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Research Article

Review on Electric Vehicle, Battery Charger, Charging Station and Standards

[1]Afida Ayob, [1]Wan Mohd Faizal Wan Mahmood, [1]Azah Mohamed [2]Mohd Zamri Che Wanik, [2]MohdFadzil Mohd Siam, [3]Saharuddin Sulaiman, [3]Abu Hanifah Azit and [4]Mohamed Azrin Mohamed Ali
[1]Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan, Malaysia
[2]TNB Research Malaysia
[3]TNB Distribution Malaysia
[4]Malaysian Green Technology Corporation, Malaysia

Abstract: Electric vehicles are a new and upcoming technology in the transportation and power sector that have many benefits in terms of economic and environmental. This study presents a comprehensive review and evaluation of various types of electric vehicles and its associated equipment in particular battery charger and charging station. A comparison is made on the commercial and prototype electric vehicles in terms of electric range, battery size, charger power and charging time. The various types of charging stations and standards used for charging electric vehicles have been outlined and the impact of electric vehicle charging on utility distribution system is also discussed.

Keywords: Battery charger, charging station, electric vehicle, standards

INTRODUCTION

In light of high energy usage, environmental pollution and rising fossil fuel prices, current dependent on Internal Combustion Engine (ICE) technology must be reduced and alternative fuel which has the potential to solve environmental pollution; global warming and energy sustainability concerns must be explored. It is suggested that electricity is the most suitable energy carrier for transportation in the next 30 years when considering risk, emissions, availability, maintainability, efficiency and reliability (Chan and Chau, 2001). The invention of automobiles with ICE began in the late 19th century and the automotive industry ever since has seen only incremental changes. ICE remains the prime mover for automobiles with fossil fuel as the main fuel. The paradigm shift towards electrification drives the development of new types of propulsion systems based on electric. Figure 1 shows the paradigm shift from ICE vehicle to advanced electric-drive vehicles (Emadi, 2011). Transportation 1.0 and Car 1.0 refer to a stage or time in which transportation and cars employ fossil fuels as the main fuels, while Transportation 2.0 and Car 2.0 refer to paradigm-shifted stage in which increasing electrification in vehicles is foreseen.

Electric drive vehicles are very attractive due to low road emissions, can potentially strengthen the power system by providing ancillary services; have a lower operating cost compared to fossil fuels and are more energy efficient. Advanced electric drive vehicles can be categorized into Hybrid Electric Vehicles (HEVs), plug-in Hybrid Electric Vehicles (PHEVs) and all-electric vehicles (EVs). HEVs can be generally classified as series, parallel and series-parallel (combined hybrid) (Maggetto and Van Mierlo, 2000) as shown in Fig. 2 to 4 respectively. In a series HEV, traction power is delivered by the electric motor while the ICE drives an electric generator that produces power for charging the batteries and driving the electric motor as shown in Fig. 2 and 3 shows a parallel HEV in which the engine and electric motor are coupled to drive the vehicle which allows simultaneous operation of ICE and motor high speeds. Figure 4 shows a series-parallel configuration in which two electric machines are used to provide both parallel and series paths for the power. This means that ICE can be used to drive the vehicle together with the motor, or used for generating electricity to be stored in the battery, depending on the operating conditions and setup. HEVs can be further divided into micro hybrids, mild hybrids, power hybrids and energy hybrids depending on the hybridization factor. Hybridization factor is defined as the ratio of the peak of vehicle electrical power to that of total electrical and mechanical power (Zeraoulia *et al*., 2006). Micro hybrids have a hybridization factor of 5-10%; mild hybrids, 10-25% and power hybrids have much higher factor. An energy hybrid has an energy

