the generation cost. Han et al. [9] proposed an optimal V2G aggregator for frequency regulation. A performance measure was mathematically formulated to maximize revenue. During the formulation, the energy capacity of the battery was considered an important factor, and weight functions were employed to reflect the energy constraint. They employed dynamic programming to compute the optimal charging control for each vehicle. The proposed method applied only to the frequency regulation and other regulation, and load leveling in V2G was not estimated.

Despite the ongoing investigation of aggregators for V2G, there is still a gap. Most of the existing works do not take into account combined roles in uncertain dynamic situation such as the number of vehicles, distributed generation, parking lots (loads), frequency regulation, voltage regulation and load leveling of the associated impacts on the grid management. The general aim of this research is to gain an in-depth understanding of the impact of the plug-in electric vehicle and intelligent control of V2G in a large-scale distribution grid.

The introduction of PEVs and the need of fast charging will be a serious challenge for the current grid, since it is not properly optimized to handle such loads, which are quite unpredictable and high-demanding for the distribution networks. Vehicle electrification will play a major role in the future portfolio of vehicle technologies, but does not make much sense if the carbon content of the electricity generated by the grid will not be reduced. Thus, the recourse to renewable energy from sources such as wind generation and solar power and other alternatives is crucial. The energy is stored in electrochemical power sources (such as battery, fuel cells, supercapacitors, photoelectrochemical) when generated and then delivered to the grid during peak demand times.

In can be expected that in the near future, vehicle charging facilities will have multiple energy sources that include electricity from electrical power grid, photovoltaic, fuel cell, etc., and local energy storage units such as batteries, flywheels, ultra-capacitors. An optimized interface that links these energy sources and loads is clearly needed. The tasks of this interface are, but not limited to, optimizing the energy flow between different sources and loads, minimizing the total energy consumption of the system, and providing ancillary functions to the grid.

Thus, the concept of smart grid and intelligent control (combined with proper communication protocol) represents a technology enabler for vehicle electrification and wider penetration of renewable energy into the power grid.

The paper is organized as follows. Section 2 describes the vehicle to grid concept including plug-in electric vehicles and grid power. Section 3 presents the grid model and main assumptions. The simulation methodology is presented in Section 4. The results and associated discussions are explained in Section 5 and finally, the concluding remarks are given in Section 6.

2. Vehicle to grid (V2G)

2.1. Plug-in electric vehicle

The terminology plug-in electric vehicle (PEV) includes pure electric vehicles and plug-in hybrid electric vehicles, and is a vehicle with rechargeable batteries that can be restored to full charge by plugging into an electric power source. However, PEVs are complex, comprising many mechanical, electrical, mechantronic, and electronic components. Their performance can be affected by factors such as road conditions, environmental conditions and driver behaviour [10,11]. Hence, advanced control systems and strategies are often employed to manage the operation of the internal components. Whenever a vehicle is plugged-in at the parking lot charging deck, the battery parameters, like initial State of Charge (SOC), battery available capacity and other user specific details, should be acquired for an optimal energy management.

2.1.1. Battery model

The function of battery in a PEV can vary. The battery may be a major power source, or may be used in conjunction with the primary power source(s) to level out the supply of power to the vehicle drivetrain. As a consequence, the amount of battery power aboard a PEV may vary between single batteries to a pack of many batteries connected together. When using batteries as a primary source of power, the PEV designer becomes concerned with the mass and volume of the battery pack required to meet the power and energy needs of the vehicle. The drive to achieve high power and energy densities has led the PEV community to investigate many types of batteries. The future of battery electric vehicles depends primarily upon the cost and availability of batteries with high energy densities, power density, and long life. Recently, it has been predicted that 100,000 battery-operated vehicles will be sold annually in 2020 in the US and 1.3 million units in the world wide (i.e. 1.8% of the 71 million vehicles) [12]. Furthermore, it is expected that 3.9 million plug-ins and hybrids will be in market in 2020 in the worldwide. There are many types of batteries that are currently being used – or being developed for use in PEVs. The aim of batteries development is to enhance their specific energy along with their energy density (see Fig. 1, extracted from [13,14]).

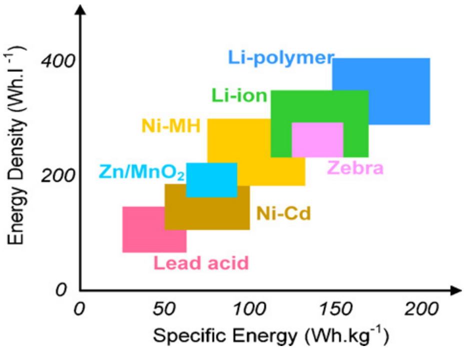

Fig. 1. Battery characteristics [13,14].

Lithium seems an ideal material for a battery. It is the lightest metal in addition to having the highest electric potential of all metals. As it can be seen from Fig. 1 the Li-ion battery has the following advantages: (i) high energy density. (ii) High specific energy. (iii) And low self-discharge rate. In PEVs, the nonlinear nature of the electrochemical processes in the battery is magnified due to dramatic current flowing in and out of the battery and the larger range of the temperature variation. According to the literature [13] batteries models were usually include equivalent circuits. The simplest battery model uses constant discharging and recharging efficiencies neglecting the fact that the power losses are related to the battery current. A simple battery model behaviour [15] which considers the open circuit voltage U_o and the internal resistance R_i is shown in Fig. 2 and used in this study.

