Chapter 12

Electric and hybrid vehicle drives and smart grid interfacing

Adel Mahmoud Sharaf[1], Noshin Omar[2], Foad Heidari Gandoman[2], Ahmed Faheem Zobaa[3] and Shady Hossam Eldeen Abdel Aleem[4]

[1]Engineering and Research Company of SHARAF Energy Systems, Incorporated, Fredericton, NB, Canada

[2] Research group MOBI - Mobility, Logistics and Automotive Technology Research Center, Vrije Universiteit Brussel, Pleinlaan 2, Brussels 1050, Belgium

[3] College of Engineering, Design and Physical Sciences, Brunel University London, Uxbridge, Middlesex UB8 3PH, UK

[4] Mathematical, Physical and Engineering Sciences, 15th of May Higher Institute of Engineering, Cairo, Egypt

Abstract

Over the few last decades, the demand for electrical energy is rising remarkably. As a result, the usage of environmentally friendly and renewable energy sources has been increased. Parallel to these developments, the number of the gasoline-powered vehicle has been increased and therefore the energy shortages and environmental concerns increased as well. From this perspective, research into the usage of renewable energy sources instead of fossil fuels in the automotive industry is proceeding fast. One of the most important issues, which play a significant role in overcoming the problem mentioned above, is the implementation of modern electrical networks including Electric Vehicle (EVs). In this chapter, the standard EVs applications in smart grids are presented and discussed. Besides, two novel low-impacts efficient Vehicle to Hybrid (V2H) battery and Hybrid Vehicle to Grid (V2G) smart grid battery are presented. The new schemes utilized switched filter-capacitive compensation to ensure fast multi-mode charging with enhanced power quality and power factor in addition to minimal inrush currents and improved energy utilization.

Keywords: Electric vehicle, smart grid, modern electrical networks, renewable energy.

1. Introduction

The smart grid is one of the new efforts in power system domain to modernize and automate electricity networks all over the world to control, monitor the network, and automatically protect its connected components. The recent developments in this area include distributed generation from renewable and conventional energy resources, automation devices, energy storage technologies, electric vehicles, and smart meters.

Electric vehicles (EVs) are a useful solution to decrease the greenhouse gas emissions and oil consumption. There are different types of EVs such as plug-in EVs, plug-in hybrid EVs, battery EVs, and fuel cell-based EVs [1, 2]. Fig. 1 shows an aggregation agent of EVs which is capable of contacting the network and the system operator. Many studies are focusing on the aggregation agent of EVs that includes concept and role, economic and technical issues, and some incentives such as offering free replacement of batteries, and free charging or low-priced charging for the EVs [3-6]. At the end of 2012, more than 180 thousand electric vehicles existed in the world that only 0.02% of the existing passenger cars accounted [7]. With increasing market penetration of electric vehicles, innovative attitudes with many benefits such as technically, commercially, socially, as well as environmental benefits can be achieved.

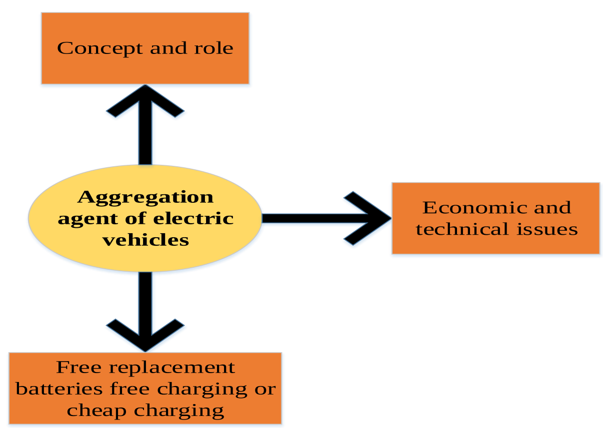

Fig. 1. Aggregation agent of electric vehicles

EVs can be used as backup power for peak shaving, and as storage technology. Besides, the EVs can participate in ancillary services. There is no constraint on the participation of an aggregator in day-ahead, intraday, joint, and sequential markets. Scheduling period can be short-term, mid-term, and long-term. Fig. 2 shows the possible places, which EVs can participate in the electricity market.

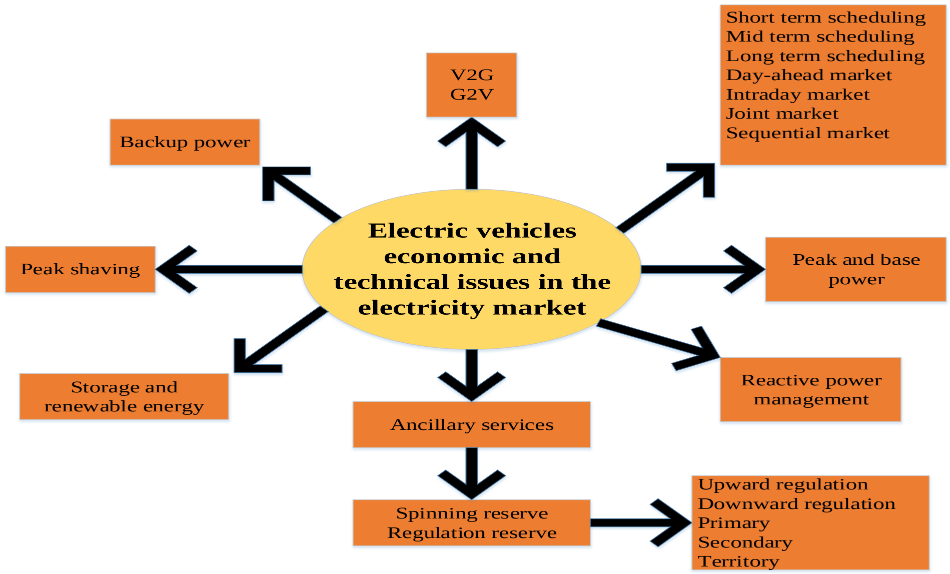

Fig. 2. Electric vehicles and electricity market

As notable in Fig. 2, Grid to Vehicle (G2V) means the grid supplies the connected EV, while the Vehicle to Grid (V2G) implies that the electrical system can be supplied from the EVs.

Since EVs have a great opportunity and challenge in the current and future energy markets [8], some studies have focused on algorithms, models, and objectives to support EVs aggregator as shown in Fig. 3.

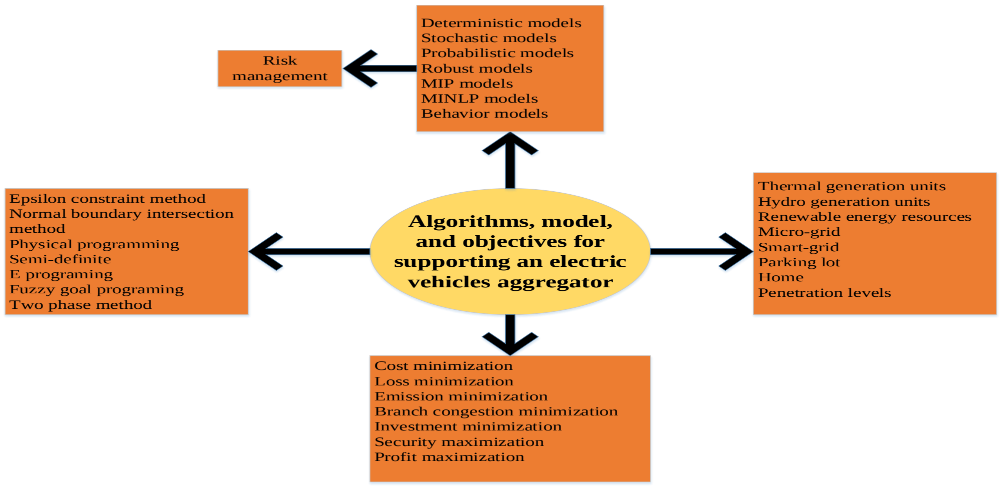

Fig. 3. Algorithms, models and objectives to support an electric vehicles aggregator

This chapter presents and discusses EVs applications in modern electrical networks. Besides, two new low-impacts efficient Vehicle to Hybrid (V2H) battery and Hybrid Vehicle to Grid (V2G) smart grid battery, are presented. Furthermore, the new schemes utilize switched filter-capacitive compensation to ensure fast multi-mode charging with enhanced power quality and power factor, while minimizing inrush currents and improving energy utilization.

The chapter is organized as follows: Section 2 presents state of the art on electric vehicles. Section 3 presents the classifications of the electric vehicles. Section 4 presents the energy management system in the electric vehicle domains. In section 5, current technologies of electric vehicles all over the world are described. A case study of smart grid battery charging schemes is also provided in Section 5. It includes the analysis of the low impact efficient vehicle to hybrid (V2H) battery and hybrid V2G smart grid battery. Finally, conclusions are summarized in Section 6.

2. State of the art of Electric Vehicle

2.1 Introduction

In the last hundred years, excessive emissions of greenhouse gases by plants and internal combustion vehicles, causing unprecedented changes in Earth's climate. One of these changes is warming of the Earth's climate that endangers plant and animal life on Earth. According to studies, if energy consumption continues to shape the amount of carbon dioxide in the environment by 2050 will double its total amount in 2005 [9]. Over the past decades, governments and fans of conservation have started with extensive efforts their plans to reduce the atmospheric pollutants. In this regard, given the widespread concerns about global warming and air pollution caused by the consumption of fossil fuels and cars, need to find new ways to change the conventional energy sources for vehicles is important. Thus, one of the solution to overcome the problem mentioned above is using electric vehicles. The most prominent characteristic of these cars is the no sound, no petrol fumes smell and no vibration.

Hybrid electric vehicles, known as HEVs, are fuel efficient compared to the conventional electric vehicles because of the optimal operation of the engine and kinetic energy recovery throughout braking.

In addition, with the Plug-in Hybrid Electric Vehicle (PHEV) option, a vehicle can operate for a driving range up to 60 km in its electric mode. Overnight, PHEVs are usually charged from the electric power grid. Else, energy can be generated from renewable sources such as the wind and solar energies, or from sustainable energy such as the nuclear energy.

