A Review Of Electric Vehicles And Their Impacts On Grid

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Abstract: Nowadays with the population growth, utilization of public transport and individual vehicles in transportation network is increasing rapidly. Concordantly the usage of fossil fuel rates is going up. Fossil fuels are not only used in transportation sector in the same breath they are intensely used in energy production, buildings and industry sector. Effectively use of these resources cause harmful gases. Besides, adopted sustainable energy policy is obstructed by the reason of these resources' exhaustible nature. More recently electric vehicles (EVs) come into prominence in order to preclude such concerns of conventional internal combustion engines (ICEs). In order for environmentally friendly EVs to be able to replace vehicles which has ICE, researches are focused on maximizing the range of batteries, optimizing the charging times and minimizing the negative effects on system. In this present study the relationship between EVs and smart grids, battery types and charging stations are examined.

Keywords: Electric Vehicles, Batteries, Charging Stations, Smart Grids

1. Introduction

In conjunction with the rapidly increasing population and developing technology in the world, the usage of individual vehicles and public transportation vehicles has been increased in order to provide the mobility. Being founded on the vehicle usage data in Europe, in 2015 there are 287 million registered vehicles, including its 251 million is individual vehicles [1]. Mentioned in Europe the amount of CO_2 emitted to environment by vehicles is 1210 million tons/year, which corresponds to %27 of the total CO_2 emission [1, 2]. Considering this data, carbon emissions in transportation sector must be dwelled on due to the large share. Worldwide common thought as a solution to this issue has been in the form of EV. The thought of EVs is quite ancient. However the interest in EVs has not reached a sufficient level by the reason of vehicles with an ICE are more cost-effective and more usable in those years. With the depletion of fossil fuel reserves and the oil crisis in the world, the concept of EV has come into prominence once again. First the advancement in the cost and energy capacities of battery technologies, which began with the usage of EVs and ICEs together, enable to produce completely electric vehicles. In order for EVs to compete with vehicles, which have an ICE, it is necessary to decrease the battery costs, reach the desired level of full charge range and charge fast. Besides, due to the increasing number of EVs, a significant value of power will be drawn from the network during charging. Thereby this causes some adverse effects on the network. In this present study, hybrid vehicles, EVs and batteries, charging stations and interactions with smart grids were investigated respectively.

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2. Hybrid Vehicles

Hybrid vehicles have been created by combining the strengths of both ICEs and electric motors. These types of vehicles are designed for more power, fuel economy and various targets like this. Hybrid vehicles are split in half; respectively, hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs). Generally, electric motors provide power to ICEs during acceleration and hill climbing. This enables more efficient and smaller volume engine. In comparison with ICEs, electric motors are more efficient at low speed. Thus electric motors operate vehicle single-handed [3]. In general, hybrid vehicles use serial and parallel power train configurations. Series design of power train, both use in HEVs and PHEVs, energy that runs the vehicle is derived from electric motor, which is supplied by ICE. In parallel design of power train configuration, energy comes to wheels simultaneously from ICE and electric motor. Another power train design is a combination of series-parallel power train configuration. In addition to parallel design, in series-parallel design ICE transfers power to batteries as in series design. With this way, hybrid electric vehicles can be produced in various configurations. In comparison with conventional vehicles, series hybrid vehicles are %25 and parallel vehicles are %40 thought to be more efficient [4]. HEVs, which were firstly used, have complementary structures, an ICE powered by fossil fuels and an EM powered by battery pack. ICE and EM operate simultaneously to transfer the power to wheels and thus wheels are ensured to turn. Owing to the non-rechargeable features of HEV, they obtain required energy from fossil fuels and regenerative braking. In the course of braking and idling of vehicle, regenerative braking technology enables to recuperate energy losses. Regenerative braking uses the forward motion of wheels to turn the engine. Thus electricity is generated and vehicle is decelerated. In comparison with conventional vehicles, hybrid vehicles have less CO2 and fuel consumption [3]. Another hybrid vehicle, PHEV, have both an EM and ICE. However the most important feature that distinguishes this type from HEV is, via a plug it enables to charge batteries from the network. At the same time ICE can take EVs place and drive it, when the charge level of battery is too low. It's easy and simple mechanical structure and low emissions make PHEV superior. In contrast with HEV, PHEV has low operating costs, but the price of batteries are still high [5].