Corresponding Author: Azah Mohamed, Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan, Malaysia
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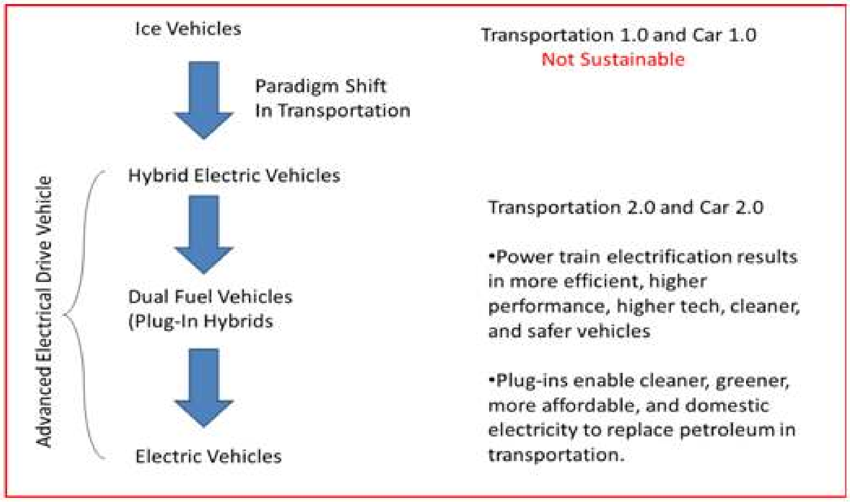

Fig.1: The paradigm shift in transportation from ICE vehicles to advanced electric-drive vehicles