Fuel cell-based vehicles (FCVs) use hydrogen as fuel to produce electricity; thus they are basically emission free. When connected to the electric power grid (V2G), and during a power outage, FCV has the ability to provide electricity for emergency power backup. However, one of the negative sides of FCVs that make them not available to the general public yet is the hydrogen production and storage, as well as technical limitations of the present fuel cells. On the other bright side, HEVs are expected to dominate the advanced propulsion in the future, as the hybrid technologies can be used for almost all kinds of fuels and engines. This means that using the HEVs is not a transition technology. Fig. 4 shows the road map of the hybrid technologies.

In HEVs and FCVs, there are different electrical parts, for example, electric machines, control electronic converters, sensors, batteries, ultra capacitors, and microcontrollers. Moreover, these components, conventional internal combustion engines, and mechanical and hydraulic frameworks are as yet present.

The challenge proffered by these advanced propulsion systems include the following:

i) advanced design of components such as power electronic converters, electric machines, and energy storage (powertrain system), ii) power management, iii) modeling and simulation of the powertrain system, iv) hybrid control theory of the vehicles, and v) optimization of the vehicle performance.

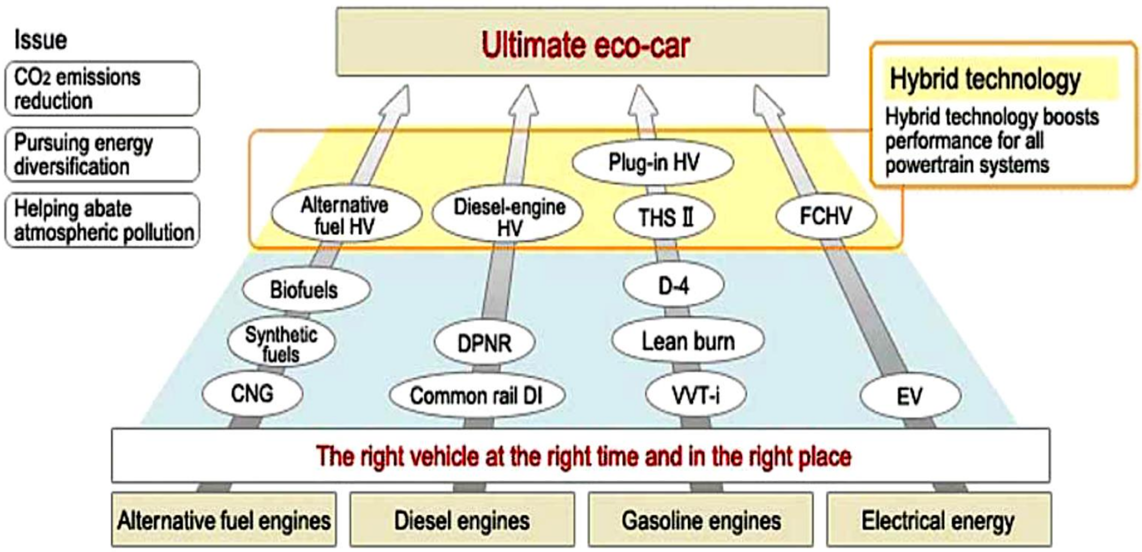

Fig. 4. Road map of hybrid technology [10]

2.2 History of electric vehicle

In 1828, Ebony Nazdik from Hungary used an electric motor to move a car. In 1834, Thomas Davenport of Vermont Black Smith used electrotherapy machine on light rail for the movement. In 1835, Prof Sybrandvs Astratyng with Christopher Becker moved a small car with non-rechargeable batteries. In the years after, exactly in 1859, the acid battery was invented by French physicist called Gaston Planté, and open the way for the manufacture of rechargeable batteries [11, 12].

Until 1920, gasoline and electric cars were in progress as well as the invention of the exhaust from high volume machines internal combustion prevented. Additionally, the invention of the electric starter and the discovery of oil field made internal combustion engines vehicles popular then and electric vehicles.

After the success at the beginning of the twentieth century, EVs gradually its former position in the car market compared to other cars. In 1970, passed a law called the Clean Air which any states have seized control of air quality in the areas. Also, the Organization of the Petroleum Exporting Countries (OPEC) oil embargo in 1973, caused gasoline prices to a dizzying rate increase and as a result the willingness of companies to find alternatives to be added. In 1976, the Congress of America acted as legal to conduct research, development, and demonstration of electric cars and hybrids passed to the energy license to the research and development of electric vehicles and hybrid endorsed.

General Motors in 1996 produced 1117 number of the electric car. It is only available to citizens of California, Arizona, and Georgia which there was the possibility of signing and merely leased. In 2000, Prius was launched in Japan for the first time in 1977, but a little later was released all over the world. Tesla in 2011 introduced the Roadster. The car manufacturer had a range of 386 km per hour, however, the price set for the over 100 thousand dollars. In 2010, Nissan's all-electric vehicle called Leaf released to the market in America. It was a distance of about 160 km per charge can travel at a more reasonable price of $ 30 thousand was sold. In 2017, Tesla's eyes fixed on the future, and it plans the first car for the mass market with the model name 3 Production. It is expected due to the many changes which have been happened in the industry of electric vehicles in the coming years, electric vehicles many of the old automakers are entering the market. Fig. 5 shown here the history of electric vehicles over last two century.

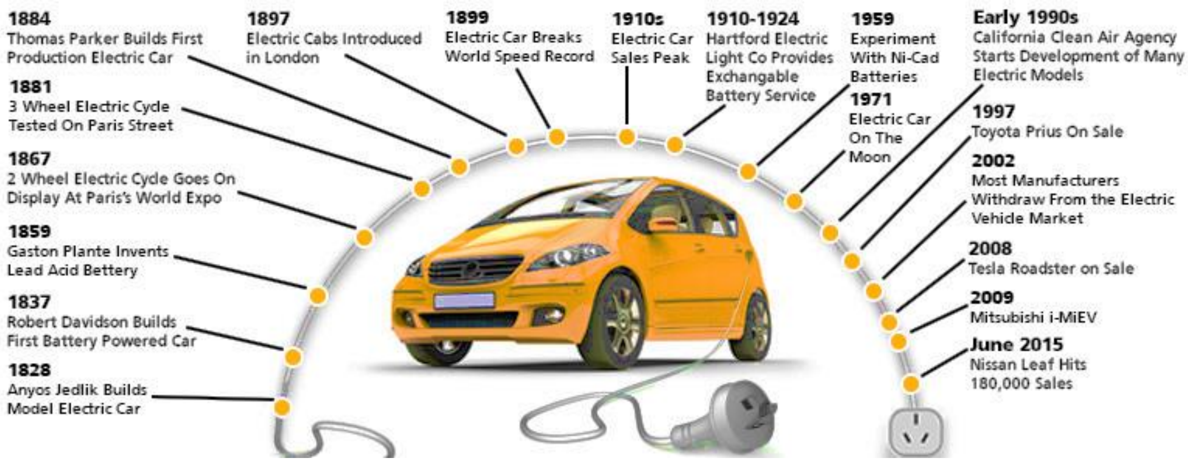

Fig. 5. History of electric vehicles

3. Classifications of electric vehicle

There are three types of EVs, classed by the degree that electricity is used as their energy source.

- Battery electric vehicle (BEV)
- Hybrid electric vehicles (HEV)
- Hybrid electric vehicles that can be connected to the network (PHEV)

3.1 Battery electric vehicle (BEV)

The car has electric motors with batteries to provide electric power and energy. Also as propulsion batteries for powering electric motors for cars and other equipment is used. Batteries of this type of vehicle can be a connection to the grid, and non-grid electrical energy from the brakes and even from sources such as solar cells will be charged.

The main advantages of these vehicles include:

- Completely free of emissions of greenhouse gases.
- Produce very little noise.

- Much higher efficiencies than internal combustion engines.
- Electric motors of low prices

. A DC/DC inverter is installed to convert the battery voltage to low voltage for the 12V electronics in the car. Fig. 6 shows all the important components of the BEV.

In part five distinct batteries are examined that can be utilized as a part of a BEV. After the battery, an inverter is installed to change over the DC in the battery to the required current required for the electric engine. A Vehicle Control Unit (VCU) and Power Distribution Unit (PDU) are set to control all the electronics in the vehicle. A DC/DC inverter is installed to change over the battery voltage to low voltage for the 12V electronics in the vehicle. Fig. 6 demonstrates all the essential components of the BEV.

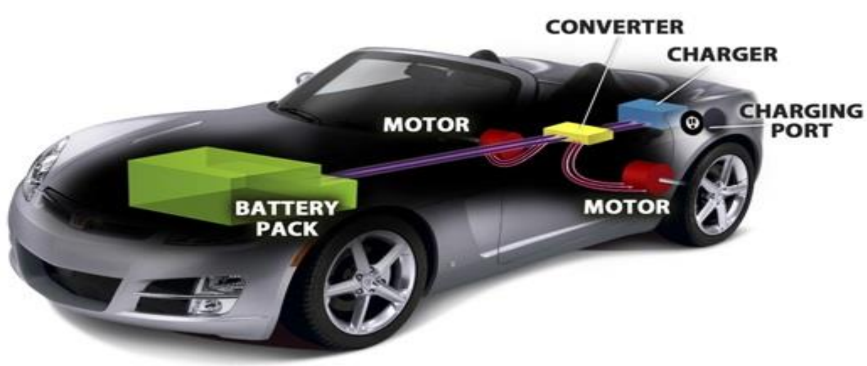

Fig. 6. Components of a BEV

3.2 Hybrid electric vehicles (HEV)

The vehicle also has an engine and an electric motor with a battery that can store energy from the engine and the brakes. The batteries in the time required to produce vehicles to come up reinforcements or at low speeds, the engine shut off fuel, to provide vehicle propulsion. Fig. 7 shows all the necessary components of the HEV.