3. Battery Electric Vehicles (BEVs)

The principle of BEVs is based on the conversion of chemical energy, which stored in rechargeable batteries, into electric energy. The biggest difference between ICE vehicles and BEVs is; the required energy for ICE vehicles is obtained by burning from fossil fuels, on the other hand the required energy for BEVs is supplied from the energy which is stored in batteries [6]. Instead of gasoline/diesel motor and fuel tank, BEVs consist of electric motor, battery packs and control systems.

2.1. Electric Motors

Electric motors are one of the most important parts in the structure of EV. Selecting convenient motor for the designed target is critical and there are various types of motors that has already used. Nowadays, AC and DC motor types are used in EV. From these engines; asynchronous induction motors, switched reluctance motors and permanent magnet brushless DC motors are more common ones. Asynchronous induction motors have high usage levels in electric vehicles, as in industrial applications. High durability, relatively low costs and good dynamic performances enable these types of motors to play an active role in EV industry. Permanent magnet brushless DC motors are used as an alternative system due to their high efficiency, compact structures and power densities. But it consists of the elements, which are found rare in the environment, and its low-high speed performances are the negative aspects of system. Generally when comparing AC and DC motor, DC motor applications are easier and less costly. With a DC motor, BEV enables overdrive feature to provide more energy input to the motor at short notice, naturally it produces more horsepower. However, if motor runs in overdrive mode too long, it overheats and causes malfunction [6].

Three-phase AC motors, which are used in AC motor applications, allow regenerative braking. Briefly, during braking, motor runs as a generator to transfer energy back to batteries. Approximately %15 of the energy that used during acceleration can be recovered by regenerative braking. Although this value is not sufficient to fully fill the batteries, BEVs extend their driving range [6].

2.2. Battery Packs

The most critical component for BEVs to replace conventional vehicles is battery packs. Generally a battery consists of a positive electrode (with a higher potential), a negative electrode (with a lower potential) and an electrolyte. During charging, positive electrode, which is anode, reacts to reduction and negative electrode, which is cathode, reacts to oxidation. During discharging the reaction is reversed. In a closed cell, electrolyte is held as a separator to prevent the direct connection between two electrodes [7]. Vehicle range, which depends on the type of battery used and battery capacity, is really important in order to compete with ICE vehicles. According to the production purpose of vehicles, the battery types to be selected vary. For instance, 6V battery, which supplies a vehicle with a 96-120V voltage system, provides high range, but low performance. 12V battery that feed the same system, provide better performance, but a lower range [8]. For this reason, studies on batteries, which are the main components of EV, concentrate on energy and power densities, cycling time, voltage value, life time and costs. At the present time; lead acid, nickel metal hydrate, sodium sulphide, lithium ion, lithium metal sulphate, lithium polymer, zinc air and zinc bromide batteries are prominent batteries that constitute the largest share of the cost of EV. In Table 1 the characteristics of battery types are given in a comparative manner.

TABLE 1. *Characteristic of Battery Types for EVs [20, 30]*

	Lead Acid	NiMH	Li-ion	Li-ion Polymer	Lithium Iron Phosphate	Zn-Air	Li-Air
Specific Energy (Wh/kg)	30-50	60-120	100-250	130-225	80-108	460	1300-2000
Specific Power (W/kg)	75-300	250-1000	250-2000	300-2000	2000-4500	80-140	-
Cycling Time	200-1500	300-1200	750-2000	1000-2000	2000	200	100
Voltage (V)	1,2	1,2	3,6	3,7	3,2	1,65	2,9
Temperature	-20 - 50	-20 - 60	-20 - 60	-20 - 60	-45 - 70	-10 - 55	-10 - 70
Daily Self-Discharge (%)	0.1-0.3	1	0.1-0.3	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.2
Maintenance Requirement	3 - 6 months	60 – 90days	-	-	-	-	-
Over Charge Resistance	High	Low	Low	Low	Low	Low	Low
Fast Charging Time (Hour)	8 - 16	2 - 4	<2	<2	<2	-	-

