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Utilization of Gridable Vehicles to Improve Spinning Reserve of Power System Including Renewable Energy Sources

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Abstract. Electric vehicles have become more popular due to a swift global transition to low-carbon and renewable energy sources in recent years. Technological advancements have led to the emergence of a new generation of vehicle-to-grid electric vehicles. These vehicles can simultaneously play the triple role of load, resource, and energy storage. Though the battery capacity of an electric vehicle is minuscule compared to the power system, considering the connection of many electric vehicles to the grid and their controllability, grid operation could be improved. Traditional thermal power plants could be used to support electric vehicles, but it is worth noting that this would be economically and environmentally expensive. Using renewable energy sources can reduce environmental pollutants, preserve natural resources, and expand the use of renewable energy sources. The optimum scheduling of electric vehicles as loads or sources has significant potential for evolving a sustainable integrated electricity and transportation infrastructure. In this paper, a model for optimum utilization of vehicle-to-grid electric vehicles is proposed and developed, while both traditional power plants and renewable energy sources are supplying the required power to the network. Optimum utilization of gridable vehicles and renewable energy sources improves grid operation and increases spinning reserve capacity during peak times.

Keywords: *Electric Vehicles, Renewable Energy Sources, Spinning Reserve, Participation of Power Plants*

INTRODUCTION

The transportation sector plays a crucial role in today's economy and society. The automotive industry's development has led to the advancement of the global economy and the improvement of social welfare. Every year tens of millions of vehicles are sold all over the world. Many of them use internal combustion engines, which cause serious problems such as air pollution, global warming, and the rapid depletion of global oil resources.

Transport-related greenhouse gas emissions are the second largest source of greenhouse gas emissions in the United States (EPA, 2013). Also, global surface temperature has increased approximately 0.3˚C per decade in the past 30 years (Hansen et al., 2006). The production and supply rate of oil has been affected by different factors, causing its price to fluctuate widely (Hamilton, 2013).

As a result, people began using electric vehicles and increasing their efficiency to reduce their dependence on oil. Since power plants are a more efficient power source than mechanical motors, electric vehicles have many advantages when it comes to reducing carbon emissions.

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Plug-in hybrid electric vehicles (PHEVs) are the latest generation of vehicles that have entered the market. PHEVs have a high-capacity battery that can be recharged via connection to the grid.

In PHEVs, it is possible to charge the batteries with the grid, so the motor function is no longer required. In addition, the All Electric Range (AER) makes it possible to travel without fuel consumption. These functions reduce the pollution that is caused by vehicles that use an internal combustion engine.

One of the most prominent characteristics of electric vehicles is their flexibility in connecting to the power grid. With electric vehicles replacing gasoline vehicles, a supplementary electrical charge has been added to the power grid. Batteries are the main energy sources of electric vehicles, and electric vehicles can consume energy whenever the grid needs it.

This means that electric vehicles can be charged whenever the grid load is low, which usually occurs at night. Electric vehicles can be charged whenever energy prices are low, then resell it to the grid when electricity demand and energy prices are high. If the battery capacity of electric vehicles is used properly, the load curve's ups and downs are reduced. Furthermore, the power grid does not rely on expensive gas units, which is why electric vehicles can be called controllable loads (Guille & Gross, 2009).

In (Clement et al., 2009; Han et al., 2010; Lu et al., 2013; Miranda et al., 2015; Saber & Venayagamoorthy, 2010b), various studies have been conducted on the optimal charging and discharging of PHEVs. Based on the results of (Hadley & Tsvetkova, 2009) , vehicle owners connect their PHEVs to the grid as soon as they arrive home, which causes the evening peak. Also in(Schneider et al., 2008), a smart charging technique has been proposed for discharging PHEVs during peak consumption hours of a real distribution grid. To eliminate the effects on the grid, certain strategies are required to charge the vehicle (Kramer et al., 2008). To discharge vehicles, assuming the use of PHEVs, vehicle-to-grid technology can provide peak charges when vehicles are not on the streets (Haines et al., 2009; Kempton & Tomić, 2005a).

According to a research conducted in the U.S., vehicles are used for only about an hour and remained unused in the parking lot for the rest of the day. Vehicle-to-grid technology can provide a rapid interface between the power system and the PHEVs' battery storage system. Plug-in hybrid electric vehicles can provide voltage and frequency adjustments, spinning reserve, and Electrical Demand Side Management (Kramer et al., 2008).