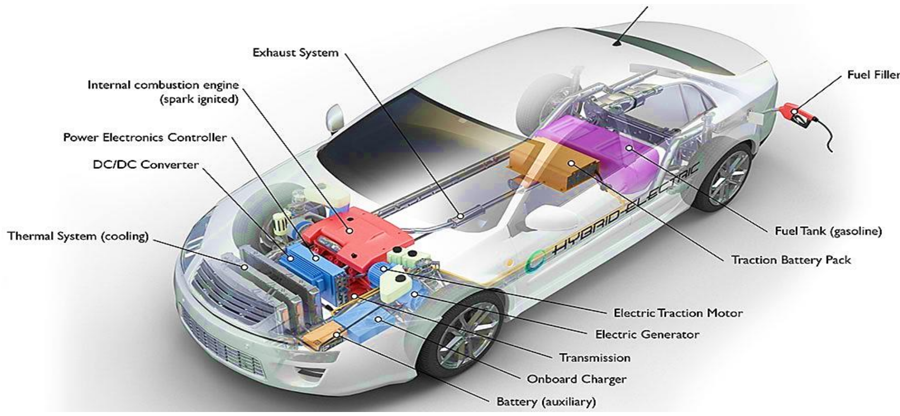

Fig. 7. Components of a BEV

The disadvantages of these vehicles include:

- Non-rechargeable battery of the electric grid
- Dependence on gasoline Engine (Inability to move the car using only the electric motor)

Hybrid Electric Vehicles (HEV) can be divided into three subgroups series, parallel, and series-parallel which this application is based on the imports power of internal combustion engine and electric motor to the wheels. In the series type, the internal combustion engine transport power to a generator which the produced electricity recharge the battery or transfer electricity directly into the electric motor. The greatest advantage of the series hybrid combined is that power output of the internal combustion engine comes to batteries which it is optimized energy consumption in electric vehicles. Fig. 8 shows the architecture of series HEV.

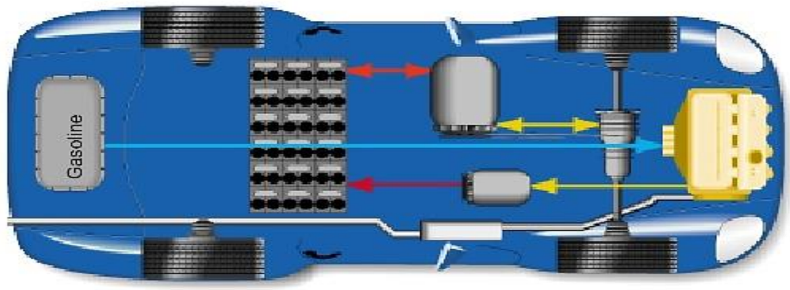

Fig. 8. Architecture of series HEV

Essentially parallel hybrid structure of a production cycle in parallel with the energy source is formed. Gears connect the structure of the internal combustion engine to the wheels, and gear spin is limited. Also, in the parallel hybrid vehicle has two driving forces are required; internal combustion engine and electric motor. The advantage of this structure to the hybrid series arrangement is that smaller internal combustion engine and the electric motor can be used for maximum performance (as long as the battery has not died). Fig. 9 shows the architecture of parallel HEV.

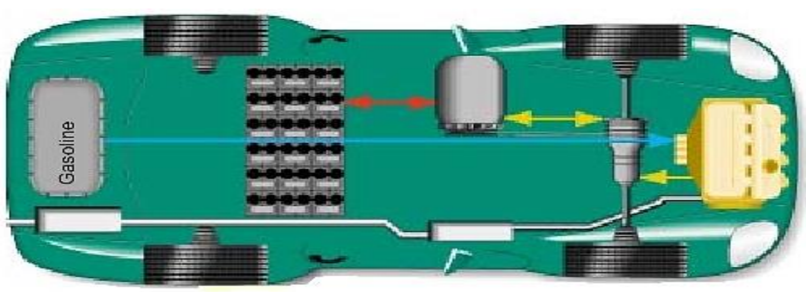

Fig. 9. Architectures of parallel HEV

In the series-parallel hybrid structure, to take advantage of any flaws and fix them, the structures of parallel hybrid and series hybrid compound. In this type of EV the power be created, the internal combustion engine is divided into two parts, mechanical and electrical which electrical parts are controlled so that the engine at its optimal point of work. This will be done by the separator and energy storage (batteries), the produced electricity in addition to uses in the electric motor it will be saved in the battery. Fig. 10 shows the architecture of series-parallel HEV.

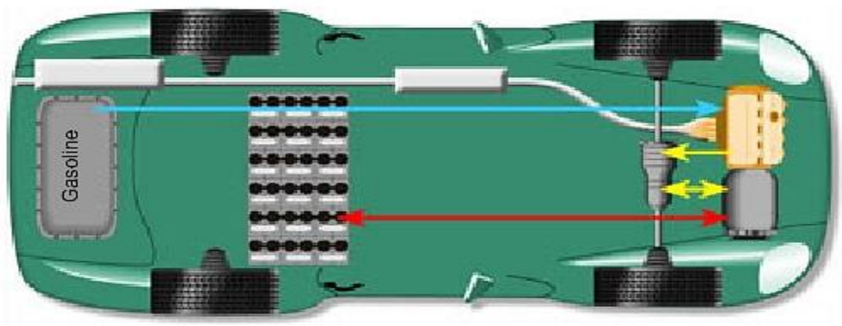

Fig. 10. Architectures of series-parallel HEV

3.3 (Plug-In) hybrid electric vehicle (PHEV)

PHEV systems are the newest type of dynamics and rapidly increased their popularity. This system by adding larger batteries that can be fed from an external power source on the concept of parallel hybrids to all-electric vehicles have been closer. The advantages of plug-in hybrid vehicles include:

- Lower fuel consumption: on average, the use of plug-in hybrid vehicles, 30-60 percent, reduce fuel consumption.
- Reduce greenhouse gas emissions: Due to the battery and charging capabilities as well as reduce fuel consumption, greenhouse gases generated by the vehicle is reduced.
- Reduce fuel costs: plug-in hybrid vehicles, less fuel is required and also can only use a battery to move EV. Therefore, this application is reduced fuel consumption cost. It should be noted that the initial cost of buying these cars, but in the long run than regular cars can be economical in terms of economy.

- Small engine: Plug-in hybrid vehicles due to several energy generators, motors are smaller, lighter and therefore reduce fuel consumption without interfering with the performance of the vehicle.

The only drawback plug-in hybrid vehicles, charge time is usually time-consuming, but you can get the car home to plug in and charge the battery for the next day. Fig. 11 shows all the essential components of the PHEV.

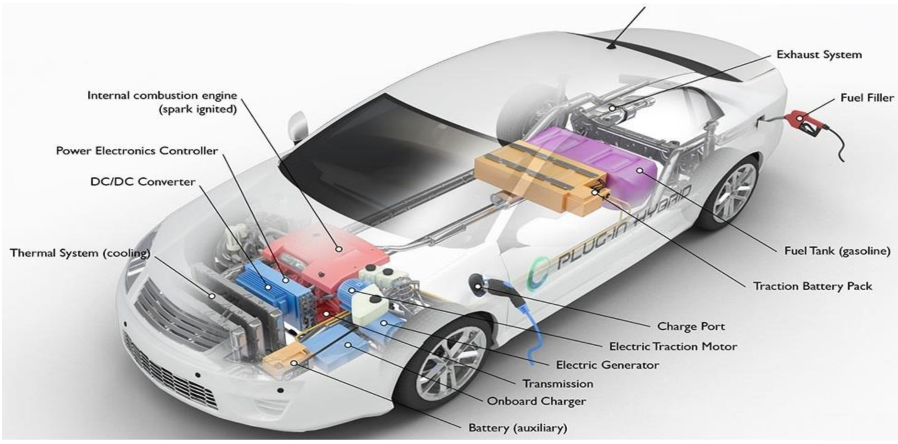

Fig. 11. Components of a PHEV

4. Energy management system in electric vehicle

Harmful effects of fossil fuels on the environment and human's health as well as the money spent on exploring, exploiting, and converting fossil fuels propel the human being into finding other sources of energy which are renewable and sustainable. The results of these incentives have been solar, wind, and wave energies, which are substituting for conventional sources. On another hand, using current loads such as EV and Personal Computer (PC) based on power electronic have been increased, remarkably [13-15]. After finding reliable sources, the next step is to handle these energies and convert them into the electrical energy. These advancements as stimuli motivate the scientists and researchers working in the field of electric engineering to seek methods by which make it probable to aggregate these renewable and sustainable sources in a uniform system. Accordingly, this idea is achieved by the advent of Microgrid/Smart grids [16]. In fact, micro renewable sources, power electronic interfaces, primary & secondary controllers, energy storages, revised protection strategies, and communication technologies are aggregated in the Microgrid concept [17-19]. According to the whole bunch of technologies mentioned, numerous potential fields of research are in front of relevant scientists.

Over the past few decades using EVs as a viable alternative to gasoline-powered vehicles because of energy security, global and local environment, and economic growth has been used in all over the world [20-22]. Also, under the term EVs, subcategories exist. HEV, FCEV, and BEV differ in specific design aspects but share the same core electrical technology. The main components of an EV are the motors, controllers, power supply and transmission system [23]. The most important part of the EVs is battery and modeling of batter play a useful role in the application of EVs power system [24]. To improve the operation of EVs underrating different types of battery and the relevant parameters of the battery such as life cycle, charge/discharge time, battery power need to be conceded.

Another important issue about EVs is energy management of power and energy which is divided into two parts: a) energy management of EV on-grid (Fig. 12) b) energy management of EVs off-grid (Figs. 13 and 14). Regarding on grid management, the operation of the charge and discharge EV regarding time and the rate of energy are important things which need to be considered [25, 26]. Additionally, in this mode, EVs can be seen as loads. Therefore, EVs may contribute to the optimization of electric power systems as mobile energy storages [27]. Also, regarding off-grid management, energy management system can be classified of EV into three layers [28]; (1) hardware-based Low-Level Control (LLC), (2) hardware based Low-Level Component Control

(LLCC) and (3) software-based High-Level Supervisory Control (HLSC). These controls work together on the electronic system during analysis, implementation, and execution of the energy management system strategy [29, 30]. Besides, the calefaction of HLSC is shown in Fig. 15.