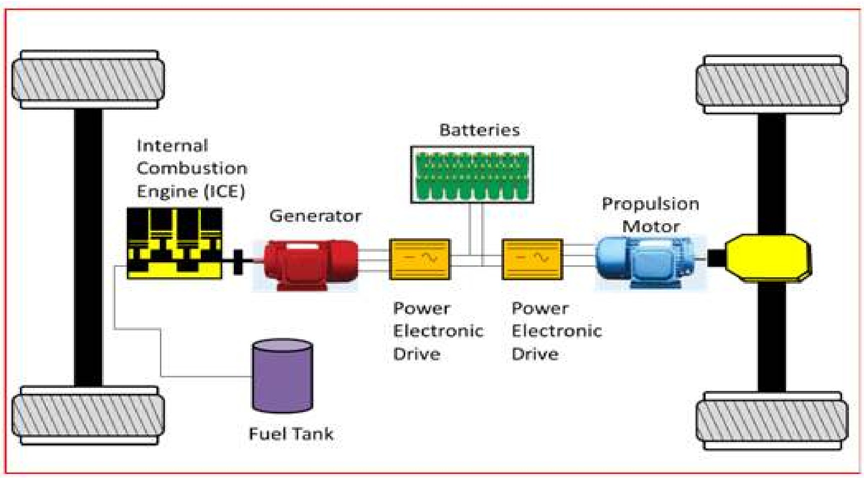

Fig. 2: A hybrid electric vehicle with a series hybrid power train

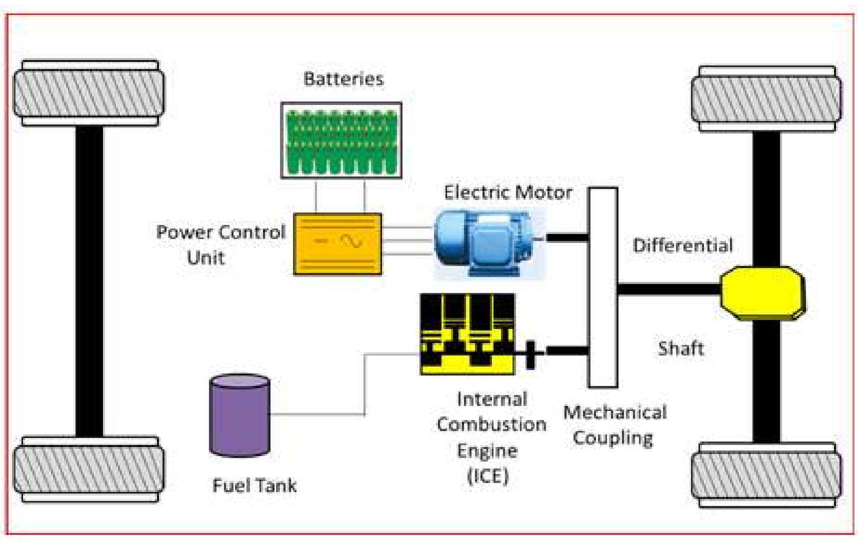

Fig. 3: A hybrid electric vehicle with a parallel hybrid power train

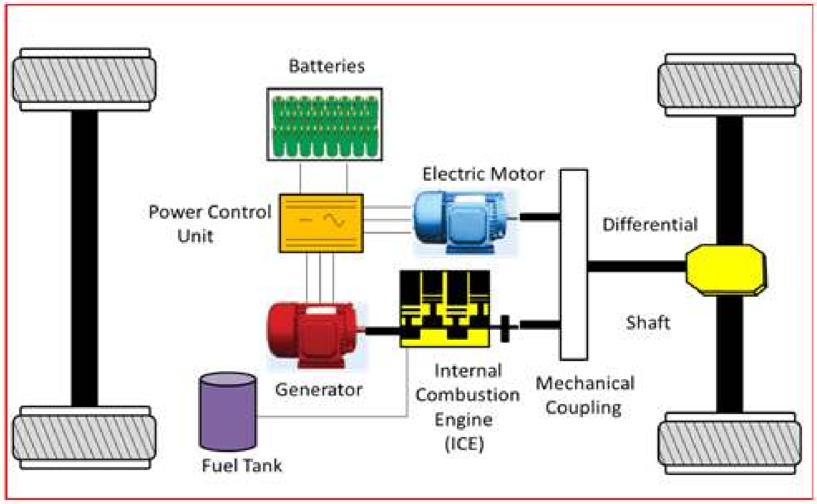

Fig. 4: A hybrid electric vehicle with a series-parallel hybrid power train

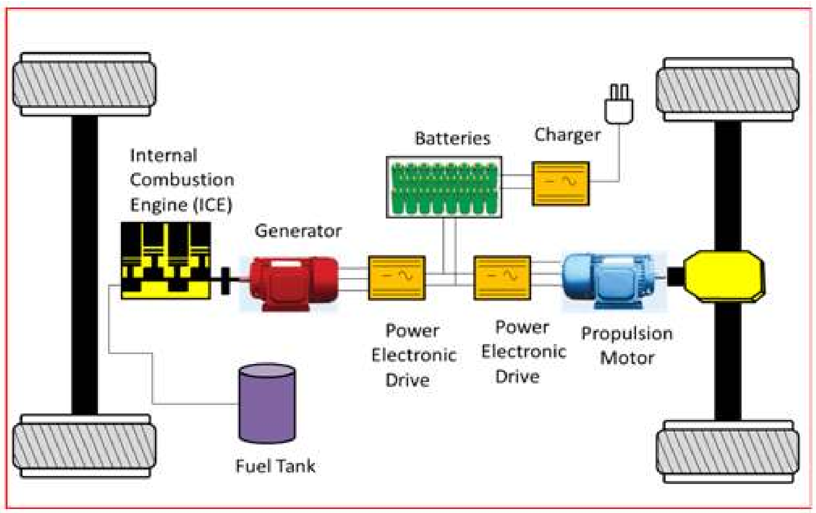

Fig. 5: A plug-in hybrid electric vehicle with a series hybrid power train

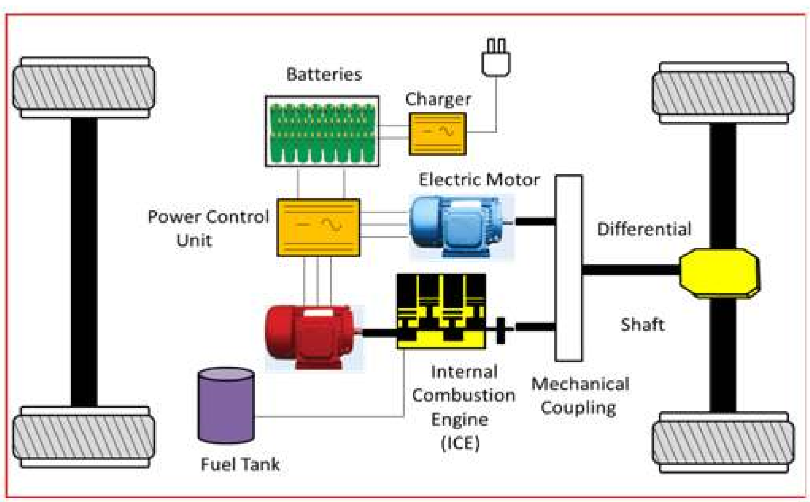

Fig.6: A plug-in hybrid electric vehicle with a series-parallel hybrid power train