Renewable and sustainable energy sources are considered viable options to reduce emissions in the environment. Among the renewable energy sources, the most applicable and popular technologies are wind and solar energy. However, their intermittent nature limits their use.

Due to the increased use of electric vehicles and because of the energy they need to recharge their batteries, resources in the grid must be allocated to this purpose. The grid benefits from the combination of electric vehicles and renewable energy sources. Many studies on this subject have been done so far and successful samples have been implemented (Birnie III, 2009; Denholm & Short, 2006; Kempton & Tomić, 2005b; Pillai & Bak-Jensen, 2010).

In some markets, the solar power plant's production peak takes place a few hours before the energy consumption peak. An electric vehicle can be used to solve the problem in (Clement-Nyns et al., 2011). Reference (Kempton & Tomić, 2005b) proposes a method to connect electric vehicles to the grid and manage fluctuations caused by wind energy. In (Guille & Gross, 2009), an estimated control framework is proposed to demonstrate the positive impacts of electric vehicles on wind energy operation.

The combination of plug-in electric vehicles with the grid and renewable energy resources has been studied extensively. A common conclusion from these studies is that vehicle-to-grid technology increases the grid's flexibility in effectively using renewable energy sources to overcome the unpredictable nature of electric vehicles. The development of smart grids' concept has made it possible to use electric vehicles with renewable energy sources.

In this paper, a method is proposed for simulating renewable electric vehicles in the power grid. The participation of power plants and changes in grid spinning reserves are then studied. Here, this method is introduced and an overview of the concepts and the simulation results on the sample grid are presented as well.

1. POTENTIAL OF ELECTRIC VEHICLES FOR IMPACTING SPINNING RESERVE

The energy that an electric vehicle can inject into the grid is very small, compared to the grid scale and can leave a negligible effect on the power system. However, if these vehicles are collected in large numbers, the impacts that they can leave on the power system will be very significant.

Considering the growing use of electric vehicles and large–scale investment of developed countries to expand the use of these vehicles, there will be a very high capacity of Distributed *Energy* Storage Systems at the level of power grids shortly. Of course, electric vehicles are not always connected to the grid and their connection plan is largely undefined, but some methods can be used for managing uncertainties related to them.

An effective approach is to form a large number of batteries (about a thousand to a hundred thousand batteries). In this case, this group becomes an integrated battery with megawatt power through the aggregator and this can be used as a large charge and energy generator affecting the power system (Guille & Gross, 2009). Aggregators are the new actors in restructured power systems and power markets, which are directly related to ISO to purchase and sell energy and provide service. Aggregators must collect plug-in electric vehicles and smartly manage and control the charge and discharge of the battery in vehicles.

One of the tasks of the grid operator is to provide the spinning reserve required for the grid. The spinning reserve is referred to as the capacity of excess production, which is synchronous with the system. The spinning reserve should react very quickly and be available in less than ten minutes when this reserve is required. The difference between spinning and non-spinning reserves is that the spinning reserve generators must be in the standby state and can help prevent frequency decay when other resources drop.

Response to load peak and supply of spinning reserve required for the grid during peak time is an important challenge for power grid operators and electric vehicles aggregator can support the grid operator under these conditions. A set of electric vehicles with a quick response can be good support for the grid operator so that it can delay lighting the peak supplier large units .If the number of vehicles is large enough ,they can play the role of moving the power in the power grid by eliminating the peak load curve during the day and filling the valleys of the load curve at night.

2. INTRODUCING THE PROPOSED METHOD

In the proposed method, the grid daily load curve and the existing power plant units are taken into account, and then, the participation rate of electric vehicles and renewable resources is modeled. Then, the different steps of the proposed model are introduced:

Firstly, the daily load curve is considered. The load curve is not usually uniform throughout the day and concerning the time pattern of the grid consumer behavior; it reaches a peak during peak demand hours and is lower during light load hours typically occurring at midnight, which is called base load. The load curve's shape is related to the nature and behavior of the grid consumers.