The battery current is then derived from power balancing the following equation.

$$P_{\text{batt}} = (U_o - R_i \times I) \times I \tag{1}$$

$$I = \frac{U_o \sqrt{U_o^2 - 4R_i P_{\text{batt}}}}{2R_i} \tag{2}$$

$$U_o = U_{o0}(1 - \text{SOC}) \tag{3}$$

$$R_i = R_{i0} + R_{i1}(1 - \text{SOC}) \tag{4}$$

where I battery current, P_{batt} battery power, R_i battery internal resistance, $R_{i0,1}$ battery internal resistance coefficients, U_o battery open circuit voltage, $U_{o0,1}$ battery open circuit voltage coefficients. The open circuit voltage U_o and the internal resistance R_i are functions of battery the State of Charge (SOC). To indicate the actual charging level of the battery, the SOC is often used. At higher SOC, the battery has larger open circuit voltage and smaller resistance. These two parameters are sometimes regarded as constants since they do not change much over the full battery operating range, e.g. 30–90%. Fig. 3 explains the efficiency of the typical battery during discharging and charging. The battery has a high discharging efficiency with high SOC and a high charging efficiency with low SOC. The net cycle efficiency [16] has a maximum in the middle range of the SOC. Therefore, the battery operation control unit of a PEV should control the battery SOC in its middle range so as to enhance the operating efficiency and depress the temperature rise caused by energy loss. High temperature would damage the battery.

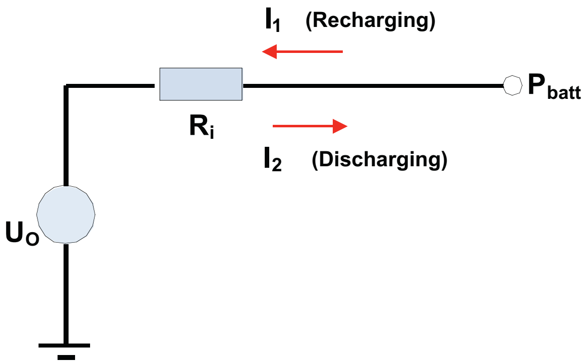

Fig. 2. Battery model.

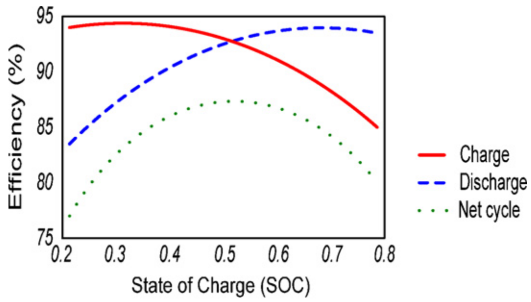

Fig. 3. Typical battery charge and discharge efficiency [16].

The battery employed in this study has a capacity of 6.5 A-h and a pack voltage of 273.6 V, and it is composed by 14 cells. The vehicle battery can draw up to 25 kW h from the grid power, depending on charging infrastructure.

2.2. Grid electricity

The electric grid delivers electricity from points of generation to consumers. Due to the characteristics of electric power generation (inefficient at managing peak loads), transmission and distribution, experts have identified local distribution as a likely part of the chain to be adversely affected by unregulated PEV charging. These issues can be addressed by using smart grid electricity. A smart grid focuses on electrical and information infrastructure, and it encompasses three major areas: (i) demand management, (ii) distributed electricity generation, and (iii) monitoring and control. Grid monitoring and control is required to ensure that electric generation matches the demand. If supply and demand are not in balance, generation plants and transmission equipment can shut down which, in the worst cases, can lead to a major regional blackout. The transmission system provides base load and peak load capability, with safety and fault tolerance margins. Controlling and dispatching centers are responsible for management and controlling of connected power networks. The equations below show the total reactive and active power generated and consumed at time t.

$$P_g(t) = \sum_{g_i=1}^{G} P_{g_i}(t), \quad P_d(t) = \sum_{d_i=1}^{M} P_{d_i}(t),$$
$$Q_g(t) = \sum_{g_i=1}^{G} Q_{g_i}(t) \quad Q_d(t) = \sum_{d_i=1}^{M} Q_{d_i}(t) \tag{5}$$

where $P_g(t)$ is generate active power, G is number of generators, $P_d(t)$ is consumption active power, M is number of reactors, $Q_g(t)$ is generate reactive power, $Q_d(t)$ is consumption reactive power. The total generated and consumed active and reactive powers of ith bus at time t are given in following equation.

$$\begin{cases} P_i(t) = P_{gi}(t) + P_{di}(t) \\ Q_i(t) = Q_{gi}(t) + Q_{di}(t) \end{cases} \tag{6}$$

However the limitations of the above equations are as follows:

$$\begin{aligned} &P_{gi\,\min} \le P_{gi} \le P_{gi\,\max}, \quad Q_{gi\,\min} \le Q_{gi} \le Q_{gi\,\max} \\ &P_{di\,\min} \le P_{di} \le P_{di\,\max}, \quad Q_{di\,\min} \le Q_{di} \le Q_{di\,\max} \end{aligned} \tag{7}$$