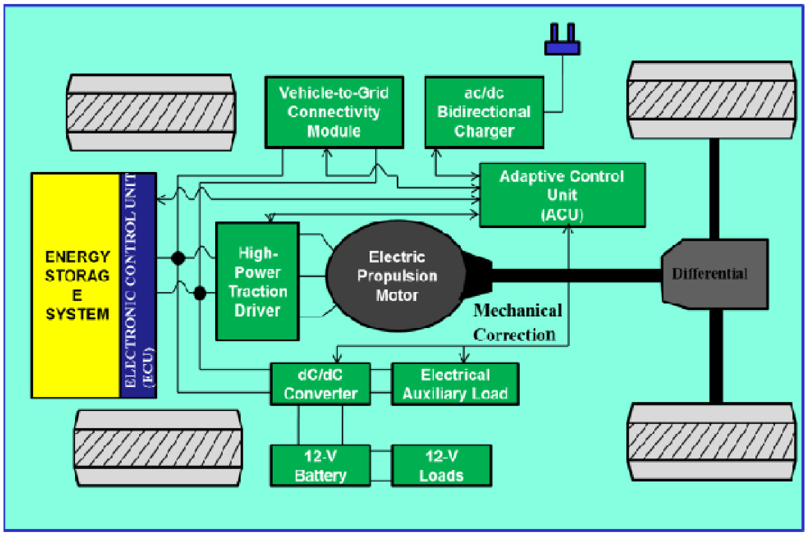

Fig.7: An all-electric power train with adaptive control unit

Table 1: Overview of technical data for commercial/ prototype electric vehicle

	Tesla Roadster (Berdichevsky *et al.*, 2006)	Nissan Leaf (Nissan, 2012)	GM Chevy Volt (Chevrolet 2012)	Toyota Plug-in Prius (Prius 2012)	Mitsubishi i-MiEV(Mitsubishi 2012)	Exora REEV (Che Din 2011)
Type	Battery	Battery	Plug-in hybrid	Plug-in hybrid	Battery	Plug-in hybrid
Electric range (Km)	394	161	56	24	160	97
Battery size (kWh)	53	24	16	4.4	16	13.5
Onboard charger (kW)	9.6	3.3	1.44	1.44	2.3	3.8
Quick charger (kW)	16.8	60	3.3	3.3	50	20
Charging time	Onboard: 6 h Quick: 3.5 h	Onboard: 6 h Quick: 0.5 h	Onboard 10 h Quick: 4 h	Onboard: 3 h Quick: 1.5 h	Onboard: 8 h Quick: 0.5 h	Onboard: 4 h Quick: 0.5 h

		Saga EV (Che Din 2011)	Mercedes-Benz Blue ZERO E-Cell plus (Mercedes 2012)	BMW i3(Autocar 2012)	Honda Fit/Jazz-EV (Honda 2012)	Mazda Demio-EV (Mazda 2012)
Type						
Electric range (Km)		Battery	Plug-in hybrid	Battery	Battery	Battery
Battery size (kWh)		97	100	160	131	200
Onboard charger (kW)		15.9	18	22	20	20
Quick charger (kW)		3.1	3.3	7.7	6.6	3.3
Charging time		20	20	12	40	50
		Onboard:6-8 h Quick: 0.5 h	Onboard: 6 h Quick: 1 h	Onboard: 6 h Quick: 1 h	Onboard: 3 h Quick: 0.5 h	Onboard: 8 h Quick: 0.67 h

storage system larger than power hybrid. Among the hybrid car models are such as the Toyota Prius, Honda Insight, Honda Jazz and Honda CR-Z. Toyota Prius uses a series-parallel configuration while the Honda family is more close to parallel configuration but allowing battery charging through motor regenerative braking.

Plug-in Hybrid Electric Vehicles (PHEVs) is essentially an HEV with the option to recharge its energy storage system with electricity from the grid (Markel and Simpson, 2006). PHEVs have a high-energy-density energy storage system that can be externally charged and they can run solely on electric power longer than regular hybrids, resulting in better fuel economy. Just like HEVs, PHEVs can have series, parallel and series-parallel configurations. Figure 5 and 6 show a PHEV with series and series-parallel configuration, respectively. PHEVs make use of utility power as the batteries are usually charged overnight. The battery can also be charged onboard to increase the vehicle range. All electric vehicles have all-electric propulsion system. Unlike HEVs and PHEVs, EVs do not have an ICE to supply the additional power. A typical EV architecture is shown in Fig. 7. These EVs rely mainly on external charge from the utility power grid and these types of advanced electric-drive vehicles are expected to affect the electricity distribution network.

