2nd Int'l Conf. on Electrical Engineering and Information & Communication Technology (ICEEICT) 2015
Jahangirnagar University, Dhaka-1342, Bangladesh, 21-23 May 2015

Smart Management of PHEV and Renewable Energy Sources for Grid Peak Demand Energy Supply

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***Abstract*—Electric Vehicles (EV) have become popular due to increasing oil prices and environmental issues. Vehicle-to-Grid (V2G) system allows bidirectional electricity flow from vehicle's battery to power grid. In this paper, Plug-in Hybrid Electric Vehicle (PHEV) has been considered as an option for energy storage in a smart system where renewable energy sources (RES) are included along with main grid. Smart charging system will ensure that an electric vehicle owner will charge the battery during off peak hours and discharge remaining energy back to the grid during peak demand hours. Development of such charging station in a smart grid network is capable of solving the problem of peak demand crisis. PHEV and grid energy management model has been analyzed using HOMER. A Graphical User Interface (GUI) is built where an electric vehicle owner will get the precise time period for charging and discharging their vehicles and the cost of energy through smart metering.**

***Index Terms*— Smart Network, Smart Charging, Smart Grid, Electric Vehicle, Vehicle-to-Grid, Priority.**

I. INTRODUCTION

Vehicle-to-Grid (V2G) system is a new concept of energy storage technology in which a PHEV transmits electricity back to the grid [1][2]. So a fleet of electric vehicles can lead into V2G system as distributed energy storage devices hence increase the load factor. Vehicle to grid technology has developed a new line where vehicle owner and power generating station both will be benefitted [3-5].Vehicle owners are benefitted with profit from discharging when the electricity prices are higher. If grid fails or unable to supply electricity during peak hours, electric vehicles will be a great back up.

Renewable based power production is very worthy solution for green environment. Fossil fuels can be saved for future by using solar, wind, hydro power as for electricity production. If production is greater than the consumption in some specific time, storing surplus energy will give back up when needed. A battery of an electric vehicle is capable of storing electricity produced by RES with the help of high standard of operating regulation, spinning reserves [6].

For example, solar power from PV cells can be stored using electric vehicle as well. Charging station development has become a present concern. When vehicles will be plugged in, it must check the batteries depletion state hence state of charge and can display the options - charging or discharging [7]. After confirmation from the owner it will display the charging time and discharging time as well as cost per energy in the developed GUI.

Electric Vehicles are not an ordinary concept nowadays. Currently, there are three types of EVs prepared to be launched in the markets: fully EVs, fuel cell EVs, and hybrid EVs. Battery and fuel cell EVs are driven only by electric power while available hybrid EV has also an internal combustion engine [8]. The Electric Power Research Institute (EPRI) projects that by 2050, 62% of the entire US vehicle fleet would consist of PHEVs [9]. PHEVs are similar to hybrid electric vehicles as this vehicle combines of electrical power and gasoline to propel the vehicle. Hybrid electric vehicles (HEV), which have seen commercial success as the Toyota Prius, Honda Insight, the Honda Civic Hybrid, and others, add a battery and electric motor to a car that uses an IC engine. The PHEV has the additional feature that the vehicle battery can be recharged from standard electric wall outlets while the conventional hybrid vehicles can only be charged from the internal combustion engines [10].

Power production using renewable based power plant, storage of energy as a backup for grid demand in peak time, charging and discharging depending on battery state of charge, cost for charging and discharging, charging station development etc are the main incentives of this work.

A model of smart network using HOMER Energy has been designed to analyze the production of electricity using solar, wind and grid. The vehicle's battery will store energy from renewable energy sources as well as get charged by renewable

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energy based power production and main power grid. Later on, a software is introduced which officiates as an Electric Vehicle charging station. This is done by Visual Studio and the designed software is named as 'Vehicle UI'.

II. Model Specification for HOMER Analysis

The software HOMER Legacy (2.68 beta) has been used to design PHEV and GRID energy management model demonstrated in Fig. 1. The Plug in Hybrid Electric Vehicle consists of three Blocks: Battery (Vehicle: Toyota Prius+), Engine and a Converter.

A. Prius+ Battery

Lithium ion PHEV battery as shown in Table I, is chosen for Homer Analysis. Ten batteries have been integrated with power generation sources to work as power storage device. We have assumed for Homer analysis that battery's minimum state of charge is 50%. It can be varied with respect to battery technologies.