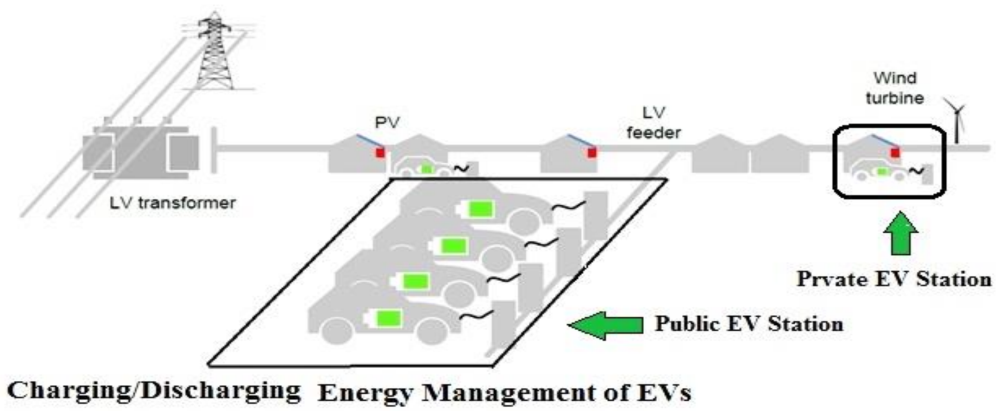

Fig. 12. Energy management of EV on grid

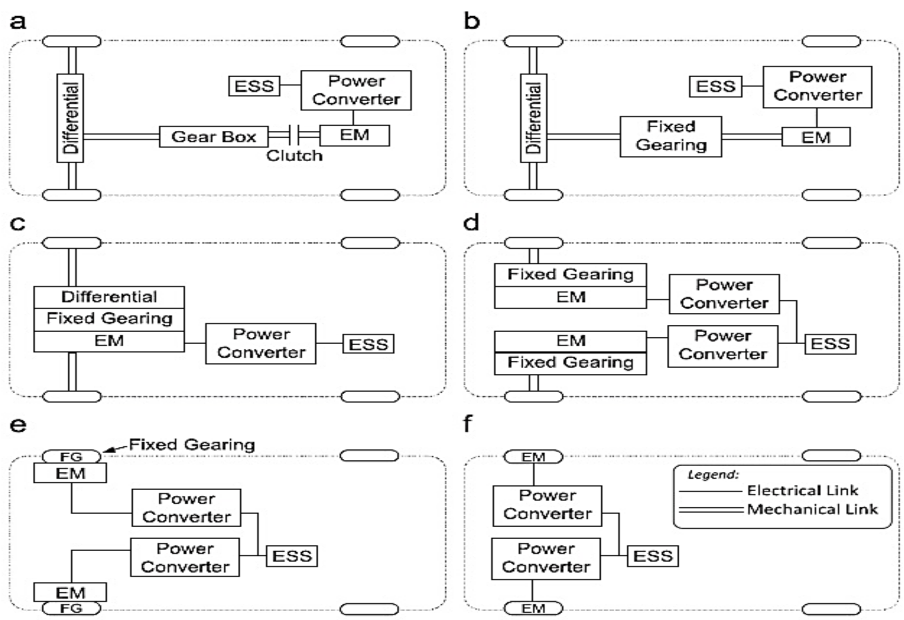

Fig. 13. The drivetrains architectures of BEV in LLC: (a) conventional driveline with clutch, (b) driveline with single-gear transmission without clutch, (c) driveline with integrated fixed gearing and differential, (d) driveline with two separate motors and fixed gearing, (e)driveline with fixed gearing and motor, (f) in-wheel drive. [22]

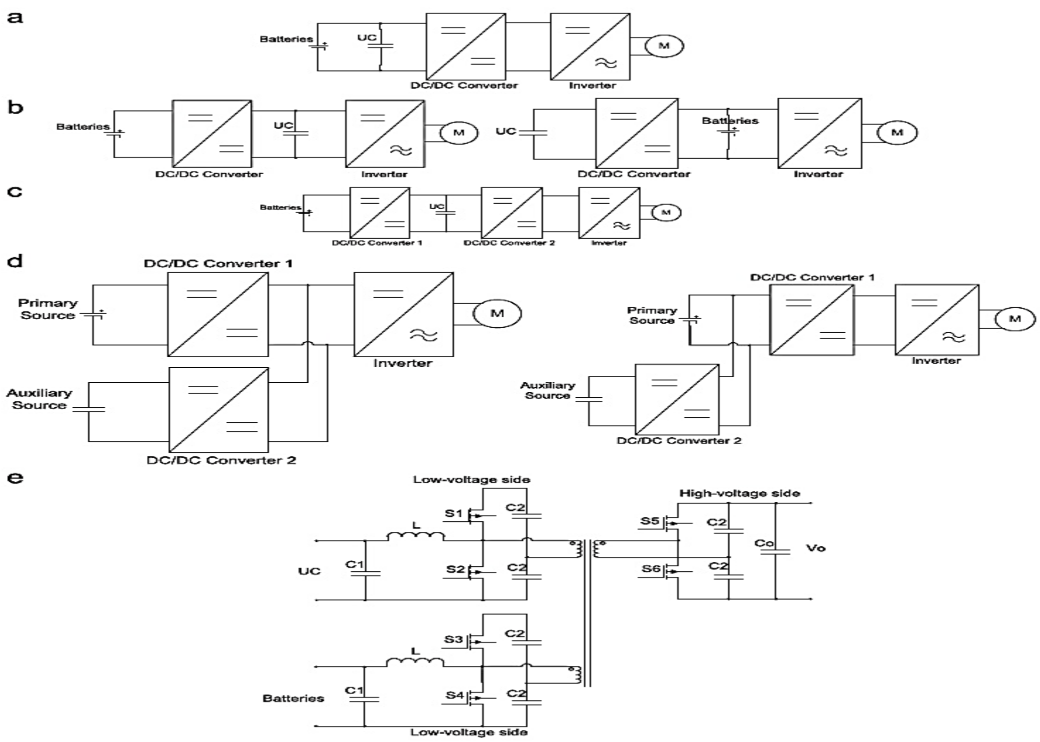

Fig. 14. The configurations in LLCC: (a) passive parallel connection, (b) one bi-directional DC-DC converter in series, (c) two bidirectional DC-DC converter in series, (d) two-input bi-directional DC-DC converter in parallel, (e) multiple-input ZVS bi-directional DC-DC converter. [22]

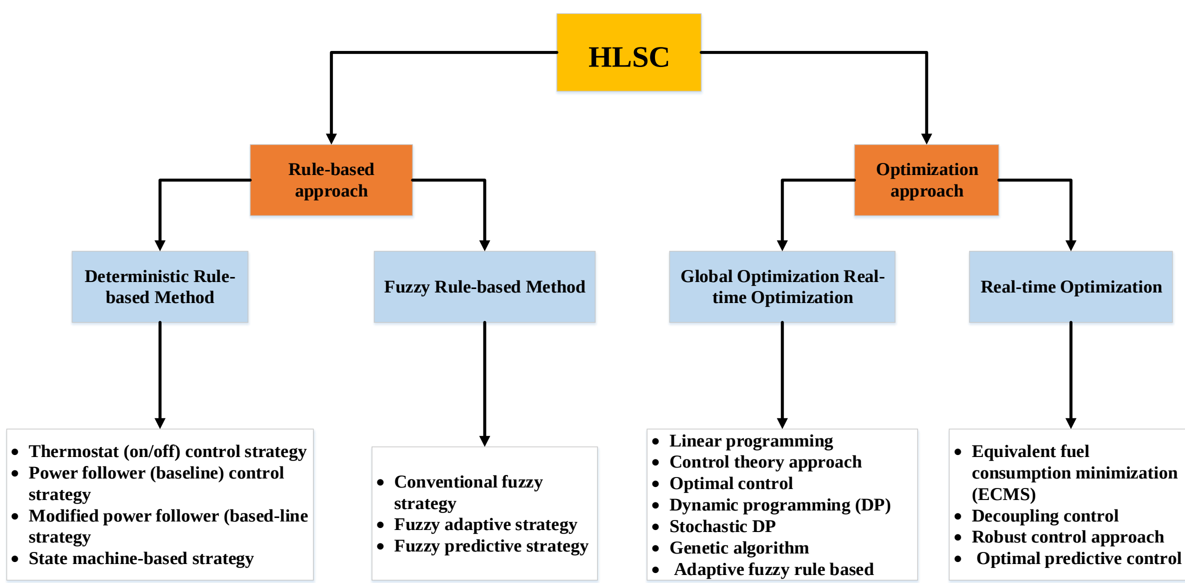

Fig. 15. Classification of HLSC strategies

5. Study of electric vehicles in the world

5.1 Application and Marketing of Electric Vehicle in the World

The EV manufactures are developing the most recent couple of years massively. All real car manufactures have officially Hybrid Vehicle, Plug-In Hybrid Vehicle and an Electric Vehicle in their program as new technology, specially the HEVs sales will dramatically increase through 2018 [31].

Market advances will be driven by micro and mild hybrids Micro hybrids are traditional vehicles furnished with start-stop systems. Mild hybrids feature highlight regenerative braking notwithstanding to start-stop systems, and some of these additionally come furnished with a small electric motor that begins the vehicle yet can't impel it without the guide of an inward burning motor. These frameworks convey significant fuel investment funds with respect to their low extra cost and can lessen general vehicle outflows. In 2018, the micro and mild hybrid request total will be 20.1 million units, full and PHEV deals will be 4.1 million units, and EV request will be about one million units. EVs will post the quickest market increases of any item sort, but from a little current deals base. Fig. 16 appeared the rate of 2014 worldwide EV stock in Electric Vehicle Activity (EVI) nations.