Power demand of EV is a function of voltage and current and its energy requirement depends on the battery size. The technical information on commercial and prototype EV sin terms of electric range, battery size, charger power and charging time is tabulated and summarized in Table 1. Such information is useful for determining the power demand required by EV. It is estimated that a single EC can increase electricity consumption of a household by 50% (WDI, 2008). Some EVs consumed more than 5 kW powers which is greater than the consumption of a typical residential house and this consumption is continuous up 10 h subject to the state of charge of the EV’s battery. This power consumption is required for EV which is charged using the slow type on board charger. If EV is charged using rapid/fast charger, the power consumption can go as high as 60 kW. Most of the figures in Table 1 refer to the technical specification of the older version and prototype EVs. For the commercial or latest version of EVs, the power consumption can be different. From the literature, it is noted that for fast charging station, there is effort to standardize the chargers so that all cars can share the same charging station. In the future, fast charger can consume 62.5 kW (CHAdeMO, 2012) or 100 kW (SAE J1772-2010 2013).

This study presents the state-of-the-art of electric vehicle technology focusing on the types of electric vehicles, types of battery chargers and charging stations and identifying supply voltage, charging current and different standards that are being used in the US, Europe and Japan.

MATERIALS AND METHODS

Types of EV battery chargers: An EV battery charger is a combination of electronics used for recharging the battery banks in an EV or a plug-in HEV. EV chargers can be installed in houses, offices, shopping stores and public places to enable EV owners to charge their EV or plug-in HEVs. There are two types of charging based on their mode of energy transfer; conductive and inductive. Conductive type EV battery chargers have direct plug-in connection to the supply by using an extension power cord to plug from the wall outlet into the EV. It is popular, simple in design and higher efficiency.

The inductive type EV battery charger uses magnetic coupling as mode of energy transfer. Through inductive chargers, a charging station is used to transfer high voltage and current directly from the grid into an inductive paddle or pad with an electro-magnet that acts as half a transformer. The other half is situated inside the EV and once full contact is made between the two magnets, the current is allowed to flow across and into the battery, charging at a higher rate due to the charging stations direct power grid connection. Figure 8 illustrates the inductive charging concept showing the path of current from the wall socket to the battery. Figure 9 shows an example of charging a Nissan leaf EV via an inductive pad located below the car (Nissan, 2012). Figure 10 shows a closer look below a car with inductive charging pads in which one pad is fixed on the surface of the road and the other fixed under the car chassis.

The main advantage of inductive type EV battery charger is electrical safety under all weather conditions. However, its disadvantages are long charging time and relatively poor efficiency. In April 2011, carmaker BMW and electrical giant Siemens introduced trials with an inductive charging system to the public in London. Located in the bottom of the car and the ground, the system's air wide gap which is between 8 and 15 cm prevents efficiencies of more than 90%. In 2012, Qualcomm Inc started a trial on their wireless charging system called Inductive Power Transfer in London and this study is still ongoing.

Fig. 8: Concept of inductive charging via the two inductive pads

Fig. 9: A Nissan leaf charging via an inductive pad below the car

Fig. 10: A closer look under a car with inductive charging showing both the inductive pads

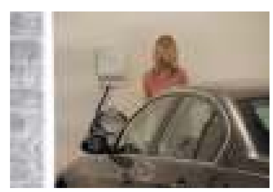

Fig. 11: Example of domestic charging stationer

Fig. 12: Example of off-street and robust charging post

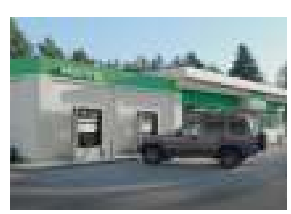

Fig. 13: Example of rapid charging station

Table 2: IEC EV charging modes based on IEC 61851-1

Mode	Supply	Duration	Charger configuration	Example charger
Mode 1	AC	Slow	Standard household-type connector	1- or 3-phase plug
Mode 2	AC	Slow	Standard household-type socket-outlet with an in-cable protection device	the Park and Charge or the PARVE systems
Mode 3	AC	Slow/Fast	Specific EV socket-outlet and plug with control and protection function permanently installed	SAE J1772 and IEC 62196
Mode 4	DC	Fast	External charger	CHAdeMO