From the past to today's the battery types that is used during the development of EV, were started with lead-acid batteries and then proceed to nickel metal hydride and finally to lithium ion. With development of battery technologies, it reveals to use batteries with higher energy intensities to overcome the biggest problem of EV, which names range. In recent years, the volume and mass energy densities of lithium ion batteries are higher in comparison with other type of batteries. Due to this reason usage of EV increase. Lithium iron phosphate, which is produced by studies on lithium based batteries, has higher power density and higher cycle times. However its lower energy density is the biggest matter in the development. Otherwise, lithium based batteries are at risk of combustion and explosion. Therefore, even if they have not been able to dominate the market yet, it is known that they have a great potential for the future. Researches have shown that metal air's energy density is 1700 Wh/kg [28], which is highly-likely to compete with lithium based batteries for the future.

2.3. Control Systems

Control systems have a great importance for BEVs' design to have high efficiency and good dynamic performance. Many units are used in BEV systems for various tasks. Advanced digital control techniques such as optimal control and fuzzy control contribute the overall performance of BEV. Speed control circuits are used for effective and smooth operation of EV. (For example, PWM is used for DC motor control).DC-DC converters and DC-AC converters take part in system in order to obtain desired voltage levels in battery and electric motor circuits. For safety, a circuit breaker allows the driver to manually isolate power train from battery packs in an emergency, even when the ignition key fails or vehicle is running. In addition to that, a circuit breaker is switched on automatically in the event of a malfunction, which causes a high current fluctuation, and can be easily switched off when the malfunction is fixed.

4. Battery Charging Methods

EV charging stations have several charging methods for energy transfer operation.

4.1. Constant Voltage

In constant voltage method, which is a simple and convenient charging method for each battery, the battery is charged at a constant voltage. During charging process, current value in battery is consistently variable. At initial level charging current can be at its maximum value, but gradually decreases to zero when battery is charged [9]. Initially high power requirement that is not convenient for buildings and parking areas, is the biggest obstacle against this method.

4.2. Constant Current

Unlike constant voltage method, battery has a constant current value, but this time voltage of the battery varies. Charge of the battery increase linearly with time. The difficulty with this system is exactly how to determine if battery is full. This process can be determined by voltage rise, charging time, minus voltage change, temperature gradient rise and temperature rise combination [9].

4.3. Combination of Constant Current and Constant Voltage

Until the voltage of the battery reaches a certain threshold point, battery can be charged with various values of currents that are determined by state of charge. When voltage reaches specified value, the process is changed to constant current mode. With this way, voltage of the battery is preserved [10]. Lithium ion batteries are the most preferred method for fast charging [29].

4.4. Pulse and Negative Pulse Charging

Batteries are charged by changing pulse width by pulse charging method and state of charge of battery can be controlled. By interleaving 20-30 milliseconds between each pulse, chemical reactions in batteries are stabilized [11]. These gap periods between pulses allow chemical reactions to keep pace with charging process and reduce the gas formations on electrode surface. New pulse charging method increases efficiency and charging speed of battery with various and convenient pulse widths. By using negative pulse charging method, quite short discharge pulses are implemented to prevent gas bubbles and battery polarization which occurs at the gap periods between pulses [11]. It is claimed that negative pulse charging method increases the overall charging process and extends battery life. Pulse and negative pulse charging methods are considered to be a convenient method for exploiting in fast charging stations [11].