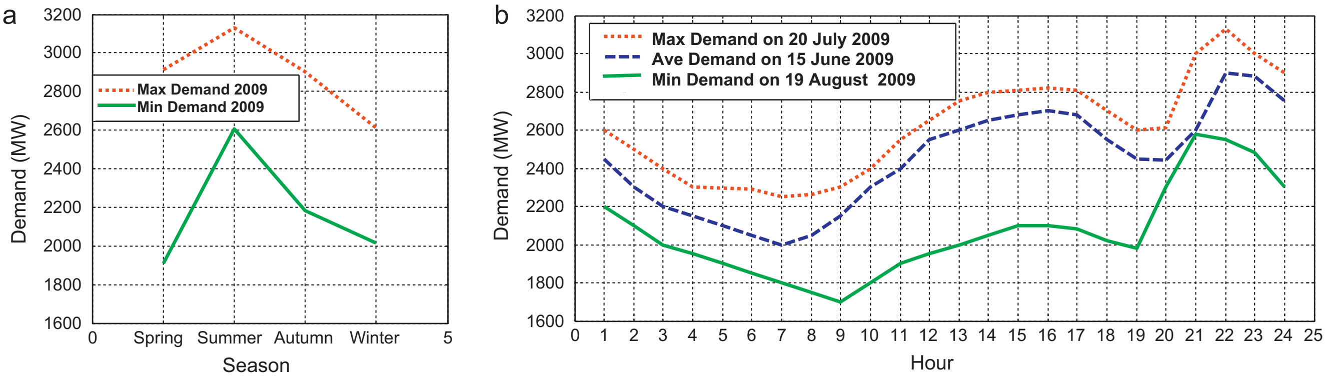

Fig. 4. Demand in large-scale city 2009 (a) seasons, (b) summer.

One aspect of grid management is to provide power reserves to maintain frequency (f), voltage (V), voltage angle (δ_i), and facilitate the efficient handling of imbalances or congestion as shown in following equation.

$$
\begin{aligned}
& f_{\min} \leq f_i \leq f_{\max} \\
& \left|V_{i\min}\right| \leq \left|V_i\right| \leq \left|V_{i\max}\right| \\
& \left|\delta_i - \delta_n\right| \leq \left|\delta_i - \delta_k\right|_{\max}
\end{aligned}
\tag{8}
$$

The current injection of ith bus is calculated by using following equation.

$$I_i = \sum Y_{ik} V_k \tag{9}$$

where Y_{ik} is the admittance between bus i and k, I_i is the current of each bus. The admittance is considered from the following equation:

$$Y_{ik} = \left|Y_{ik}\right| . e^{j\theta ik} \tag{10}$$

where θ_{ik} is admittance angle between bus i and k.

Therefore, the generated active power and generated reactive power can be calculated by Eq. (11) as follows.

$$
\begin{aligned}
& P_i = \left|V_i\right| . \sum \left|V_k\right| . \left|Y_{ik}\right| . Cos(\theta_{ik} + \delta_k - \delta_i), \\
& Q_i = -\left|V_i\right| . \sum \left|V_k\right| \left|Y_{ik}\right| . \sin(\theta_{ik} + \delta_k - \delta_i)
\end{aligned}
\tag{11}
$$

Finally, the total balance between electrical power generation and consumption in the grid is found by the following equation.

$$P_i(t) = \sum P_{di}(t) + P_{li}(t), \quad Q_i(t) = \sum Q_{di}(t) + Q_{li}(t) \tag{12}$$

3. Grid model and assumptions

The electric grid is a massive and extremely complex system consisting of centralized power plants, transmission lines, and distribution networks. One of the grid principal issues that must be addressed by smart grid is peak load. Peak load is the small period when electricity demand is highest in a day, season, or year. Electricity demand is variable, and can be only partially predicted and managed. Generators must be continuously adjusted to follow power demand; a sample of the traditional power demands in a large-scale city within different year, seasons and for 24 h in summer of 2009, is shown in Fig. 4. As can be seen from Fig. 4(a), the maximum peaks in demand are in summer and according to Fig. 4(b) the maximum peak demand in the summer 2009 is on the 20th of July. Based on the day, the operations of the power network center to guarantee to maintain enough power supply despite peaks in demand with V2G will be carefully managed. A simplified diagram of a power electrical grid from generation stations to consumers in the large-scale city and its model is shown in Fig. 5. This model includes 33 buses, 10 generators, 3 reactors, 6 capacitors, and 33 consumer centers. In addition, in this model 10 parking lots are designed to hold 150,000 vehicles each day. Table 1 illustrates that the grid model specification.

As clearly shown by Eqs. (1)–(4) – defining battery power balancing- and Eqs. (5)–(12) – defining power electricity balancing- the integrated battery charging and electrical grid [17] are complex systems comprising conglomerations of equipment all connected electrically. Their performances are affected by uncertain factors such as: loads, voltage and frequency. Intelligent controllers concern highly complex and nonlinear systems that are subject to regular disturbances. The intelligent controllers have been used in several power systems as studied in [18–21].

3.1. Intelligent controllers

Fuzzy controller is an attractive alternative to conventional control methods since it provides a systematic and efficient structure to deal with uncertainties and nonlinearities in complex systems, when an accurate system analytical model is not obtainable, not possible to acquire, or too complicated to use for control principle. As mentioned in previous sections two fuzzy controllers are implemented for grid monitoring and control to ensure that electric generation matches the demand within specific constraints. As shown in Fig. 5, there are some gorge routes and buses [18] within the grid that result in uncertainties and extra disturbances. Therefore, they must be considered for monitoring within intelligent controllers. In this study, the intelligent controllers for V2G are designed for the supply of peak power, balancing control, load leveling, and voltage regulation. The two controllers developed for this study – fuzzy load controller (FLC) and fuzzy voltage controller (FVC) – are described in the next sub-sections.