Table 3: Levels of EV charging according to SAE

Source	Level	Voltage	Phase	Max current	Max power (kW)	Time (h)
AC	Level 1	120	Single	16	1.9	6 - 24
	Level 2	240	Single	80 (typical 40)	19.2	2 - 8
	Level 3	TBD	TBD	TBD	TBD	TBD
DC	Level 1	200-450	DC	<= 80	<= 19.2	~ 20 min
	Level 2	200-450	DC	200	90	~ 15 min
	Level 3	TBD (may cover 200-600)	DC	TBD (may cover up to 400)	TBD (may cover up to240)	TBD

TBD-to be defined

Table 4: Types of coupler for EV charging

Type	Coupler	Example
Type 1	Single-phase vehicle coupler (vehicle connector and inlet)	Yazaki or SAE J1772-2009 (Japan, North America)
Type 2	Single- and three-phase vehicle coupler and mains plug and socket-outlet without shutters	VDE-AR-E 2623-2-2
Type 3	Single- and three-phase vehicle coupler and mains plug and socket-outlet with shutters	SCAME plug developed by the EV Plug Alliance.

Types of charging stations: EV charging stations when categorised in terms of voltage rating, power rating and place of application, can be classified into three different types of charging stations, namely, domestic charger at residential area, off-street and robust charger at commercial and office area and rapid charger at strategic location. Example pictures of these three chargers are depicted in Fig. 11 to 13.

In this document, the charging stations discussed will be focusing on conductive chargers due to the fact that the inductive charging method is still under development. According to Daimler's Head of Future Mobility, inductive chargers are at least 15 years away and the safety aspects of inductive charging for EVs have yet to be looked into in greater detail. Most rechargeable EVs and equipment can be charged from a domestic wall socket. However, a charging station may be required due to the following reasons:

- Charging can be provided for multiple EV owners at one time,
- The facility may have additional current or connection sensing mechanisms to disconnect power when the EV is not actually charging,
- Readily provide option for suppliers to monitor or charge for the electricity actually consumed.

Society of Automotive Engineers (SAE) and International Electro technical Commission (IEC) both have come up with standards which define EV charging. The term 'level' used by SAE and 'mode' used by IEC essentially means the same thing. According to IEC 61851-1, there are 4 modes for charging EVs as described in Table 2. However, SAE defines 6 levels of EV charging as shown in Table 3. Some information in the table is still to be defined (TBD) by the standard.

From Table 2, essentially 'Level 3' does not exist yet and the charging standard everybody has been thinking of as 'Level 3' is really either 'DC Level 1' or 'DC Level 2'.

Standards for EV charging stations: Different type of standard is being used in different region of the globe for charging of EV. This section is comparing different standard that are being used in USA, Europe and Japan. Standards that have been published are described as follows:

- **IEC 61851(IEC, 2010):** The IEC 61851 standard covers the overall EV conductive charging systems. In this standard, the IEC defines the four modes of EV charging that has been described above. This standard became the basis for IEC 62196. A few important sections in IEC 61851 are:

IEC 61851-1: This standard defines three cables and plug setups which can be used to charge EVs:

Case A: Where the cable is permanently attached to the EV
Case B: Where the cable is not permanently attached to anything
Case C: Where the cable is permanently attached to the charging station.

IEC 61851-23: This standard defines the requirements for DC fast charging stations in terms of electrical safety, harmonics, grid connections and communication architecture. The standard is expected to be published in November 2012.

Fig. 14: IEC 60309 style plugs mounted onto a wall socket

IEC 61851-24: This standard defines digital communication for DC charging control between the charging controller in the EV and the charging controller in the Electric Vehicle Supply Equipment. The standard is expected to be published in September 2013.

- **IEC 62196-Plugs, socket-outlets, vehicle connectors and vehicle inlets (IEC, 2011):** The IEC 62196 is the latest standard for EVs by IEC which is based on the IEC 61851 standard. A few important sections in IEC 62196 are:

IEC 62196-1: This standard is entitled 'Plugs, socket-outlets, vehicle couplers and vehicle inlets'. This standard contains the general requirements for EV connectors

IEC 62196-2: It standardizes three types of mains connecting systems, known as Types 1, 2 and 3 that are applied only to modes 1, 2 and 3. Which of these is appropriate depends largely upon the electrical infrastructure and regulatory conditions in each country. The coupler types for EV charging are outlined as in Table 4.