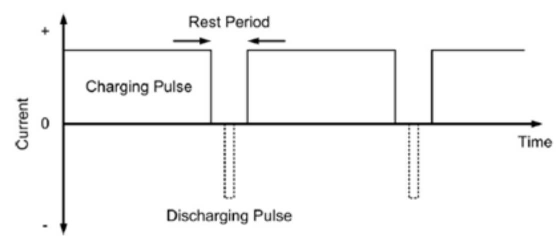

Figure 1. *Pulse and Negative Pulse Charging [14].*

5. Charging Stations

Features such as safety, durability and performance of batteries vary depending on how the batteries are charged or discharged [10]. For charging process some additional equipment are required such as charging cable, charging stand, attachment plug, vehicle connector and protection system. These equipments are significant part of EVs development, grid interaction and daily use [13]. As is known, various frequency and voltage values from country to country bring different structure of charging stations. Correspondingly, leading countries have set specific standards for charging EV under certain rules to avoid battery damage. These standards are; Society of Automotive Engineers (SAE), International Electromechanical Commission (IEC) and CHAdeMO, respectively [12]. Charge levels, voltage, current and power values of SAE and ICE standards are shown in Table 2 and 3, respectively. Charge level used when charging EV, it are directly correlated with charging time, cost, additional equipment requirement and impacts on grid. Off-board charging system enables vehicle to be charged at a higher power, while on-board system enables vehicle to be charged anywhere, where power source is available. Due to costs, weight and space issues, on-board charging system allows for lower power charging [13].

TABLE 2. *SAE Charging Configurations [14]*

	Charging Level	Current Rating (A)	Voltage Rating (V)	Power Rating (kW)
AC	Level 1	12	120	1,4
		16	120	1,9
	Level 2	< 80	240	up to 19,2
	Level 3	-	-	> 20 kW
DC	Level 1	80	200-450	up to 36 kW
	Level 2	200	200-450	up to 90 kW
	Level 3	400	200-600	up to 240 kW

TABLE 3. *IEC 61851*

	Charging Modes	Phase Number	Voltage Rating (V)	Current Rating (A)
AC	Mode 1	1	< 250	< 16
		3	< 480	
	Mode 2	1	< 250	< 32
		3	< 480	
	Mode 3	1	< 250	< 250
		3	< 480	
DC	Mode 4	-	< 1000	< 400

Charging level 1, which has a lower current, voltage and power rating, is often called slow charging. It is more convenient to charge EV at night due to long charging time and EVs usage during the day. With this way, power train from grid to EV takes place at night, which minimizes impacts on grid. The increasing voltage and current values make critical degradation in EV charging times. For instance; 30 kWh BEV is charged approximately in 7 hours with a 3,3 kW charger from %20 state of charge to fully charged. It takes 3,5 hours with a 7 kW charger and 1,2 hours with a 20 kW charger [14]. It is claimed that short charging time can increase the interest on EV usage. Charging vehicle at DC level occurs via off-board charger. Normally, additional equipment is required to convert AC power to DC. It is necessary to use more complicated system to charge vehicle at DC level. This method requires high voltage and current values. Thus investment cost increases while the charging time is seriously lower than other methods.According to IEC standards charging modes are determined in Table 3. There are three AC modes and one DC mode. 100 kWh BEV with AC mode 1 charging, reaches a fully state of charge approximately 16 hours in three phase charging state. Mode 2 and 3 three phase charging methods can charge the battery in 8 hours and 1 hour, respectively. In DC mode 4 charging time is really short and it takes nearly 20 minutes to charge the battery fully. In addition to these charging modes, 800V 350 kW charging technology, that is still on investigation, is being marketed by Porsche in the future [15, 16]. Also there is another way to full the battery and run the wheels. By replacing the used battery with another one, the required energy can be provided to drive vehicle. Zero emission BEVs make them clean and environmentally friendly. However, as it is known, source of electric energy production for EVs will become even more significant in days to come. For instance, if the station, where EV is charged, is supplied from coal or diesel power plants, EV oscillates indirectly. However, if generated energy is supplied from renewable energy sources such as wind energy or solar energy, electric production will be both more environmentally friendly and cheaper. With this way emission oscillation may actually be zero. During driving mode, vehicles can be also charged by road fitted wireless charging. For this technology, which is developed by Qualcomm, experts are still work on a prototype road in France, Versailles. This technology provides energy up to 20 kW when vehicle is moving. It is thought that the development and widespread usage of this system can prevent charging problem which is the biggest obstacle against EV [17].