3.1.1. Fuzzy load controller (FLC)

This intelligent controller is used to control the balancing of some generators and adjusting load demands on the electrical power grid by monitoring load leveling and peak power. As shown in Fig. 6, there are spinning reserves ready to generate and cope with peak demand that is influenced by the demand load of the power grid during the day. The amount of spinning reserves available is determined by previous experience. Spinning reserve generators perform at low or part speed and consequently are already synchronized to the grid. The controller dispatches the demand level by adjusting gorge generators including G2, G3, G7, G8, G11, G12 and consumption powers including B28, B20, B27, B1, B33. The fuzzy load controller (FLC) measures the average of voltages 230 kV and 400 kV, total load grid and total active power

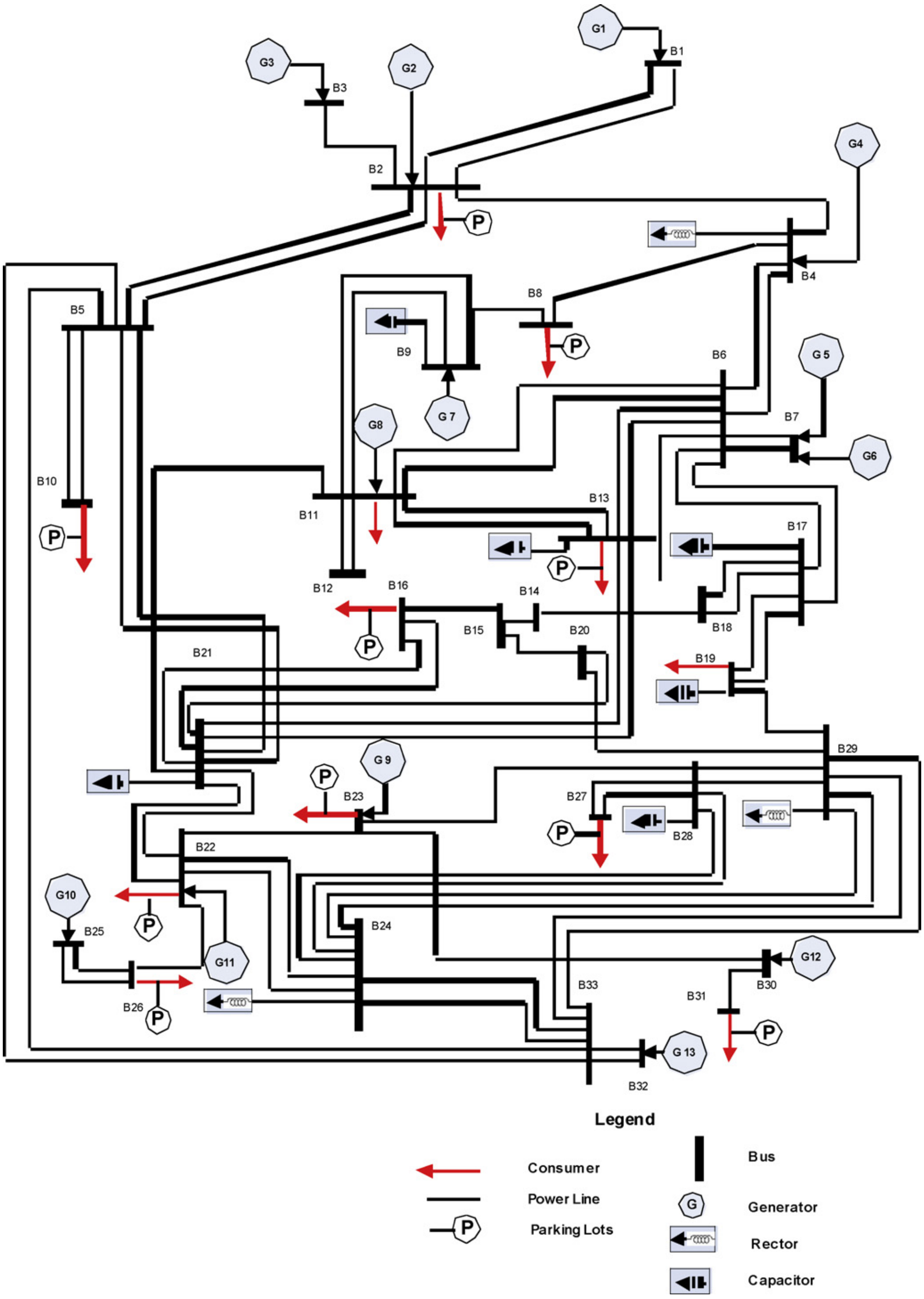

Fig. 5. Grid model layout for large-scale city.

generated. The controller automatically and continually regulates the generation so that it matches the demand loads.

3.1.2. *Fuzzy voltage controller (FVC)*

This fuzzy controller is used for the control of the grid voltage by adjusting the capacitors and reactors in the power grid. It measures the average of voltages 230 kV, 400 kV, generation and consumption of power reactive from all buses. The controller automatically and continually regulates the voltage and stabilizes the grid to avoid blackouts. As shown in Fig. 5, there are some important buses that influence the stability of the voltage in the power grid and they are obtained by experience. Therefore, the fuzzy voltage controller (FVC) regulates some significant related capacitors including B21, B9, B17, B28, B19, B13 and reactors including B29, B4 and B24 as shown in Fig. 7. The Voltage Disturbances Standard EN 50160 [22] has been obtained for the voltage regulation maintains and the voltage within limits.