TABLE I Configuration of Prius+ Battery for Homer Analysis

Nominal Capacity	1250 Ah
Nominal Voltage	24 V
Round Trip Efficiency	80%
Minimum State of Charge	50%
Float Life	12 yrs
Maximum Charge Rate	1 A/Ah
Maximum Charge Current	202 A
Maximum Capacity	1,277 Ah
Depth of Discharge	50%
Cycle to Failure	4000

B. Engine

As we have considered hybrid vehicle as a storage device so an engine has been included with the battery demonstrated in Table II, but considered as 'forced off' so that there will be no fossil fuel consumption.

TABLE II Configuration of Engine of PHEV

Lifetime (operating Hours)	15000
Minimum Load Ratio	30%
Fuel	Gasoline
Intercept coefficient (L/hr/kW rated)	0.1
Slope (L/hr/KW output)	0.3
Density	740 kg/m3
Lower heating value	44 MJ/kg

C. Converter

A bi-directional DC converter as illustrated in Table III, is introduced which can control the amount of power flowing between AC grid and DC battery. In this particular micro grid analysis an AC primary load peak demand is considered around 8 kW as indicated in Table IV, so preferable designed converter has been introduced. In this analysis this converter has been worked as both inverter and rectifier.

TABLE III Configuration of Converter

Size	**Inverter Inputs**		**Rectifier Inputs**	
8 KW	***Lifetime***	***Efficiency***	***Capacity Relative to Inverter***	***Efficiency***
	15 years	95%	100%	90%

The grid of a home or an office building with a defined ac primary load is considered as main 'grid' which is integrated with "Net Metering" system. Under this arrangement when generation of electricity is more than consumption, the meter spins in anti clockwise direction. However in peak times power consumption is more than generation so meter spins clockwise. This system is able to provide net consumption as well as surplus production of power. Table V and Table VI demonstrate the composition of PV and Wind Turbines. This microgrid model analysis as shown in Fig. 2 will provide optimized result of power production and consumption between the grid and EV. The variation of cost, depending on energy sources are achieved successfully by HOMER's optimization and sensitivity analysis.

TABLE IV Configuration of AC Primary Load

Average (kwh/d)	126
Average(KW)	5.25
Peak(kW)	7.83
Load factor	0.670

TABLE V Configuration of PV for Homer Analysis

Quantity	4
Lifetime	20 yrs
Diurnal Factor	80%
Ground Reflectance	30%
Scaled Annual Average	4.79 kwh/m2/d

TABLE VI Configuration of Wind Turbines for Homer Analysis

Rated Power	1 KW
Lifetime	15 yrs
Hub height	25m
Quantity	6
Scaled annual average	4.15 m/s
Weibull k	2
Autocorrelation factor	0.85
Diurnal Pattern Strength	0.25
Hour of peak wind speed	15
Anemometer Height	10m

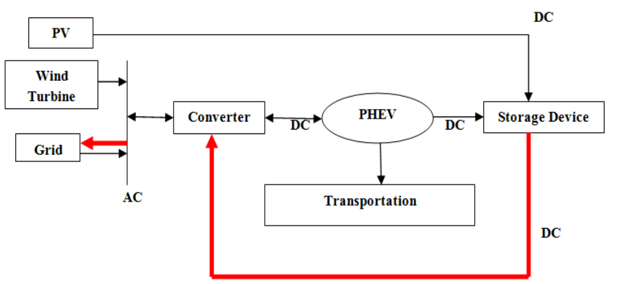

Fig. 1. Block Diagram of PHEV and Grid Energy Management Model

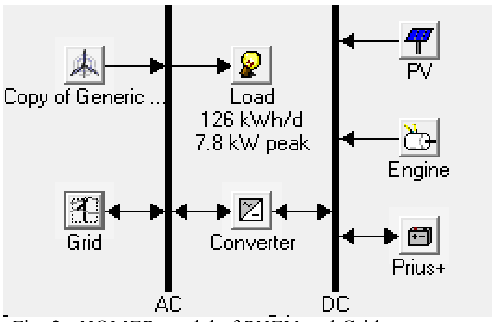

Fig. 2. HOMER model of PHEV and Grid

NASA Research Center gives annual solar radiation data to HOMER software as shown in Fig. 3. Solar data is obtained for an area Cox's Bazar of Bangladesh which has latitude of 21°58' North and Longitude of 92°02'east. Unit of average daily solar radiation (kWh/m^2/day) is known as "peak sun hours" and this defines that how much sun was shining at its maximum on a particular location [11].