6. Impacts of EVs on Grid

Increased use of EV due to precautions taken to reduce CO_2 emissions, it causes negatory impacts such as; economic, environmental and grid. Due to initial investments and the requirement to generate more electricity costs are increased. Even if EVs are not release CO_2 the energy sources that charging stations use, get more important. If the production of generated energy from coal or fossil fuel sources, EV also release CO_2 emissions indirectly way. As a result of connecting a large number of EVs to the grid, effect such as harmonic distortion, system losses, voltage drop, phase imbalance, equipment overload and stability problems may occur (18,19]. When EV users charge their vehicles at an undetermined time and place, increase in peak loads is observed. To remove this load enhance, a controlled charging system must be applied as well as EV should be charged during night times or off-peak hours [20]. In Germany an uncontrolled connection of one million vehicles to the grid in 2030 is resulted in 1,5% increase in peak loads. When the same number of vehicles is connected to the grid with a controlled way, 16% decrease in maximum peak load is observed. With this study, when 42 million conventional vehicles replace to EV, peak loads are expected to become double [26]. To achieve controlled charging process and the correlation between production- consumption more efficient, smart grids are required. Smart grids are modernized electrical power systems that utilize computer-aided control and automation systems to enhance efficiency, continuity and reliability of power supply [27]. These systems are constitutively; smart meters, smart devices and energy measures, respectively [21]. Electronic power conditioning and control of electricity generation and distribution are the prominent features of smart grids [21, 22].

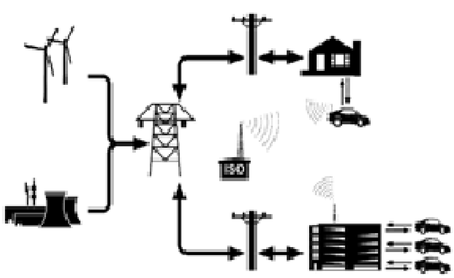

Figure 2. *Connection Diagram of EVs and Electric Power Grid [25].*

There are various operation status of correlation between grid and EV.

1. V0G

In this mode of operation, where there is no connection with any controller, charging is performed directly when vehicle is plugged in. By this reason, there is always a risk for grid.

2. V1G

This operating mode the real-time communication between grid and vehicle, allow vehicle to be charged between the set time limits. Apart from this, it suggests advantage to vehicle user for fuel cost decrease by charging during off-peak hours [23].

3. V2G

In addition to V1G mode, the stored energy in EV battery can be supplied back to grid when grid requires it. Thus, balancing of energy production and consumption, stabilization of intermittent energy obtained from renewable energy sources and integration into grid are possible [24]. In order for these processes to take place, two basic elements must be found in each vehicle: a connection element that provides bi-directional energy flow and a logic connection element on both sides (vehicle-grid) for communication and control [25]. Though V2G it is significant to know how much power a vehicle can provide to grid. Three independent factors limit the power of V2G. These are; (1) current carrying capacity of cables and other circuitry elements that connect vehicle to the grid, (2) time portion of stored energy in vehicle, and (3) maximum nominal power of power electronics on vehicle. The lacks of these factors bring V2G structure closer to its maximum power capacity [25].

4. V2B

Unlike V2G mode, vehicle is in communication with building instead of grid. The stored energy in EV's battery acts as a generator and it is transferred to the building by using necessary connecting elements during demand periods and the vehicle is used as auxiliary energy.

TABLE 4. *Correlation between Smart Grid and Evs*

Features	V0G	Timed Charge	V1G	V2G	V2B
Real Time Communication	×	×	✓	✓	×
Cheaper Fuel	✓	✓	✓	✓	✓
Timed Charging	×	✓	✓	✓	✓
Off-Peak Load	×	×	✓	✓	✓
Load Shifting	×	×	×	×	✓
Bi-directional	×	×	×	✓	×
Uni-Directional	×	×	✓	✓	×
Back-Up Power	×	×	×	✓	✓
Controllable Load	×	×	✓	✓	✓

7. Conclusion

In order to solve problems such as increasing CO_2 emissions (27% of general emission), reduction of fossil fuel resources and therefore increased oil prices, conventional vehicles replace with HEVs, PHEVs and BEVs. In comparison with conventional vehicles, HEVs have lower emissions. However HEVs still emit toxic gases to the environment substantially. For this reason, BEVs have become more prominent due to its zero emission characteristic. In this study, we have investigated battery selection with respect to characteristic features, ideal charging methods and smart grid systems that respond to problems on grid. According to this study, use of high density batteries such as metal-air, fast charging methods and smart grids that provide bidirectional real time communication, will be the most significant parts of EVs deployment.

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