4. Simulation methodology

Three simulations were conducted:

- without parking loads (no intelligent control),
- with parking lots loads (no intelligent control),
- and controlled by the intelligent controller of vehicle to grid.

Table 1
Grid model specification.

Bus no.	Voltage (kV)	Gen min (MW)	Gen max (MW)	Gen nor (MW)	Reactor max (MVAR)	Capacitor max (MVAR)	Ave load (MVA)	Parking max capacity (MW day^{-1})	Parking demand (MW) During day	Vehicle numbers availability during day
1	400	25	150	100	–	–	20+j5	–	–	–
2	400	250	800	600	–	–	90+j24	320.000	266.724	14,818
3	400	100	600	400	–	–	100+j25	–	–	–
4	400	25	50	25	100	–	30+j6	–	–	–
5	400	–	–	–	–	–	50+j15	–	–	–
6	230	–	–	–	–	–	50+j15	–	–	–
7	230	45,10	90,40	60,40	–	–	17+j7	–	–	–
8	230	–	–	–	–	–	70+j15	290.000	264.600	14,700
9	230	150	450	300	–	40	50+j10	–	–	–
10	230	–			–	–	876+j4	310.000	268.848	14,936
11	230	100	800	600	–	–	10+j5	–	–	–
12	230	–	–	–	–	–	10+j4	–	–	–
13	230	–	–	–	–	20	20+j5	298.000	278.982	15,499
14	230	–	–	–	–	–	20+j4	–	–	–
15	230	–	–	–	–	–	30+j6	–	–	–
16	230	–	–	–	–	–	50+j5	261.000	254.322	14,129
17	230	–	–	–	–	40	15+j2	–	–	–
18	230	–	–	–	–		50+j3	–	–	–
19	230	–	–	–	–	20	30+j10	–	–	–
20	230	–	–	–	–	–	100+j60	–	–	–
21	400	–	–	–	–	60	70+j40	–	–	–
22	230	25	700	500	–	–	50+j10	278.000	272.466	15,137
23	230	75	200	150	–	–	30+j5	300.000	288.108	16,006
24	400	–	–	–	100	–	100+15	–	–	–
25	230	100	500	300	–	–	50+j10	–	–	–
26	230	–	–	–	–	–	200+j10	298.000	287.496	15,972
27	230	–	–	–	–	–	80+j10	272.000	267.102	14,839
28	230	–	–	–	–	20	50+10	–	–	–
29	400	–	–	–	100	–	80+j25	–	–	–
30	230	40	100	50	–	–	70+j15	–	–	–
31	230	–	–	–	–	–	30+j5	292.000	282.654	15,703
32	400	50	700	500	–	–	60+j10	–	–	–
33	400	–	–	–	–	–	100+j20	–	–	–

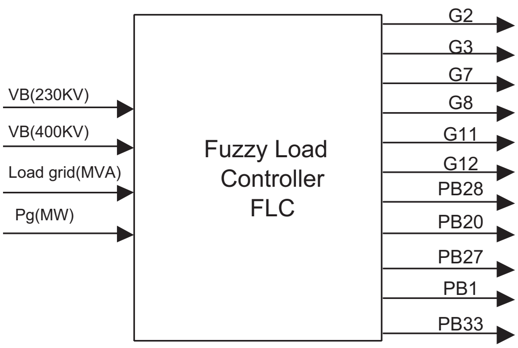

Fig. 6. Fuzzy load controller.

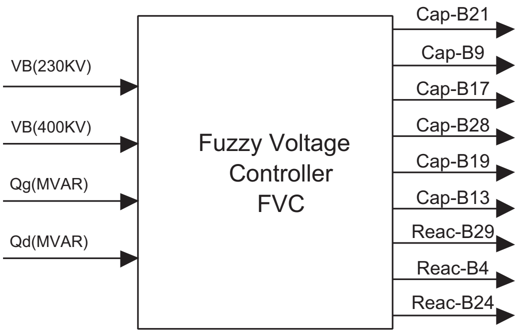

Fig. 7. Fuzzy voltage controller.

In these simulations, a set of data associated with 10 parking including 150,000 PEVs charged at different times, is used (Table 2). The parameter values at the 100% grid to vehicle rate are as follows:

- the vehicle can draw up to 25 kW from the grid, depending on (1 h to charge 25 kW h battery capacity),
- minimum battery capacity = 10 kW h,
- average battery capacity = 18 kW h,
- charging–discharging frequency = 1 per day,
- scheduling period = 24 h,
- min and max State Of Charge = 30–90% respectively.

5. Result and discussions

5.1. Simulation 1

In this simulation, the ordinary grid model without parking lot loads is evaluated and runs for 24 h base on July 20th 2009 generated power and consumer demand.

The results of the first simulation are given in Fig. 8. Fig. 8(a) demonstrates that the ordinary grid model without V2G was operated to ensure enough power generation despite peaks in demand based on July 20th 2009. As can be seen from the figure, the generated power follows the demand power during the day based on Eqs. (5)–(12). The maximum generated power is 3600 MW and maximum power demand is 3250 MW. Fig. 8(b and c) illustrates the average voltage of the 230 kV and 400 kV during the day. These average voltages in non-peak load hours are approximate, with 6% error, and during peak load hours they are approximately stable.