IEC 62196-3: This standard defines connectors and inlets for fast DC charging to be used with mode 4 charging according to IEC 61851-1. The standard is expected to be published in December 2013.

- **IEC 60309-Plugs, socket-outlets and couplers for industrial purposes (IEC, 2012):** IEC 60309, formerly known as IEC 309 is an international standard from the IEC for 'plugs, socket-outlets and couplers for industrial purposes'. The maximum limits under this standard include; voltage 690V AC or DC, current 125A, frequency 500 Hz and temperature range -25 to 40^{o}C. The two parts of IEC 60309 are:
  - **IEC 60309-1:** General requirements and
  - **IEC 60309-2:** Dimensional requirements. A few details outlined under this standard include i) a range of plugs and sockets of different sizes with differing numbers of pins, depending on the current supplied and the number of phases accommodated, ii) limited weather proofing and iii) color coded connectors depending on the voltage range and frequency e.g., yellow for 100-130 volts at 50-60 Hz. An example of IEC 60309 style plug mounted on to a wall socket is depicted in Fig. 14.
- **IEC 60364-electrical installations for buildings (IEC, 2005):** IEC 60364 'Electrical Installations for Buildings' is the standard on electrical installations of buildings. This is the standard attempting to harmonize national wiring standards in one IEC standard. The latest versions of many European wiring regulations (e.g., BS 7671 in the UK) follow the section structure of IEC 60364 very closely, but contain additional language to cater for historic national practice and to simplify field use and determination of compliance by electrical tradesmen and inspectors. National codes and site guides are meant to attain the common objectives of IEC 60364 and provide rules in a form that allows for guidance of persons installing and inspecting electrical systems. The standard has several parts described as:

Part 1: Fundamental principles, assessment of general characteristics, definitions

Part 4: Protection for safety (including sections on electric shock, thermal effects, over current, voltage disturbances and electromagnetic disturbances)

Part 5: Selection and erection of electrical equipment (including sections on common rules, wiring systems, isolation, switching and control, ear thing and safety services)

Part 6: Verification

Part 7: Requirements for special installations or locations (for range of locations such as bathrooms, swimming pools, rooms/cabins, construction sites, caravans, external lighting, mobile units and others).

- **SAE J1772:** This SAE Recommended Practice covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America (SAE International, 2013). This document defines a common EV/PHEV and supply equipment vehicle conductive charging method including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector.SAE J1772-2009 is the most recent standard in use and maintained by the SAE. The previous standard, SAE J772-2001 was manufactured by Avcon but is being phased out.

Details on SAE J1772-2009 are described as follows:

Fig. 15: SAE J1772-2009 connector

Fig.16: The new SAE J1772-2010 connector

- Based on a connector design from a company called Yazaki.
- Allows for both 120 V and 240 V quick charging with power delivery up to 16.8 kW at 70 amps.
- Companies participating in or supporting the revised 2009 SAE J1772 standard include GM, Chrysler, Ford, Toyota, Honda, Nissan and Tesla.
- Currently being used by Nissan Leaf (has both SAE J1772 and CHAdeMO protocol on board), Chevy Volt and other newer models
- Manufacturers of the charging interface include Coulomb Charge Point.
- The connector is shown in Fig. 15. The connector supports communication over power lines to identify the vehicle and control charging. It is designed to withstand up to 10,000 connection/ disconnection cycles and exposure to all kinds of elements. The connector lifespan given one connection/disconnection daily is estimated to be 27 years. The J1772 2009 standard includes several levels of shock protection, ensuring the safety of charging even in wet conditions.

Connection pins are isolated on the interior of the connector when mated, ensuring no physical access to those pins. When not mated there is no voltage at the pins.

In 2010, SAE developed a DC fast charging with a combined charging system or 'combo connector' for short. Details on SAE J1772-2010 are as follows:

- An adaptation of the existing J1772 connector.
- Charging port has two parts; upper section retains the configuration of the existing standard, meaning that slow-charging EVs already on the market can transition seamlessly to the new connector and lower section contains a second set of pins to accommodate fast-charging battery technology that was not commercially available before 2010.
- All together the combo connector will enable charging up to 500 volts, at 200A enabling a charger with a yield of 100kW.
- Final approval for this new standard is expected by August 2012 and SAE expects the eight US and German car makers to begin production of vehicles equipped with the new J1772 in 2013. Figure 16 shows the combo connector.