In 2015 offers of EV and PHEV cars was 477,000, as indicated by the International Energy Agency (IEA), simply over a portion of these immaculate EVs. The primary markets were China, the USA, the Netherlands and Norway. At the same time, these nations represented 70% of EVs sold around the world. Before the finish of 2015 there were around 1.26 million electric vehicles in administration, around 700,000 of them BEVs, and over a portion of the aggregate were in China and the USA.

In 2016 Renault-Nissan and Mitsubishi sold 424,797 EVs. The Chinese government has an objective of putting 500,000 EVs and PHEVs out and about before the finish of 2016, and 5 million by 2020. With around 320,000 toward the finish of 2015 it was on track for these objectives. Additionally, China has the greatest armada of battery-electric bikes, with more than 150 million in administration, and 36 million fabricated every year. It additionally expanded its electric buses from 29,500 in 2014 to more than 170,000 in 2015.

Before the finish of 2015 there were 1.45 million electric vehicle supply gear outlets, about twofold the 2014 number. Around 162,000 of these were openly accessible moderate outlets and 28,000 freely accessible quick outlets (44% of the last in China). A ten times increment in electric vehicle supply gear outlets is visualized by 2020.

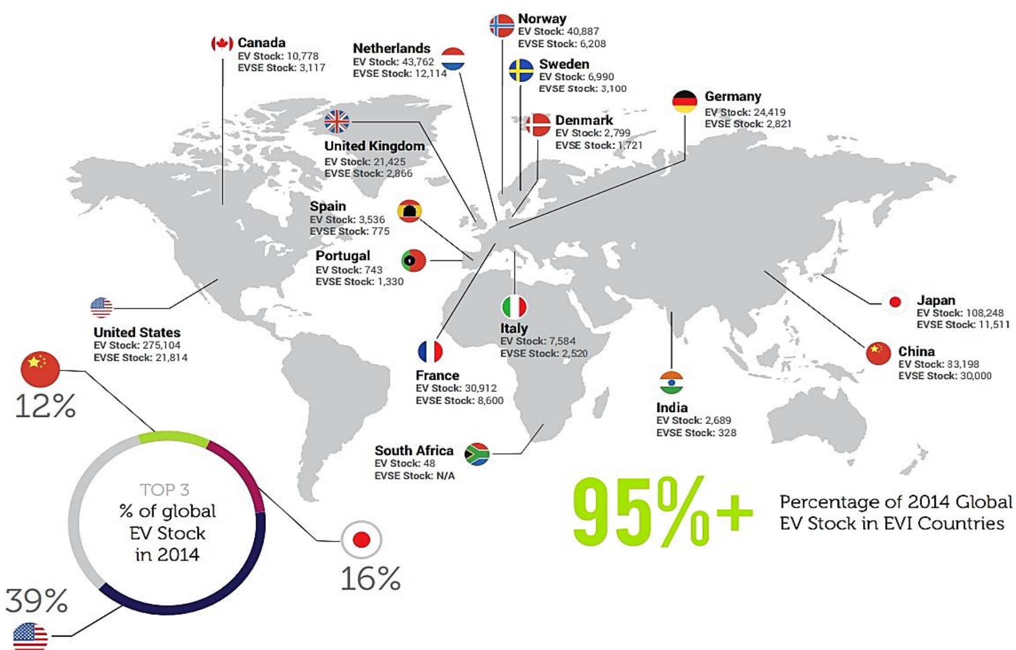

Fig. 16. The rate of 2014 worldwide EV stock in EV activity nations

As appeared in the Fig. 16, the main 2015 EV advertises inside China, Europe, and the US have yearly EV deals that are in the many thousands every year or that make up around one in each 10 new vehicles. Fig. 17 demonstrates the EV take-up for the 14 metropolitan territories distinguished [32]. These 14 markets illustrate 32% of worldwide EV deals in 2015.

Oslo had the most elevated EV share at 27%, trailed by Utrecht at 15%, and Shanghai at 11%. Shenzhen, Amsterdam, and San Jose finished the main six in deals share with 9%-10% of new vehicles being electric. The main six urban areas by EV offer are conveyed crosswise over four nations on three landmasses. As far as aggregate yearly new EV volume, Shanghai leads by a wide edge with 41,179 EVs sold in 2015. Los Angeles, with 23,652 deals, and Beijing, with 18,065 deals, had the following most new EVs being sent.

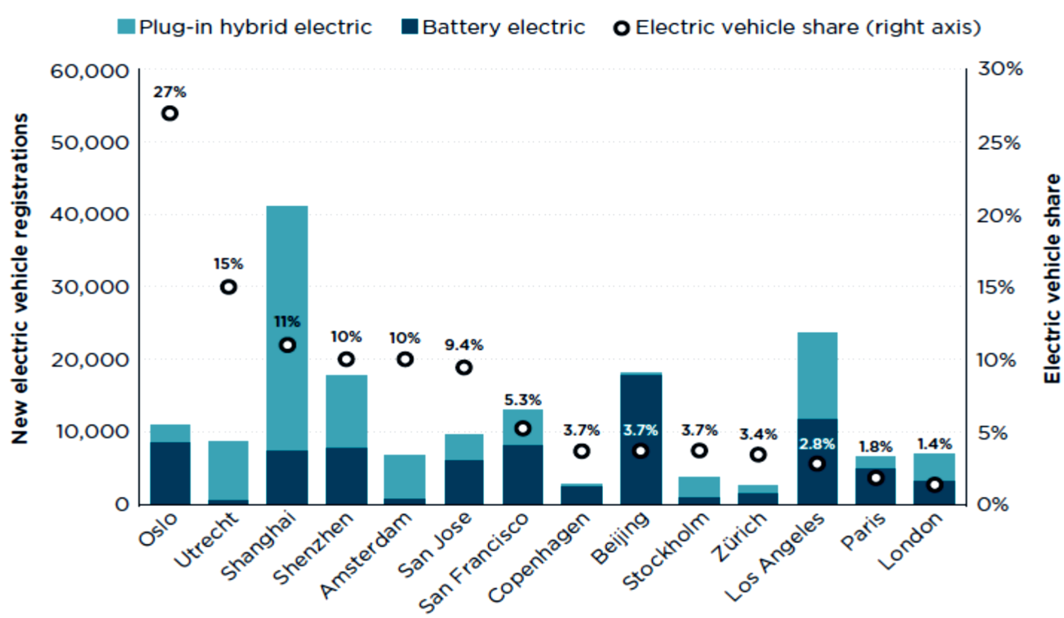

Fig. 17. EV new enlistments and offer of new vehicles in 2015 in high electric vehicle take-up business sectors [32]

5.2 Future of Industry of Electric Vehicles in the World

Projections show that in the near future using EVs will be increased among other cars. The cars will be charged with connection to the electricity grid homes and there are so many schemes to owners of these vehicles which makes it possible to recharge their car outside the house. However, the biggest issues which need to be considered are fast charging/discharging, battery life and technology, EVs energy management and cost of the EVs. Tesla battery will have a range of 1,000 miles, which will have a huge impact on the automobile industry.

One interesting trend is that newer EVs are more likely to be a plug-in, and the sales show that plug-ins have outsold hybrids recently. As the range issue is solved and the battery costs decrease, more and more EVs will switch from hybrids to plug-ins. The biggest reason is that more electric power means more efficiency and fewer petrol costs.

Due to each country has different electricity infrastructure, use of EV technologies will be different in all part of the world. For instance, plug-in vehicles will be more advantageous in countries like U.S., where most homes have garages where cars can be charged overnight. Moreover, in countries like Korea and Singapore, where land is scarce and homes are mostly condominiums (unless charging stations are spread throughout) PHEV will not be very popular. This is why clean diesel and hybrid Liquefied Petroleum Gas (LPG) vehicles are much more popular in South Korea. Also, diesel/LPG prices are much lower than gasoline prices, while range and fueling time are much better than EVs in South Korea.

There are five reasons which show that future will be growing for EVs in the market of the world:

1. *Battery expenses are dropping quickly:*

Battery costs are falling, quicker than numerous specialists would have anticipated. To an ever increasing extent, researchers, industry specialists, and automakers are in understanding that battery costs are going underneath the enchantment $150 per kilowatt-hour in the following decade.

2. *Longer range, reasonable EVs are coming:*

Longer-go, moderate EV that work exclusively on power and are equipped for voyaging 200 miles on a charge, are coming to showrooms.

3. *More charging stations are coming:*

Lack of charging stations decries use of EVs these days. However, utilities are moving to increase the number of charging stations at workplaces, apartment complexes, campuses, transit stations and other public gathering places.

4. *The auto industry is grasping EVs:*

Automakers are investing billions of dollars to bring more electric vehicle models to market. Since 2010 up to now, the number of EV models has grown from 2 to 25.

5. *The global imperative to cut carbon contamination and oil reliance:*

The human look for ways to reduce the carbon pollution and oil dependency which EVs play an important role to overcome the problems. A study by Natural Resources Defense Council (NRDC) and the Electric Power Research Institute (EPRI) shows that use of EVs could cut carbon pollution by 550 million metric tons annually till 2050. It also would reduce other harmful pollution, such as ozone and particulate matter.

As indicated by the EVI and the IEA, there will be 20 million EVs by 2020, which implies that offers of EVs are required remarkability. KPMG organization expects the generation of powertrains to develop from 3.1 million in 2015 to 5.1 million in 2020, which would positively meet the developing needs of the EV business, Fig. 18.