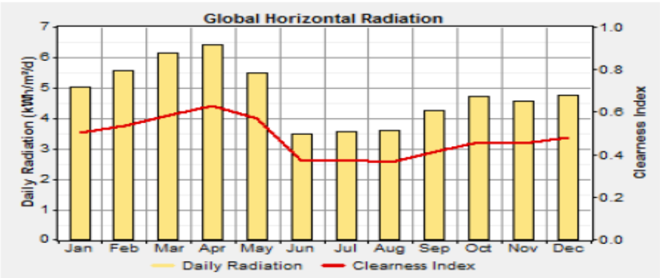

Fig. 3. Graphical representation of monthly radiation and clearness index of Cox's Bazar

Wind data is also collected for same region as mass production is possible in the southern part of Bangladesh due to geographical advantages. HOMER gives the graphical representation of daily wind speed as shown in Fig. 4 according to given data [12].

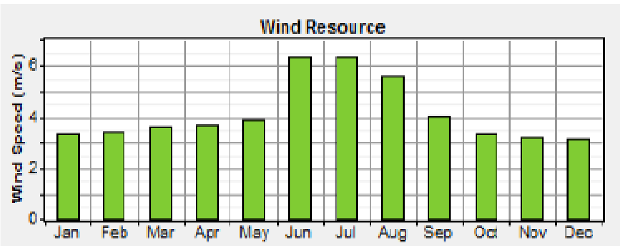

Fig. 4. Graphical Representation of Monthly Wind Speed of Cox's Bazar

III. RESULTS OF HOMER ANALYSIS

A. PV Output and Wind Output

Monthly variation of solar data (Fig. 5) have been taken in different times of the day and measured in KW.

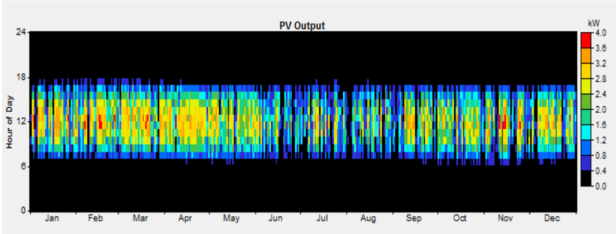

Fig. 5. Solar Output

Wind output (Fig. 6) shows the power generated by wind turbine in kW. Output shows monthly variation which can be taken different times of the day.

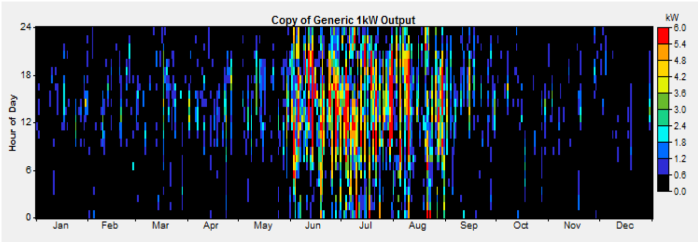

Fig. 6. Wind Output

B. Battery State of Charge

Battery bank state of charge as shown in Fig. 7, indicates remaining charge status when the vehicle is used for storage purpose. This graph as shown in Fig.8 provides an idea of how much power can be available in a PHEV battery, when surplus of generation occurs.

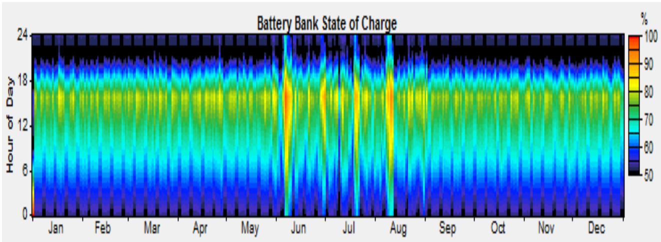

Fig. 7. Battery Bank State of Charge

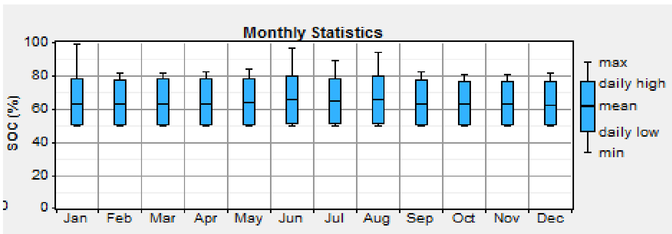

Fig. 8. Monthly Statistics of PHEV battery State of Charge

C. Recharging PHEV using Renewable Sources and Grid

The solar power output is taken as 0.7kW (Fig. 9) and at wind speed 6 m/s the power output 0.1kW (Fig. 10) in one hour. So in order to charge a '4.4kWh PHEV' grid must provide rest of 3.6 kW power in one hour. So PHEV charging largely depends on Grid.