Table 2
Power capacity demand for 10 parking lots in 24 h.

Time (h)	P 2 Veh (No) *D* (kW)	P 8 Veh (No) *D* (kW)	P 10 Veh (No) *D* (kW)	P 13 Veh (No) *D* (kW)	P 16 Veh (No) *D* (kW)	P 22 Veh (No) *D* (kW)	P 23 Veh (No) *D* (kW)	P 26 Veh (No) *D* (kW)	P 27 Veh (No) *D* (kW)	P 31 Veh (No) *D* (kW)	Total Veh (No) *D* (kW)
1	342	307	334	256	363	416	384	491	363	438	3694
	6156	5526	6012	4608	6534	7488	6912	8838	6534	7884	66,492
2	238	219	305	334	306	305	243	246	210	233	2639
	4284	3942	5490	6012	5508	5490	4374	4428	3780	4194	47,502
3	175	188	221	235	215	266	219	161	242	188	2110
	3150	3384	3978	4230	3870	4788	3942	2898	4356	3384	37,980
4	137	128	175	172	131	155	137	181	197	172	1585
	2466	2304	3150	3096	2358	2790	2466	3258	3546	3096	28,530
5	240	199	252	288	268	260	210	195	146	317	2375
	4320	3582	4536	5184	4824	4680	3780	3510	2628	5706	42,750
6	393	406	266	330	317	274	418	279	304	444	3431
	7074	7308	4788	5940	5706	4932	7524	5022	5472	7992	61,758
7	490	325	323	439	336	465	684	465	310	387	4224
	8820	5850	5814	7902	6048	8370	12,312	8370	5580	6966	76,032
8	507	544	391	527	544	612	595	646	629	544	5539
	9126	9792	7038	9486	9792	11,016	10,710	11,628	11,322	9792	99,702
9	582	509	522	546	528	497	553	473	570	497	5277
	10,476	9162	9396	9828	9504	8946	9954	8514	10,260	8946	94,986
10	559	497	405	551	481	535	497	512	450	528	5015
	10,062	8946	7290	9918	8658	9630	8946	9216	8100	9504	90,270
11	356	412	394	365	356	450	412	347	417	450	3959
	6408	7416	7092	6570	6408	8100	7416	6246	7506	8100	71,262
12	428	467	544	467	447	413	535	516	476	457	4750
	7704	8406	9792	8406	8046	7434	9630	9288	8568	8226	85,500
13	739	692	645	692	632	753	793	706	632	578	6862
	13,302	12,456	11,610	12,456	11,376	13,554	14,274	12,708	11,376	10,404	123,516
14	1103	1433	1355	1372	1129	1338	1159	1277	1164	1338	12,668
	19,854	25,794	24,390	24,696	20,322	24,084	20,862	22,986	20,952	24,084	228,024
15	1970	1576	1801	1576	1576	1407	1210	1801	2083	1886	16,886
	35,460	28,368	32,418	28,368	28,368	25,326	21,780	32,418	37,494	33,948	303,948
16	1259	1356	1744	2131	1259	1744	2412	1889	1162	1405	16,361
	22,662	24,408	31,392	38,358	22,662	31,392	43,416	34,002	20,916	25,290	294,498
17	1043	1391	956	1043	1434	1202	1333	1507	1362	1396	12,667
	18,774	25,038	17,208	18,774	25,812	21,636	23,994	27,126	24,516	25,128	228,006
18	1025	1236	955	1188	1081	836	955	1180	920	1180	10,556
	18,450	22,248	17,190	21,384	19,458	15,048	17,190	21,240	16,560	21,240	190,008
19	1039	784	975	902	580	1002	984	875	957	875	8973
	18,702	14,112	17,550	16,236	10,440	18,036	17,712	15,750	17,226	15,750	161,514
20	801	681	862	590	696	622	870	718	741	809	7390
	14,418	12,258	15,516	10,620	12,528	11,196	15,660	12,924	13,338	14,562	133,020
21	477	444	519	432	506	553	477	440	523	642	5013
	8586	7992	9342	7776	9108	9954	8586	7920	9414	11,556	90,234
22	416	371	466	506	393	586	438	607	495	472	4750
	7488	6678	8388	9108	7074	10,548	7884	10,926	8910	8496	85,500
23	272	289	303	289	267	244	211	239	272	253	2639
	4896	5202	5454	5202	4806	4392	3798	4302	4896	4554	47,502
24	227	246	223	268	284	202	277	221	214	214	2376
	4086	4428	4014	4824	5112	3636	4986	3978	3852	3852	42,768
Total	14,818	14,700	14,936	15,499	14,129	15,137	16,006	15,972	14,839	15,703	151,739
	266,724	264,600	268,848	278,982	254,322	272,466	288,108	287,496	267,102	282,654	2,731,302