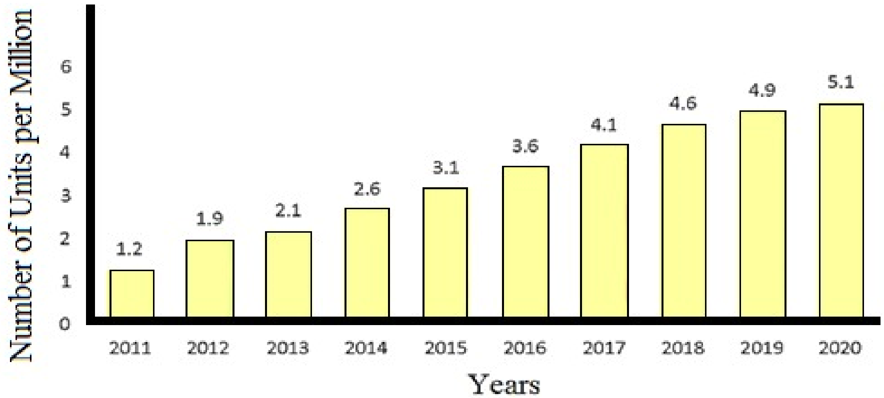

Fig. 18. Assessed electric power-prepare generation

6. Simulation of Electric Vehicle

Recently, more advanced AC and DC motor drive systems have found new applications in industry and EV, using induction motors, permanent magnet synchronous motors, and permanent magnet DC motors. FACTS is defined by the IEEE as a power electronic based system and other static equipment that provide control of AC transmission system parameters [33, 34].

In the proposed case studies, EVs are supplied by efficient Lithium-ion batteries that can be recharged through AC/DC interface V2H and V2G charging stations that require robust interface of DC-AC systems. Battery charging stations can be supplied by renewable energy sources such as (Photovoltaic and Wind). In the proposed case studies the EVs can be utilized in power systems as a back-up storage. Batteries can be charged during low-demand times and discharge when power is in shortage [35, 36].

The section addresses engineering challenge to find efficient, robust, secure and reliable FACTS-based DC-AC schemes for renewable energy, motor drives and V2H/V2G battery charging schemes for EV. The research scope covers interface issues and problems of voltage stabilization and security as well as efficient energy utilization using new FACTS architecture and control topologies. Also, in control strategy, using emerging solid-state power electronic devices FACTS schemes in smart grid and motor drive applications.

6.1 Case Study 1: Low Impact Efficient Vehicle to Hybrid (V2H) Battery

Fig. 19. shows the low-cost, efficient V2H battery charging scheme for EVs with an AC single-phase source, AC/DC reciter, boost chopper, Lithium-ion battery, and Green Plug-Switched Filter Capacitor (GP-SFC). The Nortel Point- Switched Filter Capacitor (NP-SFC) scheme is used to ensure stable, efficient, and minimal inrush operation of the V2H scheme. The new Proportional Integral Derivative (PID) multi-regulators and coordinated controller are used for the following purposes, Fig. 19:

- AC/DC power converter regulator to regulate the DC voltage at the AC bus and ensure limited inrush conditions as well as dynamic power matching to reduce current transients and improve utilization at the AC/DC bus.
- NP-SFC filter compensator uses Pulse Width Modulation (PWM) to regulate the DC Bus voltage and minimize inrush current transients. The NP-SFC device acts as a matching DC/DC interface device between the DC dynamic characteristics and charging the battery.
- The boost converter controller uses PWM to regulate the output voltage magnitude.

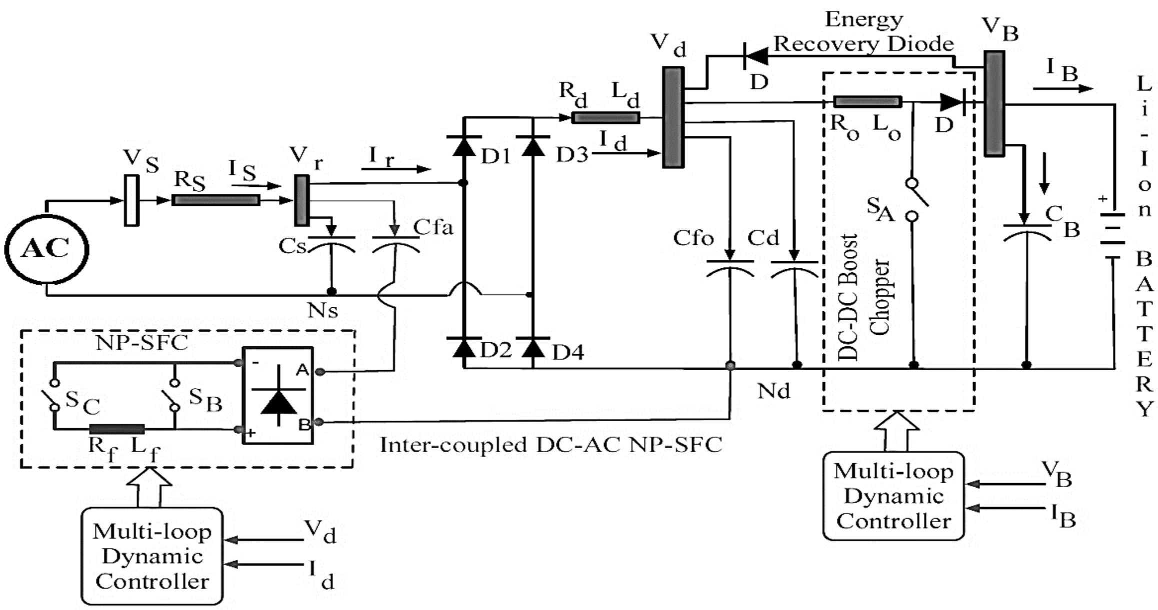

Fig. 19. V2H battery charging scheme for EVs

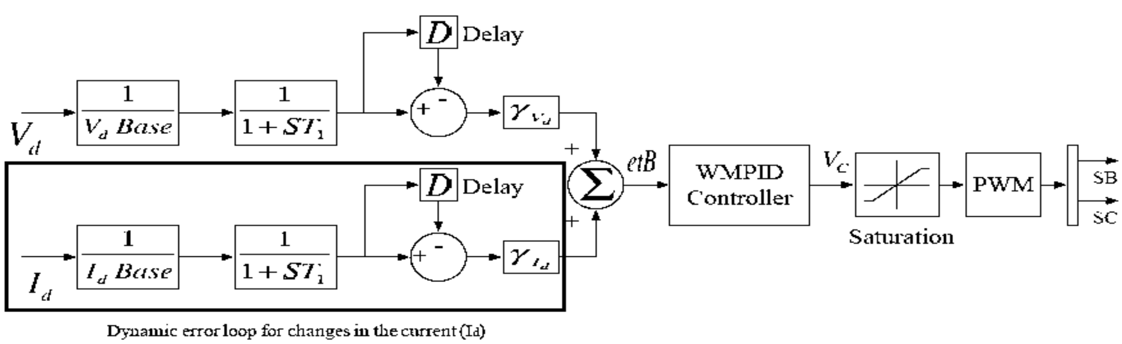

Fig. 20. Dual-loop error-driven the proposed PID for the DC boost DC/DC chopper

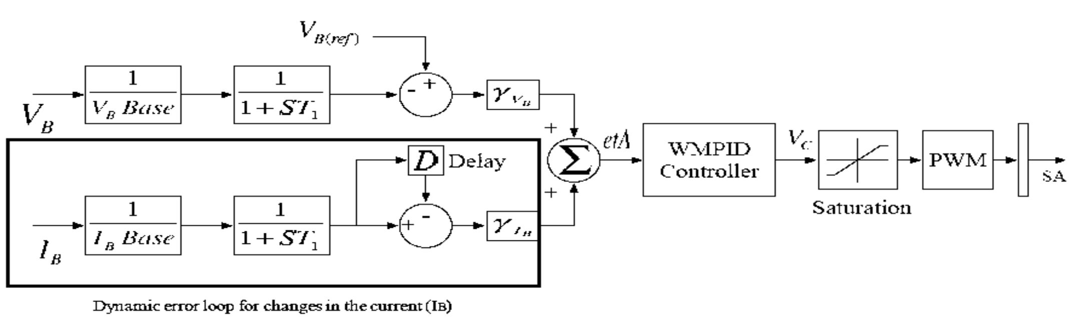

Fig. 21. Dual-loop error-driven the proposed PID for FACTS NP-SFC

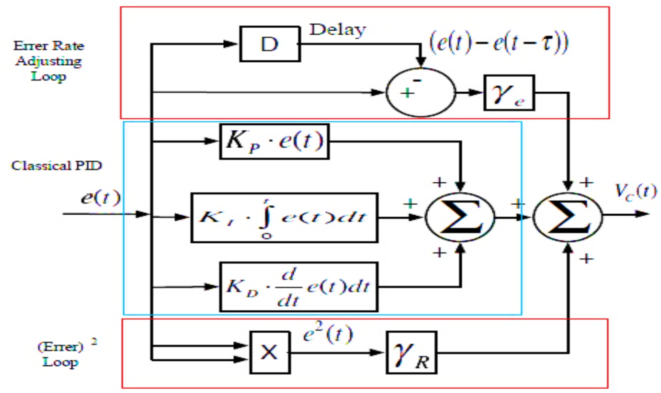

Fig. 22. Acting dynamic controller with error squared and rate compensation loops

Fig. 23 a and c, show the system dynamic response for the voltage at Vs and Vd Buses without using the filter. Fig. 23 b, shows the system dynamic response for the voltage at Vd Bus with using the filter. Also, Fig. 23 d, shows the relation among Vd, Id, and Pd at the Vd Bus.

The simulation result illustrates that the new dynamic dual action filter compensator with tuned controller parameters did incredibly enhance the AC and DC buses dynamic performance from a general power quality perspective. The system is controlled utilizing the new dual-loop error-driven dynamic action filter using the NP-SFC. All the results showed that the proposed modified controller is far superior compared to the proposed PID controller in damping current and voltage excursions. The digital simulation results approved the effectiveness of the NP-SFC scheme in stabilizing the common AC side bus and reducing AC inrush current conditions.