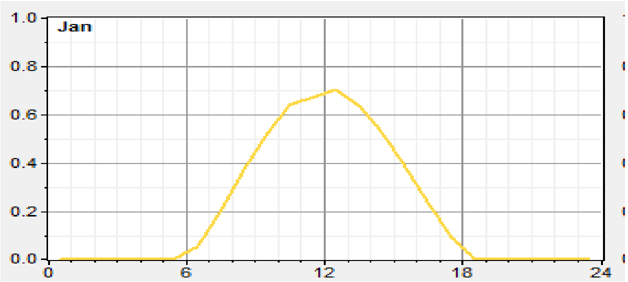

Fig. 9. Solar output of Daily Profile

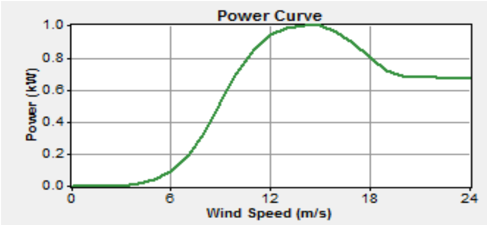

Fig. 10. Power Curve of 1KW Wind Turbine

D.Power production, consumption and Storage analysis

Power production, consumption and storage analysis are done by HOMER. Renewable sources can provide maximum 14% of total power generation. In Fig.11 the proposed micro grid's power generation has been observed. Power production, consumption and PHEV storage result rate charts have been presented in Table VII, VIII and IX, respectively.

TABLE VII Production Rate

Production	kWh/yr	%
PV array	5,566	7
Wind turbines	5,598	7
Engine	0	0
Grid purchases	64,303	85
Total	75,468	100

TABLE VIII Consumption Rate

Consumption	kWh/yr	%
AC primary load	45,990	72
Grid sales	17,603	28
Total	63,594	100

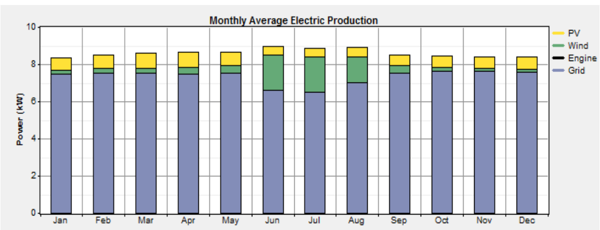

Fig. 11. Monthly Average Power Production of Proposed Homer Model

TABLE IX PHEV Storage Rate

Quantity	Value	Units
Energy in	34,170	kWh/yr
Energy out	27,466	kWh/yr
Storage depletion	141	kWh/yr
Losses	6,562	kWh/yr
Annual throughput	30,705	kWh/yr
Expected life	12.0	yr

IV. MODEL SPECIFICATION FOR VISUAL STUDIO ANALYSIS

Visual Studio 2010 code editor has been used to develop a self controllable Graphical User Interface (GUI) charging station by which vehicle to grid (V2G) power flow can be capitalized.