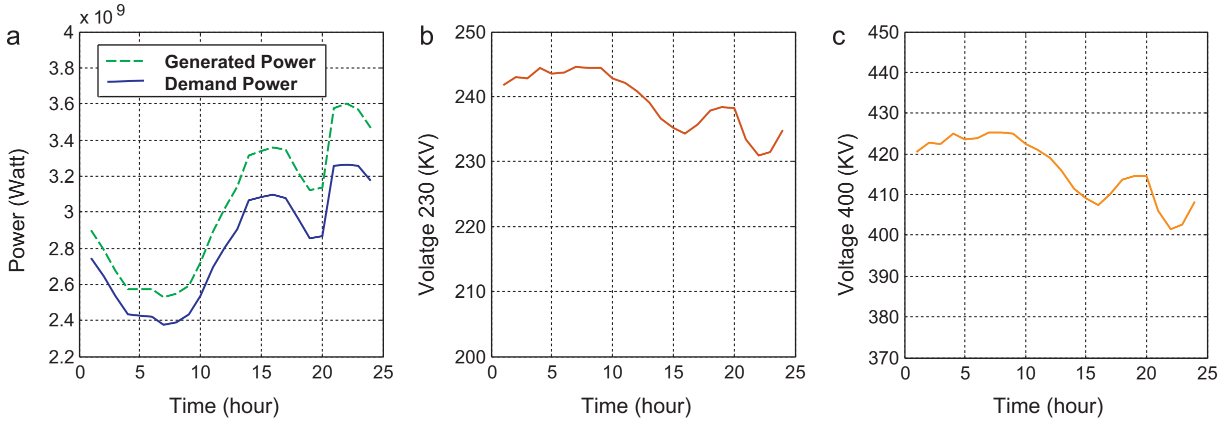

Fig. 8. Results of simulation 1. (a) Generated power and demand load, (b) average 230 kV, and (c) average 400 kV.

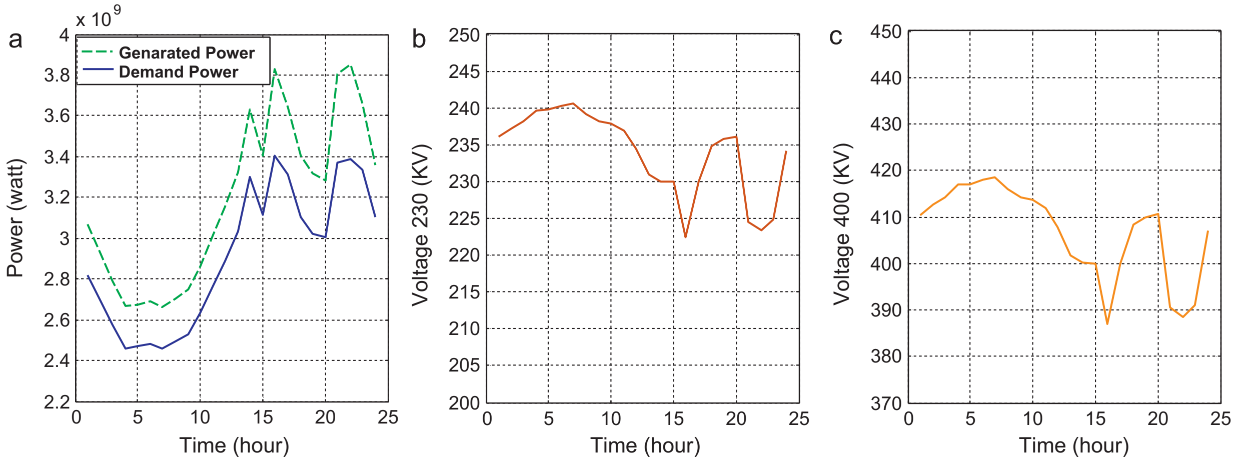

Fig. 9. Results of simulation 2. (a) Generated power and demand load, (b) Average 230 kV and Average 400 kV.

5.2. *Simulation 2*

The ordinary grid model with parking lot load is evaluated and runs for 24 h based on July 20th 2009 generated power and consumer demand.

The results of the second simulation are given in Fig. 9. Fig. 9(a) gives the ordinary grid model with V2G was operated to ensure enough power generation despite peaks in the demand based on July 20th 2009. As can be seen from the figure, the generated power follows the demand power during the day based on Eqs. (5)–(12). The maximum generated power is 3850 MW and maximum demand power is 3405 MW. This figure demonstrates that using V2G services on peak loads demand from all consumers including gridable vehicles and others, the maximum power demand increased to 3450 MW and the generators are required to add power from spinning reserves. These disturbances affect the grid system: the average voltages are not stable and Fig. 9(b and c) confirm the instability. These average voltages in non-peak loads hours have approximately 6% error and during peak load hours they have approximately 10% error.

5.3. *Simulation 3*

The grid model employing the algorithm intelligent control vehicle to grid is evaluated using a set of data associated with combined parking lot loads similar to simulation 2.

The results of the third simulation are given in Fig. 10. Fig. 10(a) illustrates that the intelligent grid model with V2G was operated to ensure enough power generation despite peaks in demand based on July 20th 2009. As can be seen from the figure the generated power follows the demand power during the day based on Eqs. (5)–(12). The maximum generated power is 3650 MW and maximum power demand is 3350 MW. This figure demonstrates that using V2G on peak load demand from all consumers including gridable vehicles and others, the maximum power demand increased to 3650 MW and the generators are required to add power from spinning reserves. Also it illustrate that intelligent controllers reduce unnecessary loads on peak load hours if they cannot produce the power. The intelligent controllers ensure that enough power is generated despite peaks within stability constraints, as shown in Fig. 10(b) and (c). These average voltages in non-peak load hours have approximately 6% error and during peak load hours they are approximately normal.