In the next step, to include electric vehicles, it is necessary to obtain the number of consumers on the grid so that electric vehicles can be allocated to consumers. Considering the base load of the grid, the number of home consumers in the grid can be estimated. The number of electric vehicles can then be calculated considering the number of home customers. It is evident that if a larger percentage of customers, have a plug-in electric vehicle and their degree of participation in the power exchange with the grid is great, then their impact on the change of spinning reserve will be more serious. If the number of electric vehicles allocated to each customer is zero, the problem will be analyzed regardless of the existence of electric vehicles and renewable resources considering the optimization of unit commitment in supplying the grid load.

After estimation of the number of electric vehicles connected to the grid, renewable sources should be embedded into the grid to respond to the power needed for electric vehicles. As mentioned in the preceding sections, electric vehicles require electric energy to charge their battery. Therefore, instead of increasing the capacity of conventional plants to respond to the required power of vehicles, renewable resources of energy are considered in the Grid in proportion to the amount of plug-in electric vehicles. Since wind and solar energy are known as the most important sources of renewable energy. In this paper, wind power plants and photovoltaic plants are also considered in the grid.

In the next step, the conventional power plant units are considered in the grid. Power plant units are faced with constraints and limitations to deliver power to the grid, which must be taken into account.

Considering the above-mentioned cases, it is time to form the objective function of the problem. In this paper, the operating cost of plant unit generation is considered an objective function. Besides this objective function ,all constraints and limitations associated with different components have been considered, which will be explained later in this paper. One of the most important components considered in this way is the amount of spinning reserve required for the grid. The minimum amount of spinning reserve required is considered a constraint in the objective function of the problem.

In the final step, the optimization problem is solved and the results of the plan are obtained. The optimization is done using Particle Swarm Optimization (PSO) algorithm (Kennedy & Eberhart, 1995).

3. THE OBJECTIVE FUNCTION OF THE PROBLEM

In the proposed method, the daily load curve, the contribution rate of power plant units, plug-in electric vehicles, and renewable resources have been considered.

It should be noticed about the contribution of thermal power plant units that large power plant units with high capacity and high operating cost are always operating for supplying base loads. Smaller units have less start-up cost and start operating to compensate for overload.

Here, the objective function is considered the operating cost of power plant units. The operation cost of the plant units, mainly including the fuel cost, is usually expressed as a quadratic function of the unit generation power(Ting et al., 2006). Therefore, the objective function can be written as Equation (1):

$$\sum_{i=1}^{n} F_i(P_i(t)) = \sum_{i=1}^{n} a_i + b_i P_i(t) + c_i P_i^2(t) \tag{1}$$

Where $P_i(t)$ is the generation power of the power plant i at time t ,a_i ,b_i and c_i are cost coefficients of the ith power plant unit and n is the number of units . The power generation of each unit should be within the specified limit. This limit is expressed as Equation (2):

$$P_i^{\min}(t) \le P_i\ (t) \le P_i^{\max}(t) \tag{2}$$

Where $P_i^{\min}(t)$ and $P_i^{\max}(t)$ are the minimum and the maximum generation power of unit *i* at time t. On the other hand, the resources should respond to the electrical energy demand on the grid at any time, that is if electric vehicles and renewable resources are not in the grid, power plant units should be able to respond to the entire grid demand at any time. This constraint can be written as Equation (3):

$$\sum_{i=1}^{n} P_i(t) = D(t) \tag{3}$$

Where *D(t)* is the grid demand at time t. In addition, the resources should be able to provide the minimum rate of the spinning reserve for the grid. If the minimum spinning reserve required at time t is equal to *R(t)*, if there are no plug-in electric vehicles and renewable resources, this condition can be written as Equation (4):

$$\sum_{i=1}^{n} P_i^{\max}(t) \geq D(t) + R(t) \tag{4}$$

Considering the steps of the proposed method, which are presented in Section 3, in this paper, plug-in electric vehicles and wind and solar power plants are taken into account. Therefore, the constraints of Equations (3) and (4) vary given their presence. Wind and photovoltaic plants deliver power to the grid at any time considering their specifications and constraints but plug-in electric vehicles sometimes appear as a resource and sometimes as load. If the electric vehicle is connected to the grid as a resource, Equation (3) will be rewritten as Equation (5):

$$\sum_{i=1}^{n} P_i(t) + P_{PV}(t) + \sum_{j=1}^{NV2G(t)} P_{V_j} + P_{Wind}(t) = D(t) \tag{5}$$