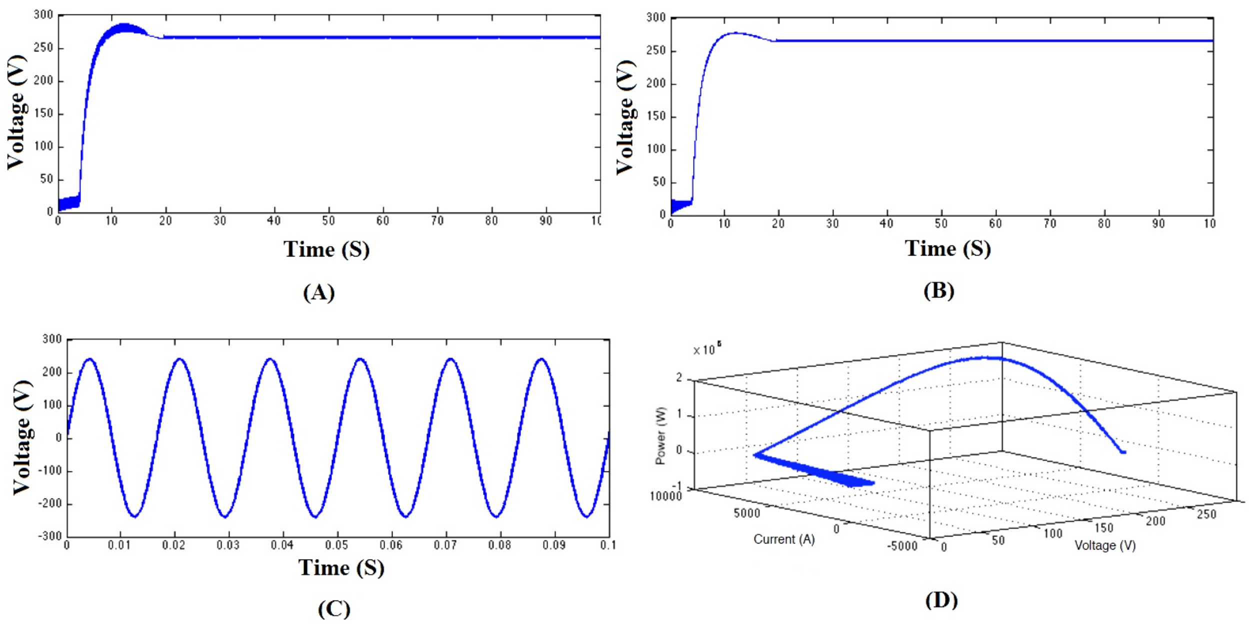

Fig. 23. A) The voltage Vd on the Vd Bus without the NP-SFC filter, B) The voltage Vd on the Vd Bus using the NP-SFC filter, C) AC voltage waveforms Vs on the Vs Bus without the NP-SFC filter, D) Voltage Vd vs. current Id vs. power Pd using the NP-SFC filter

Moreover, the edible multi-loop weighted DC side chopper used for the battery charging scheme has an assigned multi-modal (V-I-P) charging strategy that can be adjusted to limit initial charging transients and inrush currents during fast charging modes, hence improving dynamic energy exchange efficiency and reducing excessive voltage transients in the common AC bus.

6.2 Case Study 2: Hybrid Vehicle to Grid (V2G) Smart Grid Battery

Fig. 24 shows the micro grid utilization scheme with the PV source, AC source, and backup battery. The DC and AC filter compensator schemes are used to ensure the stable, efficient, and minimal inrush operation of the hybrid DC/AC renewable energy scheme. The multi-regulators and coordinated controller are used for the following purposes:

- The AC source control regulator is based on excess generation and loads dynamic matching.
- The AC/DC power converter regulator regulates the DC voltage at the AC Bus and ensures limited inrush conditions as well as dynamic power matching to reduce current transients and improve utilization at the AC and DC Buses.
- The GP-SFC regulator for the PWM scheme is used to regulate the DC bus voltage and minimize inrush current transients and load excursions and/or PV and. The GP-SFC device acts as a matching DC/DC interface device between the DC load and that of the hybrid main PV and backup battery.
- The buck-boost converter controller using the PWM regulator regulates the output voltage magnitude.
- The permanent magnet DC motor drive with the speed regulator that ensures speed reference tracking with minimum inrush conditions, reduced voltage transients, and improved energy utilization.
- The AC side switched filter regulator provides an effective low-cost energy utilization and power quality improvement tool for increasing dynamic. AC side voltage, current transients, and load excursions.

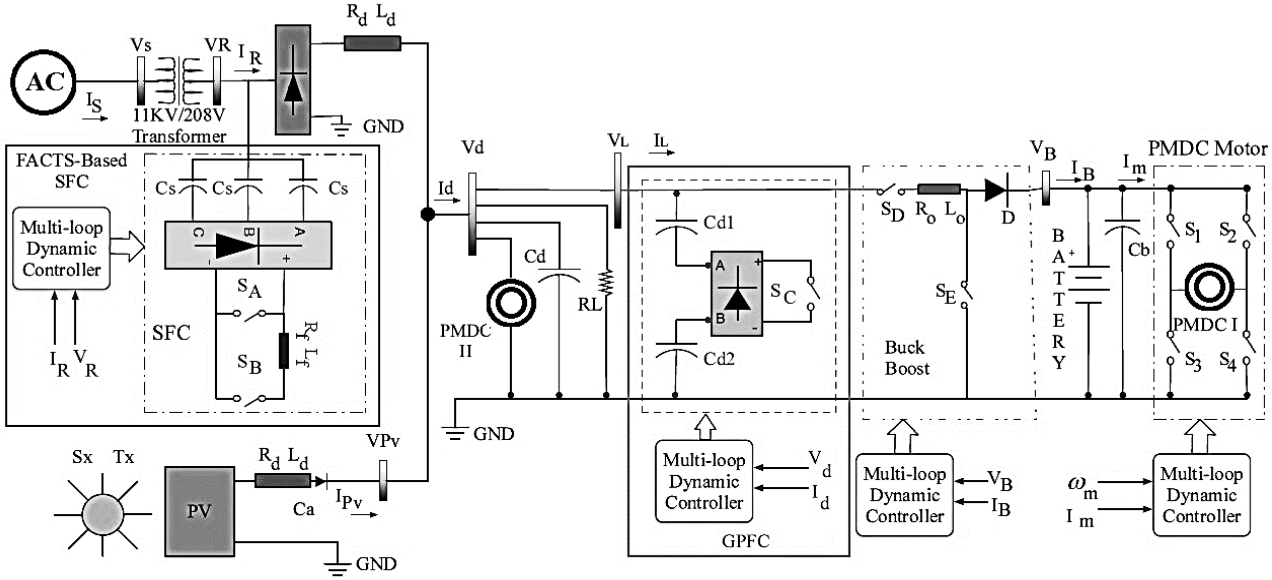

Fig. 24. Hybrid V2G-Smart Grid-PV-Battery charging scheme for EVs.

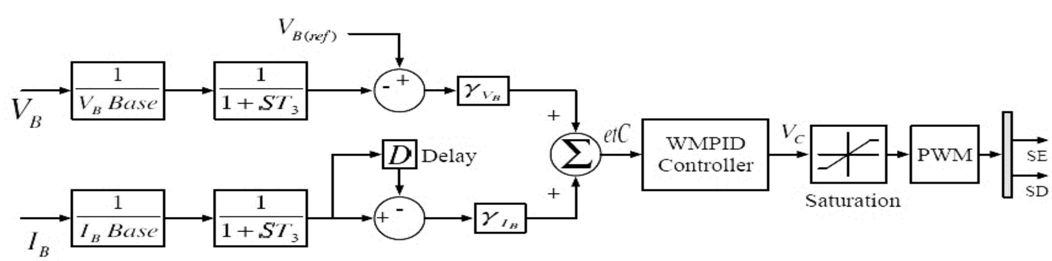

Fig. 25. Dual-loop error-driven dynamic controller for the DC buck-boost DC/DC converter

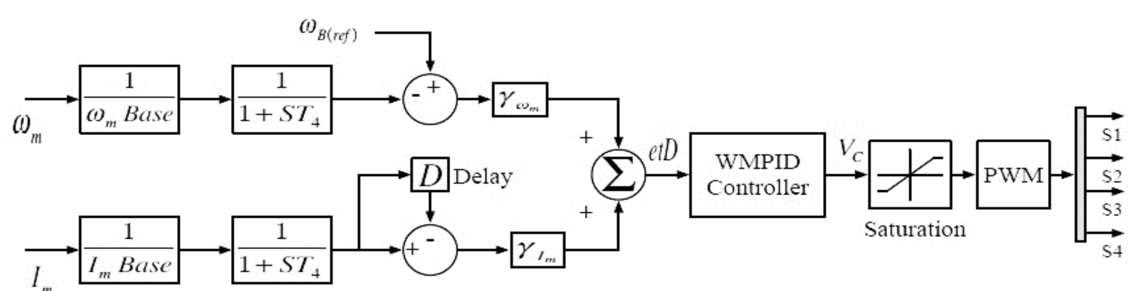

Fig. 26. Dual-loop error-driven dynamic controller for the PMDC motor drive using the four-quadrant DC chopper