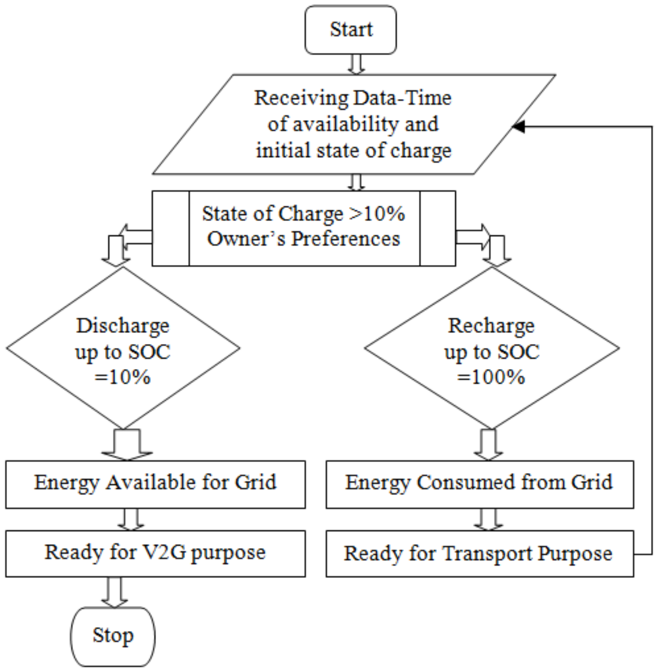

Fig. 12. Flow Chart of V2G Power Flow

This process involves some crucial parameters such as the power available from grid, charging time required for PHEV and their initial state of charge which will ensure when the vehicles are available to provide energy back to the grid. In order to demonstrate the idea provided in Fig 12, battery design is considered according to Table X.

TABLE X Configuration of Battery for Visual Studio

Maximum Capacity	4.4kWh
Full Charging Time	180 mins
Minimum State of Charge	20%

An operator will provide data as input parameters. After fulfilling few conditions, user's preference will be enabled. After analyzing state of charge of the vehicle, this interface will be able to confirm the charging or discharging process.

V. CHARGING PROCESS MANAGEMENT

At first Vehicle Name, Registration Number has to be entered. Default charging time for a 4.4kWh PHEV is 40.9 min [13]. In this paper, power grid selling amount has been assumed as 10 BDT per kWh. Then Vehicle owner will enter the value of state of charge of the vehicle for recharging purpose. For simplicity, this model assumes that the battery of the vehicle is scheduled to be fully charged when they disconnect and start driving. The vehicle user interface then provides time, energy and cost for recharging the vehicle illustrates in Fig. 14 and Fig. 15.

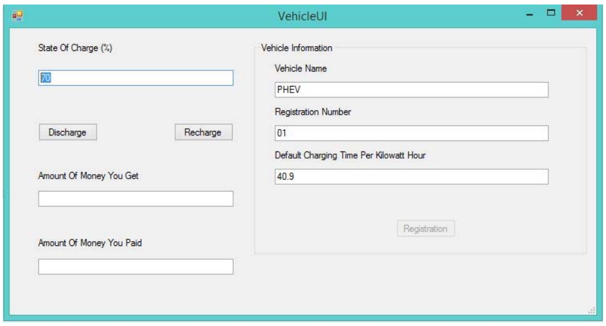

Fig. 13. Vehicle Owner Providing Input (soc)

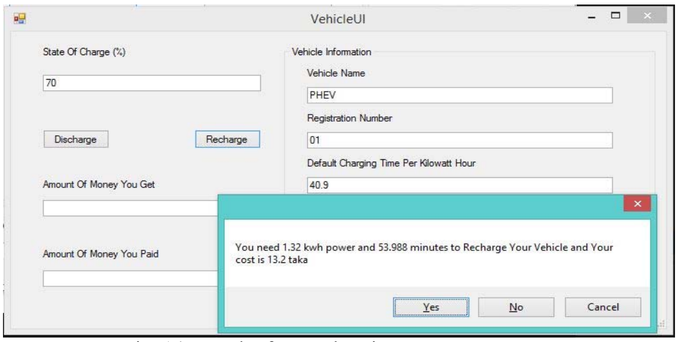

Fig. 14. Result after Recharging

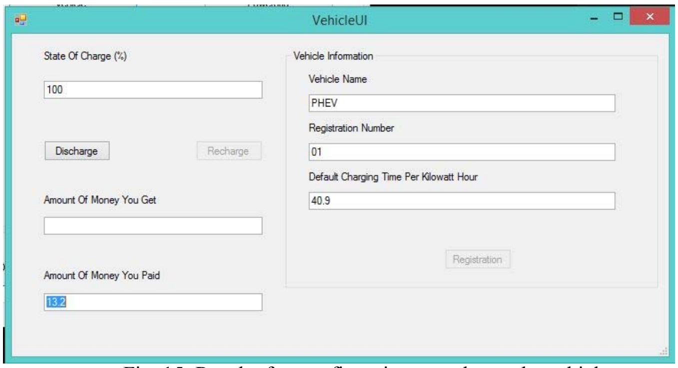

Fig. 15. Result after confirmation to recharge the vehicle.