Where the *PPV(t)* is equal to the power of the photovoltaic power plant at time t, *NV2G(t)* is equal to the number of plug-in electric vehicles at time *t*, *PV* is equal to the power of the power plant at time t. If the electric vehicle is connected to the grid as load, the stated constraint in Equation (5) converts to Equation (6):

$$\sum_{i=1}^{n} P_i(t) + P_{PV}(t) + P_{Wind}(t) = D(t) + \sum_{j=1}^{NV2G(t)} P_{V_j} \tag{6}$$

On the other hand, the spinning reserve constraint of the grid, which had been expressed as Equation (4) in the absence of electric vehicles and renewable resources, should be rewritten in the case of the electric vehicle and the renewable sources. If the electric vehicle is operated as a resource, this Equation should be rewritten as Equation (7) and if the electric vehicle acts as load, the grid reservation constraint will be as Equation (8).

$$\sum_{i=1}^{N} P_i^{\max}(t) + P_{PV}(t) + \sum_{j=1}^{NV2G(t)} P_{V_j}^{\ \max} + P_{Wind}(t) \geq D(t) + R(t) \tag{7}$$

$$\sum_{i=1}^{N} P_i^{\max}(t) + P_{PV}(t) + P_{Wind}(t) \geq D(t) + \sum_{j=1}^{NV2G(t)} P_{V_j} + R(t) \tag{8}$$

As in Equation (7), $P_{V_j}^{\ \max}$ is equal to the maximum power of the plug-in electric vehicle.

According to the above equations, it is observed that if the electric vehicle is connected to the grid as a load, it will not have any effect on the grid reserve but if it is connected as a resource to the grid, it will increase the grid reserve.

4. SIMULATION IN THE SAMPLE NETWORK

The proposed method has been studied on the IEEE sample grid, which has 10 power units and related data are listed in Table 1.

Table 1: Traditional Power plant Properties of the sample grid

Unit No.	Priority	Pmax	Pmin	a($/h)	b($/Mwh)	c($/Mwh^2)
1	1	455	455	1000	16.19	0.00048
2	1	455	150	970	17.26	0.00031
3	2	130	20	700	16.6	0.002
4	3	130	20	680	16.5	0.00211
5	4	162	25	450	19.7	0.00398
6	5	80	20	370	22.26	0.00712
7	6	85	25	480	27.74	0.0079
8	7	55	10	660	25.92	0.00413
9	8	55	10	665	27.27	0.00222
10	9	55	10	670	27.79	0.00713

Typical information on wind and photovoltaic power outputs is required as input data for the program. Here, the data using the reference (Saber & Venayagamoorthy, 2010a) for the 25.5 MW wind power plant and the 40 MW photovoltaic power plant are listed in Table 2.

Table 2. Typical values of delivered power of wind and photovoltaic power plants to grid in MW

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Wind	10.54	22.27	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5	25.5
Solar	0	0	0	0	0	0	0.09	17.46	31.45	36	38	35.9
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Wind	25.5	24.8	20.7	14.6	25.5	18	18	18	25.5	21.4	0	2.55
Solar	36.8	31.6	9.7	12.92	0	0	0	0	0	0	0	0

Data about the initial adjustments of the sample grid are mentioned in Table 3.

Table 3 Values of initial adjustments data for analysis of the sample grid

parameter	Value
The ratio of residential customers to total grid load in percent	30
The monthly average rate of electrical energy demand for every residential customer (kWh)	1500
The average distance which every vehicle travels during a year(km)	20000
The average distance which every vehicle travels for 1 kWh power consumption (km)	6.4
The minimum battery capacity of each electric vehicle (kWh)	10
The average rate of the battery capacity of each electric vehicle (kWh)	15
The maximum battery capacity of each electric vehicle (kWh)	25
The ratio of renewable energies (use of wind energy compared with solar energy in the grid)	2:1
The number of electric vehicles for every home customer	1
Contribution rate – Percent of electric vehicles connected to the grid, which are involved in the proposed plan.	50
Minimum percent of acceptable reserve in the grid	10
Percent of the load which is regarded as an overload (this percent is considered as compared with load peak)	80
Minimum percent of plug-in electric vehicles per hour	2.5
The maximum battery capacity of each electric vehicle (kWh)	12.5
Is every electric vehicle involved in charging or discharging only once a day and night?	No

The setting data of the PSO algorithm are given in Table 4.