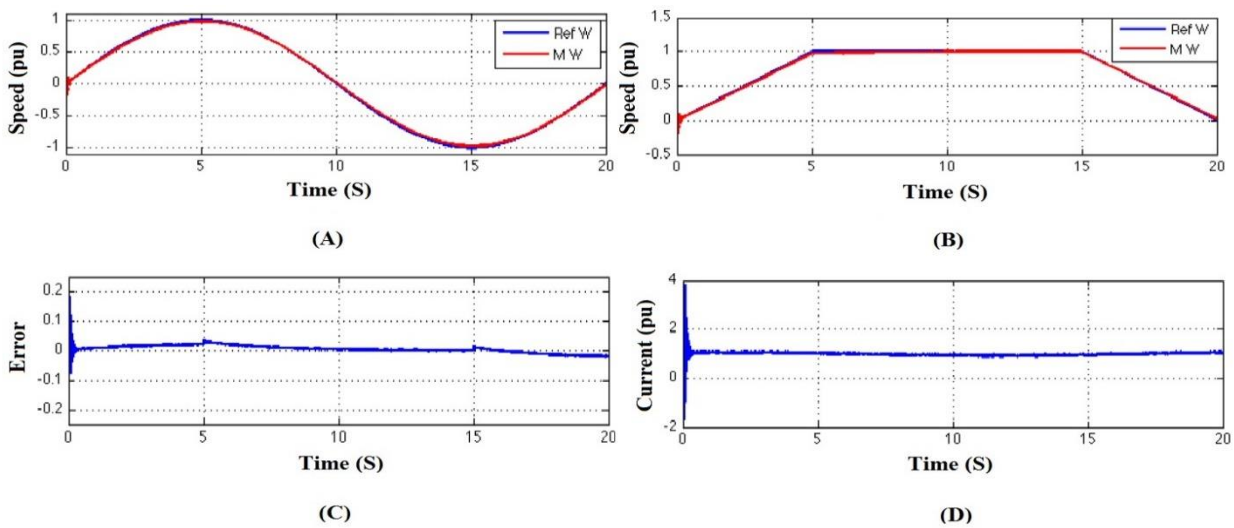

Fig. 27. A) Dynamic speed reference tracking of PMDC sinusoidal speed reference, B) Dynamic speed reference response of PMDC motor, C) Speed-error vs. time, D) Motor current vs. time

Fig. 27 b and Fig. 27 c, show the system dynamic response speed trajectories and show the error speed trajectories, respectively. In addition, Fig. 26 c, show the PMDC motor current Im and, the controller effectiveness in tracking speed reference trajectories was tested for the step reference, as shown in Fig. 27 a.

It is quite apparent that the dynamic filter compensator with tuned controller parameters did highly improve the AC and DC Buses' dynamic performance from a general power quality point of view. The system is controlled using the new dual-loop error-driven dynamic action filter using GP-SFC. All the simulation results indicated that the proposed modified controller is far superior in damping current and voltage excursions.

References

[1] S. Micari, A. Polimeni, G. Napoli, L. Andaloro, V. Antonucci,” Electric vehicle charging infrastructure planning in a road network.” Renewable and Sustainable Energy Reviews, vol. 80, pp. 98-108, 2017.

[2] N. Daina, A. Sivakumar, J. W. Polak, "Modelling electric vehicles use: a survey on the methods," Renewable and Sustainable Energy Reviews, Part 1, vol. 68, , pp.447-460, 2017.

[3] R. J. Bessa, M. A. Matos, F. J. Soares and J. A. P. Lopes, "Optimized Bidding of a EV Aggregation Agent in the Electricity Market," in *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 443-452, March 2012.

[4] M. Shafie-khah, E. Heydarian-Forushani, M.E.H. Golshan, P. Siano, M.P. Moghaddam, M.K. Sheikh-El-Eslami, J.P.S. Catalão, "Optimal trading of plug-in electric vehicle aggregation agents in a market environment for sustainability," Applied Energy, vol. 162, pp. 601-612, 2016.

[5] A. Brooks, D. Reicher, C. Spirakis, B. Weihl, “Demand dispatch,” IEEE Power Energy Mag, vol. 5, pp. 9-20, 2010.

[6] S. Han, S. Han, K.Sezaki ,”Development of an optimal vehicle-to-grid aggregator for frequency regulation,” IEEE Trans Smart Grid, vol. 1, pp. 65-72, 2010.

[7] D. Zhu, D. P. Patella, R. Steinmetz, P. Peamsilpakulchorn,” The Bhutan Electric Vehicle Initiative : Scenarios, Implications, and Economic Impact,” International Bank for Reconstruction and Development / The World Bank, vol. 1, 2016.

[8] B. Illing and O. Warweg, "Achievable revenues for electric vehicles according to current and future energy market conditions," 2016 13th International Conference on the European Energy Market (EEM), Porto, 2016, pp. 1-5.

[9] J. Y. Yong, V. K. Ramachandaramurthy, K. M. Tan, N. Mithulananthan,” A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects,” Renewable and Sustainable Energy Reviews, vol. 49, pp. 365-385, 2015.

[10] C. C. Chan, "The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles," in *Proceedings of the IEEE*, vol. 95, no. 4, pp. 704-718, April 2007.

[11] C. C. Chan, "The Rise & Fall of Electric Vehicles in 1828–1930: Lessons Learned [Scanning Our Past]," in Proceedings of the IEEE, vol. 101, no. 1, pp. 206-212, Jan. 2013.

[12] J. A. P. Lopes, F. J. Soares and P. M. R. Almeida, "Integration of Electric Vehicles in the Electric Power System," in Proceedings of the IEEE, vol. 99, no. 1, pp. 168-183, Jan. 2011.

[13] H. Xing, M. Fu, Z. Lin Y. Mou, “Decentralized optimal scheduling for charging and discharging of plug-in electric vehicles in smart grids,” IEEE Transactions on Power Systems, vol. 31, no. 5, pp. 4118-4127, Sept. 2016

[14] D. Tran A. M. Khambadkone, “Energy management for lifetime extension of energy storage system in micro-grid applications,” in IEEE Transactions on Smart Grid, vol. 4, no. 3, pp. 1289-1296, Sept. 2013.

[15] R. Bayindir, I. Colak, G. Fulli, K. Demirtas, “Smart grid technologies and applications,” Renewable and Sustainable Energy Reviews, vol. 66, pp. 499-516, 2016.

[16] L. M. Camarinha-Matos, “Collaborative smart grids – A survey on trends,” Renewable and Sustainable Energy Reviews, vol 65, pp. 283-294, 2016.

[17] S. Majeed Malik, X. Ai, Y. Sun, C. Zhengqi, Z. Shupeng, “Voltage and frequency control strategies of hybrid AC/DC microgrid: a review,” IET Generation, Transmission & Distribution, 13 October 2016, DOI: 10.1049/iet-gtd.2016.0791.

[18] L. Mariam, M. Basu, M. F. Conlon, “Microgrid: Architecture, policy and future trends,” Renewable and Sustainable Energy Reviews, vol. 64, pp. 477-489, 2016.

[19] W. Bai, M. R. Abedi, K. Y. Lee, “Distributed generation system control strategies with PV and fuel cell in microgrid operation, Control Engineering Practice, vol. 53, pp.184–193, 2016

[20] P. Y. Kong and G. K. Karagiannidis, “Charging Schemes for plug-in hybrid electric vehicles in smart grid: A survey,” in IEEE Access, vol. 4, pp. 6846-6875, 2016.

[21] H. Shin, R. Baldick, “Plug-in electric vehicle to home (V2H) operation under a grid outage,” IEEE Transactions on Smart Grid, vol.1, no. 99, pp.1-9, 2016.

[22] S. FuiTie, C. WeiTan, A review of energy sources and energy management system in electric vehicles," Renewable and sustainable energy reviews, vol. 20, pp. 82-102, 2013.

[23] A. Kavousi-Fard, A. Abunasri, A. Zare, R. Hoseinzadeh, “Impact of plug-in hybrid electric vehicles charging demand on the optimal energy management of renewable micro-grids. Energy, vol.78, pp. 904-915, 2014.

[24] K. Fleurbaey, N. Omar, M. El Baghdadi, J.M. Timmermans, J. V. Mierlo, “Analysis of hybrid rechargeable energy storage systems in series plug-in hybrid electric vehicles based on simulations, Energy and Power Engineering, vol. 6, pp. 195-21, 2016.

[25] D. Tenfen, E. C. Finardi, B. Delinchant, F. Wurtz, “Lithium-ion battery modelling for the energy management problem of microgrids,” IET Generation, Transmission & Distribution, vol. 10, no. 3, pp. 576 – 584, 2016.

[26] D. Tenfen, E. C, Finardi, “A mixed integer linear programming model for the energy management problem of microgrids’, Electr. Power Syst. Res, vol. 122, pp. 19–28, 2015.

[27] L. Yu, T. Jiang, Y. Zou, “Distributed online energy management for data centers and electric vehicles in smart grid,” IEEE Internet of Things Journal, vol. 99, pp.1-12, 2016.

[28] M. Shahidehpour, C. Shao, X. Wang, X. Wang, B. Wang, “Partial decomposition for distributed electric vehicle charging control considering electric power grid congestion,” IEEE Transactions on Smart Grid , no.99, pp.1-12. 2016

[29] S. F. Tie and C. W. Tan, “A review of power and energy management strategies in electric vehicles” in 4th International Conference on Intelligent and Advanced Systems (ICIAS2012), 2012.

[30] B. Ganji A. Z. Kouzani, “A study on look-ahead control and energy management strategies in hybrid electric vehicles," Conference on Control and Automation (ICCA), 2010 8th IEEE International, 2010, pp. 388-392.

[31] P. Plötz, T. Gnann, M. Wietschel," Modelling market diffusion of electric vehicles with real world driving data — Part I: Model structure and validation," Ecological Economics, vol. 107, pp. 411-421, 2014.

[32] D. Hall, M. Moultak, N. Lutsey, " Electric vehicle capitals of the world: Demonstrating the path to electric drive," International Council on Clean Transportation, wihite paper, 2017.

[33] F. H. Gandoman, A. M. Sharaf, “A flexible facts based scheme for smart grid-PV-battery storage systems," International Journal of Distributed Energy Resources, vol. 10, no. 4, pp. 261-271, 2014.

[34] A. M. Sharaf , F. H. Gandoman, " A robust FACTS PV-smart grid interface scheme for efficient energy utilisation," International Journal of Power and Energy Conversion, vol. 6, no 4, pp. 344-358, 2015.

[35] A. M. Sharaf, M. E. Şahin, "A Flexible PV-powered battery-charging scheme for electric vehicles," IETE Technical Review, vol. 34, no.2, pp. 133-143, 2017

[36] O. Emre; A. Ismail, O. H. Ibrahim, A. M. Sharaf,"A fuzzy logic sliding mode controlled electronic differential for a direct wheel drive EV," International Journal of Electronics, vol. 102, no. 11, pp.1919-1942, 2015.