5.4. *Discussion*

Results show that the intelligent controllers developed for this work can achieve the balance of the generated and demand power, while controlling the average voltage of 230 kV and 400 kV. In addition, comparing Figs. 9 and 10, it is clear that the intelligent controllers can reduce power losses (increased due to the added PEV charging infrastructure), especially in

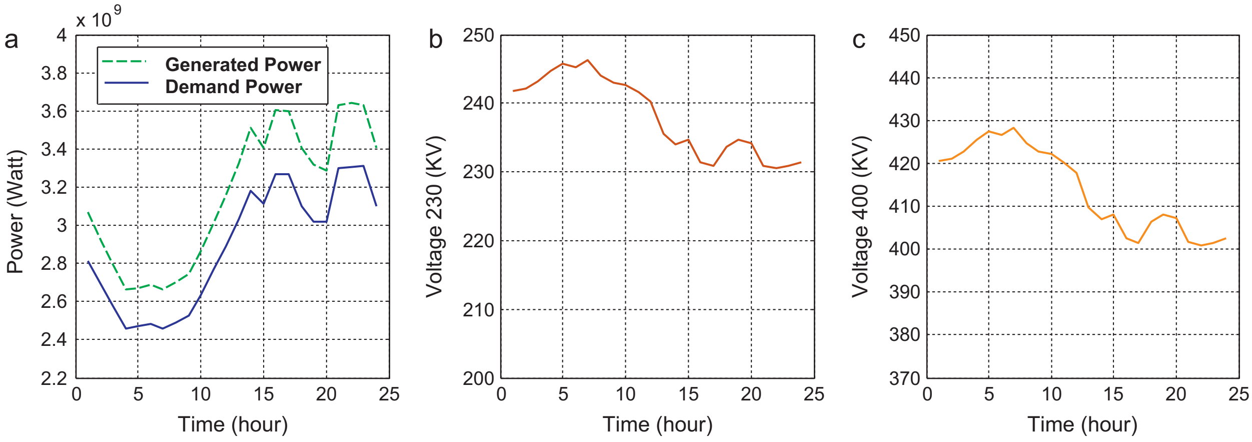

Fig. 10. Results of simulation 3. (a) Generated power and demand load, (b) average 230 kV, and (c) average 400 kV.

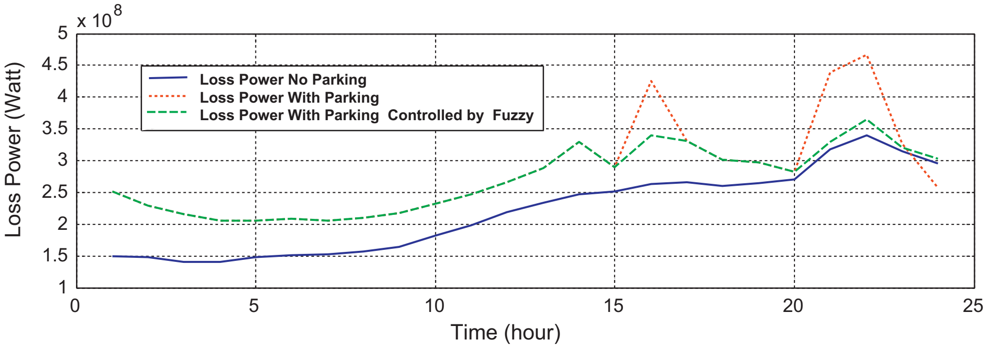

Fig. 11. Loose power results of simulations.

peak hours. Fig. 11 demonstrates the loss power for the cases without intelligent control (with and without parking lots) and with intelligent controllers. The figure also confirms that the intelligent controllers can increase the efficiency of the power grid.

6. Conclusion

A significant deployment of plug-in electric vehicles over the next few decades would represent a major drain on the electric power grid. Plug-in electric vehicles are gradually being connected to the power grid, thus rising further concerns on grid stability and control. In order to support a wide penetration of PEVs and renewable power plants into the energy scenario, it is key to develop intelligent systems that can interface the grid (not designed or suitable for this complexity) with these cleaner technologies. Due to the nature of the charging cycles of plug-in electric vehicles, intelligent controller solutions have been used in this study to monitor and control the electrical grid in real time. In order to achieve this, smart grid technology has been developed to play a major role in vehicle electrification and to help stabilize voltage and frequency to reduce the need for spinning reserves when PEVs are connected to grid electricity. A power electrical grid from generation stations to consumers in the large-scale city has been modelled. This grid model included 33 buses, 10 generators, 3 reactors, 6 capacitors, and 33 consumer centers. In addition, 10 parking lots with the infrastructure to charge up to 150,000 vehicles per day has been planned within the grid model. The grid model becomes “smart” by using intelligent controllers. Two intelligent controllers including (i) fuzzy load controller and (ii) fuzzy voltage controller have been used in this study to optimize the grid stability of load and voltage. The results show that the developed smart grid can react to any disturbance in less time and stabilize the grid perfectly. Although the V2G will play a major role in the future portfolio of vehicle technologies, but does not make much sense if the carbon content of the electricity generated by the grid will not be reduced. Thus, the recourse to renewable energy from sources such as wind generation and solar power and other alternatives is crucial.

The energy is stored in electrochemical power sources (such as battery, fuel cells, supercapacitors, photoelectrochemical) when generated and then delivered to the grid during peak demand times. According to vehicle expected to be sold in next few decades, the advanced battery types promise to be greater cycle depth, power and energy capacity with low cost and availability. Therefore it needs to study and research more.

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