Table 4 PSO setting data

Penalty factor	W2	W1	C2	C1	Iteration number	Population
10	0.3	1	1.05	1.05	1000	30

Using the proposed method in the sample grid, the power plant unit production data and their costs per day in 24 hours have been calculated in Table 5.

Table 5. Power generation of units and production cost per hour at night and day considering electric vehicles and renewable energy sources (the minimum spinning reserve is assumed to be 10%).

	Power Generation of Units(MW)										
Time	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	cost
1	455.00	310.80	20.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15879.46
2	455.00	248.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13745.17
3	455.00	175.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12466.68
4	455.00	230.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13435.67
5	455.00	287.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14432.21
6	455.00	295.90	75.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16534.84
7	455.00	150.90	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	17799.85
8	455.00	211.87	130.00	91.98	0.00	0.00	0.00	0.00	0.00	0.00	18214.04
9	455.00	361.22	130.00	20.00	25.00	0.00	0.00	0.00	0.00	0.00	20558.49
10	455.00	268.78	130.00	130.00	25.00	0.00	0.00	0.00	0.00	0.00	20794.79
11	455.00	455.00	50.63	71.69	25.00	20.00	0.00	0.00	0.00	0.00	22535.74
12	455.00	455.00	130.00	104.30	25.00	20.00	0.00	0.00	0.00	0.00	24432.09
13	455.00	325.66	130.00	130.00	25.00	80.00	85.00	0.00	0.00	0.00	26878.43
14	455.00	455.00	102.26	120.63	25.00	20.00	25.00	10.00	10.00	0.00	27271.76
15	455.00	455.00	117.85	130.00	72.73	20.00	25.00	10.00	10.00	0.00	28655.90
16	455.00	455.00	130.00	130.00	162.00	20.00	25.00	10.00	14.22	10.00	31769.52
17	455.00	455.00	130.00	130.00	141.75	78.71	25.00	10.00	10.00	10.00	32578.97
18	455.00	455.00	130.00	20.00	162.00	58.00	85.00	10.00	55.00	10.00	33621.70
19	455.00	455.00	20.00	130.00	87.68	80.00	85.00	10.00	18.71	55.00	32861.66
20	455.00	455.00	130.00	130.00	66.25	80.00	25.00	10.00	10.00	0.00	30110.63
21	455.00	455.00	91.71	130.00	25.00	20.00	25.00	0.00	0.00	0.00	25394.60
22	455.00	436.75	20.00	130.00	25.00	0.00	0.00	0.00	0.00	0.00	21871.70
23	455.00	306.27	38.89	130.00	25.00	0.00	0.00	0.00	0.00	0.00	19905.39
24	455.00	170.01	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	18131.54

The total number of electric vehicles in the grid is estimated using the number of home customers in the grid. As the grid load curve is available, one can calculate the number of residential customers as equation (9) with a “The ratio of residential customers to total grid load in percent“ and “The Monthly average rate of electrical energy demand for every residential customer” which are parts of input data.

$$N_{Res.} = \frac{C_{RL} \times Load_{\min}}{Load_{AVm} / (30 \times 24)} \tag{9}$$

Where N_{Res} is the number of residential customers, CRL is the percent of residential customers to the total grid load, $Load_{min}$ is the minimum hourly load and $Load_{Avm}$ is the monthly average electrical energy demand per residential customer. Considering the sample grid and Equation (9), the total number of participating vehicles is calculated to be 45500. Based on the data in Table 3, the average battery energy per vehicle is found to be 15 kWh. For the overall estimation, the renewable energy should be added to the grid as below:

$$15kWh * 45500 = 682.5MWh \tag{10}$$

The values of wind and solar renewable energies in this example are shown in parts A and B of Figure 1, respectively. The load curve matching the number of plug-in electric vehicles is presented in Figure (2). Concerning the settings given in Table(3), overload percent has been set as equal to 80% when the load rate is greater than or equal to 80% of the peak load. Plug-in electric vehicles are considered as the resource and at other times, electric vehicles are connected to the grid as a load.

To investigate the impact of electric vehicles connected to the grid as the spinning reserve of the grid, it is necessary to model the absence of electric vehicles in the grid; in the studied grid, if the number of electric vehicles connected to the grid is zero, the output Table (5) will change into Table (6).