The recharging of vehicle is mainly done during off peak hours.

VI. DISCHARGING PROCESS MANAGEMENT

The vehicle's state of charge has been considered above 20% (Fig.16) for discharging purpose. During peak hours, Grid's buying amount is assumed 15 BDT per kWh so that the owner will be encouraged to sell surplus energy. This discharging process (Fig. 16 and Fig. 17) is mainly the vehicle to grid process through which an electric vehicle can supply its stored energy back to grid successfully.

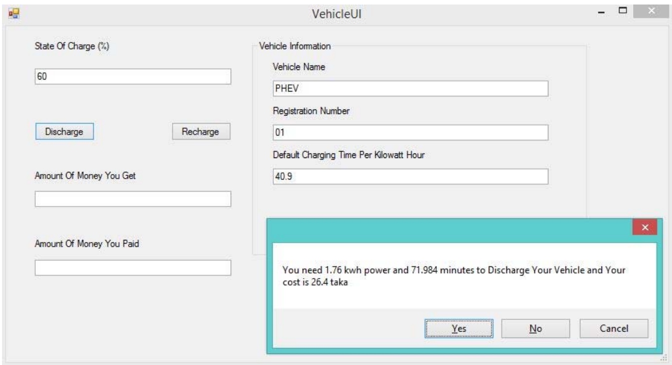

Fig. 16. Results after Discharging

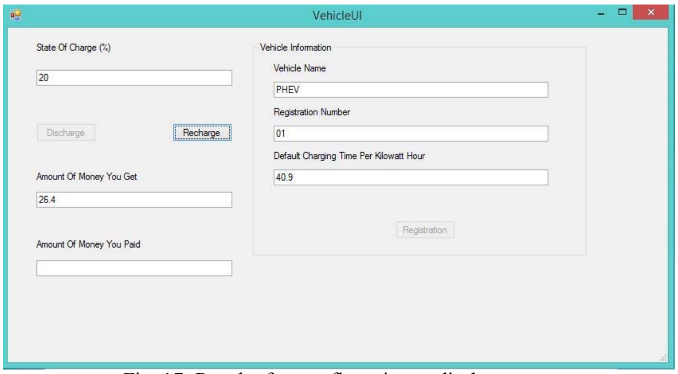

Fig. 17. Result after confirmation to discharge

VII. PRIORITY BASED CHARGING PROCESS

If an electric vehicle fleet to be taken into account then more efficient management is required in charging/discharging process. User priority can be served based on different fleet strategies such as first come first serve, charging according to the range, group of top priority vehicles. In Fig. 18-"11" registration number PHEV has been set as a top priority to get recharged first.

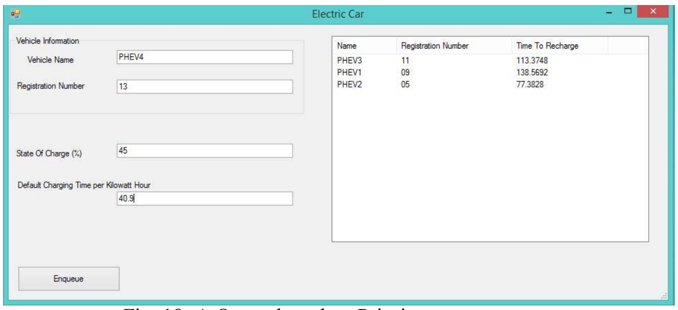

Fig. 18. A Queue based on Priority

VIII. CONCLUSION

This paper focused on hybrid vehicle storing energy from renewable energy sources and monitoring power flow between vehicle and grid. In this way an electric vehicle not only remains as a load but also work as an alternate of power plant or generator. However, the vehicle to grid (V2G) idea is both incredibly simple and highly complex in terms of technology and policy which includes national grid infrastructure, battery life, and charging/discharging efficiency. If the development of current electricity grid to Smart Grid is at an initiating stage in any country, there will be much confusion on how to coordinate and combine all the elements of smart grid together. The opportunities to develop and modernize the grid and all the distributed energy sources like electric vehicle are still open for the experts and scholars for further study. Intelligent management of the charging infrastructure and algorithm, development of grid codes and efficient integration management will ensure the availability of PHEVs in large extent in future [14] [15].

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