CHAdeMO: CHAdeMO is a trade name for global quick charging method that is proposed by the CHAdeMO Association as an industry standard (CHAdeMO, 2012). The CHAdeMO Association was founded by the Tokyo Electric Power Company, Nissan Motors, Mitsubishi Motors, Fuji Heavy Industries (the manufacturer of Subaru vehicles and Toyota Motor Corporation. Other members include automakers, charger makers, supporting businesses, administrative entities and others united towards the core business of developing quick charging infrastructures. CHAdeMO is an abbreviation for "CHArge de MOve" equivalent to "charge for moving" and is a pun for "O cha demo ikaga desuka" in Japanese, meaning "Let's have a tea while charging" in English. Under the CHAdeMO protocol, the charger sometimes also spelled CHΛdeMO is capable of delivering up to 62.5 kW of high voltage direct current. This type of high voltage high-current charging is called DC fast charge and is sometimes referred to as level 3 charging to contrast with less powerful AC charging levels. The approximate charging time is 15 min. Compatible vehicles with the CHAdeMO protocol include the Nissan LEAF, Mitsubishi i-MiEV, Subaru R1e (prototype) and Citroen C-ZERO.

The CHAdeMO connector has been designed for fail-safe operation. The CHAdeMO quick charger design has a controller that receives EV commands via a CAN bus and the quick charger sets the current to meet the EV's command value. Via this mechanism, optimal and fast charging becomes possible in response to battery performance. Currently, CHAdeMO chargers are very popular in Japan and Europe.

RESULTS AND DISCUSSION

Impact of EV charging on utility distribution systems: EV charging is considered as a big load to the utility. The worst case if all EVs are charged at the same time. However, this scenario will be unlikely to happen because of many factors. One of the factors is that the number of charging station is limited. As for the impact of EV battery chargers on the power supply system, it depends on the technology of the chargers. Older version of chargers is based on full-wave rectification using diodes and progressively, thyristors are used. Later designs use microprocessor-controlled charging technologies with several algorithms being implemented for parameter monitoring and control. Today, smart battery chargers are available which can interactively communicate with the utility system in order to receive and send information about the state of charge, energy availability, tariffs and management data in general. Such designs have resulted in reduction of harmonic distortion and power factor improvement. A survey of battery charger manufacturers from 1993 to 1995 shows that the average total harmonic distortion decreases from 50.1 to 6.12% (Gomez and Morcos, 2003).

The general effect of home battery chargers on distribution systems will be load increase and large increment of system voltage distortion. Another issue that should be considered is the coincidence between the charging start time and the eventual evening load peak period, which varies with customer and country (Autocar, 2012). However, the net effect of a population of EV chargers is not merely the numerical sum of the THDs, which involves both the magnitude and phase angles of individual harmonic components (Lambert, 2000). For higher harmonic orders, harmonic cancellation effect can take place.

Another issue of EV charging that has been investigated is on the lifetime of transformers. For calculation of transformer life reduction or the derating factor, parameters that are required are the winding eddy-current loss, harmonic current magnitudes and harmonic order values (IEEE, 1998). However, THD values do not give enough information for transformer temperature and life span calculations, as the harmonic order is very important for thermal effect evaluation. Two harmonics of the same magnitude, but having different order, can have dissimilar thermal effects. Therefore, as a conclusion, EV charging should be looked at not only in harmonics and voltage overload issues, but also its effects on distribution equipments such as transformers, cables, circuit breakers and fuses.

The degree of impact on power system depends on how much the EV penetrates the market. This penetration will depends on the battery cost, gasoline prices, charging infrastructure, competition from other vehicles and government policy. When referring to impact of EV to power grid, the regional or local penetration is of importance to utilities. Some parts of the region will be more severely impacted by the presence of EVs than others. Even within the same region, only certain part will need significant focus. The distribution of these EV will depend on promotional policies, incentives and the deployment of charging infrastructures.

CONCLUSION

Electric vehicles are expected to enter the world market such that by 2030, 10% of the vehicles will be of EV type. To have a better understanding on EV technology, this study outlines the various types of EV, battery chargers and charging stations. A comprehensive review has also been made on the standards currently adopted for charging EV worldwide. For better understanding on the state of the art EV technology, a comparison is made on the commercial and prototype electric vehicles in terms of electric range, battery size, charger power and charging time.

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