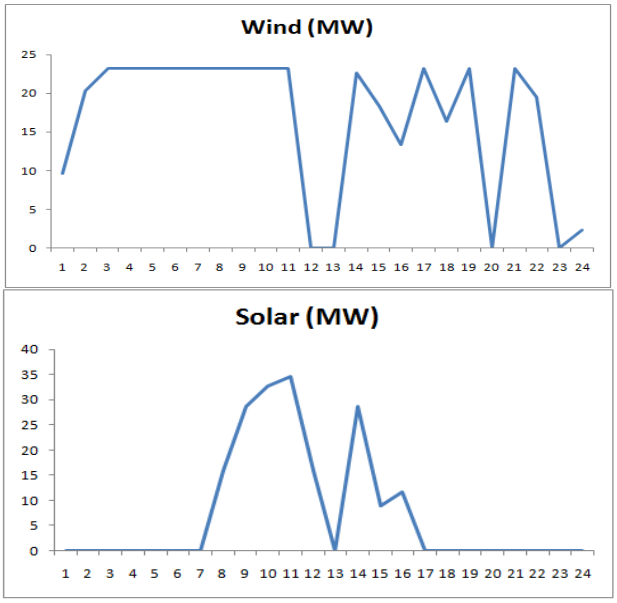

Figure 1. Daily power received from (A) wind power plant and (B) solar power plant

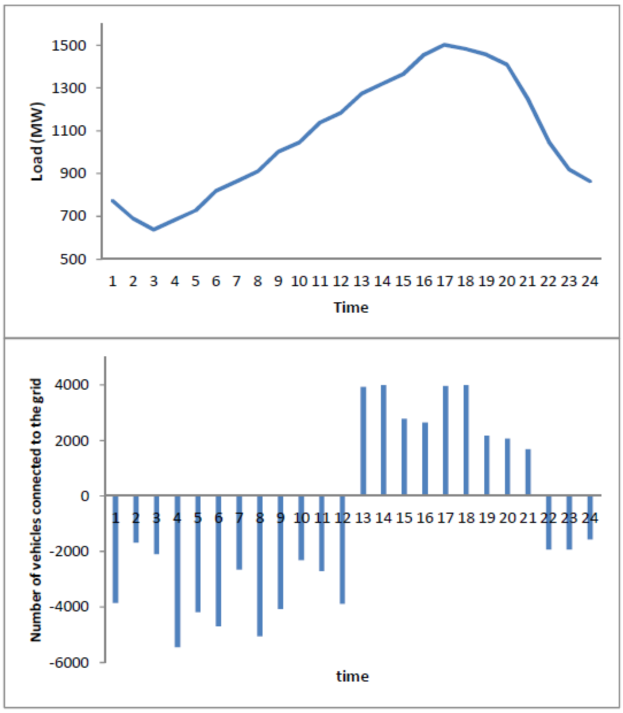

Figure 2. Number of vehicles connected to the grid

Next, to investigate the impact of electric vehicles on grid spinning reserve, the daily load curve and the available power per hour for two modes of presence and absence of electric vehicles and renewable sources are shown in Figure (3).

Table 6. Power generation of units and production cost per hour at night and day in absence of electric vehicles and renewable energy sources (the minimum spinning reserve is assumed to be 10%).

Power Generation of Units(MW)

Time	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	cost
1	455.00	189.91	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15616.70
2	455.00	234.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13507.53
3	455.00	181.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12585.90
4	455.00	229.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13420.51
5	455.00	269.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14117.10
6	455.00	234.91	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16399.33
7	455.00	154.91	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	17869.52
8	455.00	194.91	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	18564.26
9	455.00	259.91	130.00	130.00	25.00	0.00	0.00	0.00	0.00	0.00	20640.31
10	455.00	454.59	20.00	95.33	25.00	0.00	0.00	0.00	0.00	0.00	21595.96
11	455.00	455.00	20.00	130.00	44.90	20.00	0.00	0.00	0.00	0.00	23407.35
12	455.00	369.06	63.86	130.00	162.00	20.00	0.00	0.00	0.00	0.00	25040.86
13	455.00	455.00	108.44	126.48	25.00	20.00	85.00	0.00	0.00	0.00	27335.52
14	455.00	454.91	130.00	130.00	25.00	80.00	25.00	10.00	10.00	0.00	29281.55
15	455.00	455.00	130.00	130.00	162.00	80.00	25.00	55.00	10.00	0.00	30950.75
16	455.00	455.00	130.00	130.00	159.90	20.00	25.00	10.00	55.00	10.00	32843.72
17	455.00	455.00	130.00	130.00	149.90	20.00	85.00	55.00	10.00	10.00	34295.78
18	455.00	455.00	130.00	20.00	132.90	20.00	85.00	10.00	55.00	10.00	33996.92
19	455.00	455.00	20.00	130.00	162.00	80.00	25.00	55.00	55.00	12.86	33665.64
20	455.00	455.00	130.00	130.00	66.25	80.00	25.00	17.87	55.00	0.00	31672.67
21	455.00	455.00	20.00	130.00	144.90	20.00	25.00	0.00	0.00	0.00	26631.25
22	455.00	309.91	130.00	130.00	25.00	0.00	0.00	0.00	0.00	0.00	21512.14
23	455.00	294.91	130.00	20.00	25.00	0.00	0.00	0.00	0.00	0.00	19400.61
24	455.00	154.91	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	17869.52

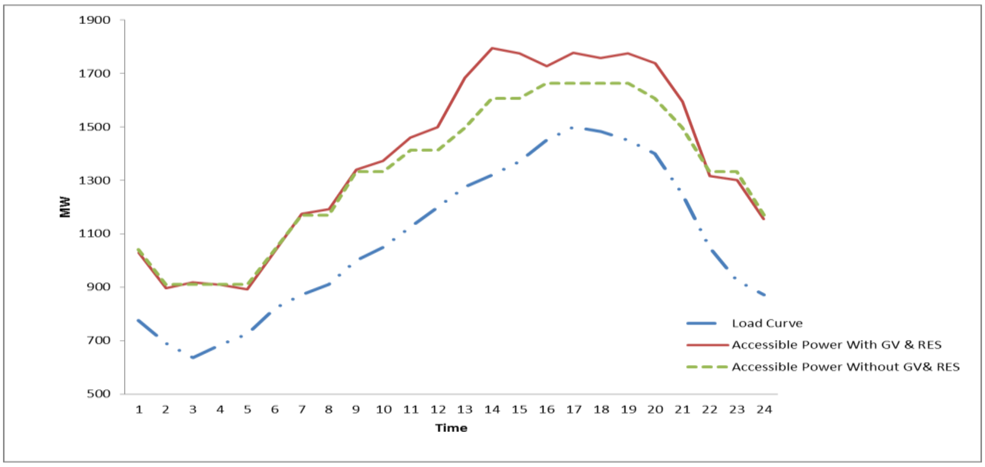

Figure 3. Load curve and accessible power rate in the grid in the presence and absence of electric vehicles and renewable resources (the minimum spinning reserve is assumed to be 10%).

Considering Figure (3), it is observed that electric vehicles are connected to the grid as resources, during overload, thereby increasing the accessible power in the grid and helping increase reserve capacity. During other times when the grid load is small or medium, electric vehicles are connected to the grid as load and charged their batteries. Cost column comparison in Tables 5 and 6 shows that power plant units' operation cost is reduced when electric vehicles exist. Therefore, the effectiveness of the proposed method has been shown in the sample grid.

CONCLUSION

An efficient power system consisting of gridable vehicles, renewable energy sources, and conventional thermal power plants was presented in this paper. A unit commitment was implemented in this network. It has been shown that smart utilization of gridable vehicles and renewable energy sources can increase the grid spinning reserve effectively. According to the proposed method, the charging and discharging of electric vehicles should be managed considering the load curve pattern. Renewable energy sources including wind and solar are applied to respond energy demand of electric vehicles. It was observed that gridable vehicles could be used as loads or energy sources; they may be connected to the grid in 24 hours, when the grid load is low using electric vehicles as loads may reduce reserve capacity, however, they can be useful in evolving the reserve capacity of the grid in peak times by connecting as sources. Thus, they have a desirable impact on grid capacity optimization. The PSO method has been used to minimize the cost, to generate a successful schedule, and manage the gridable vehicles and renewable energy sources. Furthermore, this work can be continued by studying more practical constraints of gridable vehicle applications in the real world.

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