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Towards Smart Grids: International Standards, Impacts, Prospects and Challenges of Electric Vehicle Technology

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ABSTRACT

Imminent environmental challenges associated with internal combustion engine vehicles globally has driven the need for technologies that meet cleaner and sustainable energy in the power generation systems for transportation development. While the adoption of road electrification for the transportation systems will minimize issues on climate change, it will also pose a threat to existing grids due to added load of electric vehicles in power systems distribution network. This paper examines the deployment and challenging issues in the implementation of electric vehicles infrastructure, equipment service and charging systems in conjunction with different international standards and charging codes. It also identifies the yet to be replaced components of the conventional automotive technology with the advent the of electric vehicle technology. The charging systems for electric vehicles through battery charging techniques, electric vehicles impacts, harmful impact remedies and benefits are equally highlighted. It identifies its prospect with respect to developing countries. It is expected that the researchers interested in automotive applications will find this paper valuable and as an informative source.

Keywords: Electric Vehicles, Automobile technology, Climate change, Distribution network.

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1. INTRODUCTION

In modern times, studies to address pollution caused by combustion engines apart from the depletion of fossil fuel reserves has led to the introduction, coordination and implementation of electric vehicles (EVs). In other words, the environmental challenges of burning fossil fuels in the transportation sectors is being gradually addressed with clean solutions (Darabi & Fedowsi, 2011; Rezaee et al., 2013). This technological advancement involves electrification of transportation domain to address environmental issues. The study of power transfer started with tesla' study (Tesla, 1905) and today power is typically transferred via an electromagnetic field (EMF). This includes wireless charging electric vehicles (EVs), cell phones, robots, implanted medical devices and other home electronic appliances. Electric powertrains are advanced and fast emerging technologies for propulsion of vehicles with potential to reduce greenhouse and other exhaust gas emissions from road transport (Sadek, 2012; Nemry & Brons, 2010). Electric vehicle technology (EVTs) have gone through a remarkable development in recent decades. The continuous development in Electric vehicles (EVs) technology is such that it can compete with existing internal combustion engine vehicles (ICEVs). As a result of series of technological advances, EVs is taking over a considerable share of automotive market throughout the world.

This huge market share has been influenced by many governments incentive offers to overcome greenhouse gas (GHG) emission. An instance is in Norway where there are certain tax exemptions in addition to free parking for EVs in several areas, which has therefore led to a 37% market share of EVs tip points in Norway (Lambert, 2017). There is a high possibility for large scale penetration of EVs in nearest future with continuous research and development leading to the EVs market expansion (Sarlioglu et al., 2017). The available EVs in the market today includes the battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and plug-in electric vehicles (PEVs). The class of EVs that requires the least technical operability are the battery electric vehicles (BEVs) since they rely entirely on battery power.

2. ELECTRIC POWER TRAIN

Power train is a series of system which provides drive from an engine to an automotive axle. The BEVs operate exclusively on three major constituents (Power train), on battery, electric motor and transmission. This is shown in the figure below:

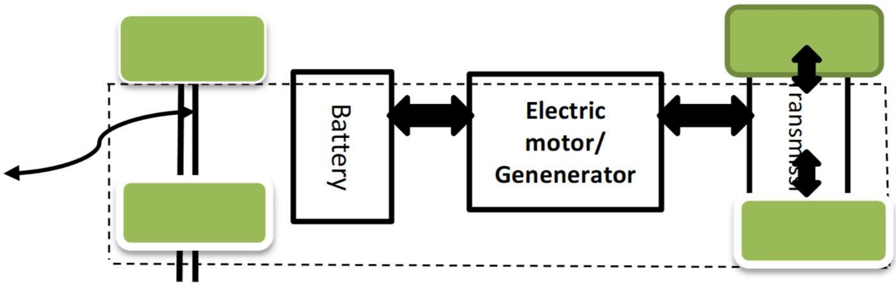

Figure I: Schematic of BEV’s Power Charging Infrastructure

Generally, there are debates that electric powertrains have better energy efficiency for propelling vehicles than conventional internal combustion engines that are fueled by petrol or diesel, and that full electric propulsions do not emit carbons in the tail-pipe (IAE, 2011; Sadek, 2012). Furthermore, that electric powertrains can assist in the decoupling of the transport sector from its high dependence on fossil fuels. On the other hand, electric vehicles may require additional electricity production (Tran et al., 2012) and this can be done using several different energy sources with diverse environmental impacts. In addition, electric powertrains require new advanced service components (Chan, 2007), causing additional, or at least different, environmental impacts compared to conventional vehicles. Also, a battery is needed for electric energy storage. The life span of a battery is a function of several complex and interacting mechanisms relating to cell chemistry on storage, charging and discharging modes such as temperature, cycle depth, and several of chemical degradation forms (Corrigan & Masias, 2011).

3. CONSTRAINTS ON EVS TO POWER GRID INTEGRATION

Different standards and codes regarding utility interface and equipments are currently being worked on by organizations such as IEEE (Institute of Electrical and Electronic Engineering), SAE (Society of Automotive Engineers), IWC (International Working Council) and other automotive research centre /councils to improve EVs acceptance. Notable setbacks which EVs need to overcome includes: incremental costs, life cycle of batteries, deficiency in the infrastructure of charging the EVs and issues regarding battery chargers, as well as issues on the production of harmful harmonics by EV chargers that have serious impacts on distribution system parameters. This challenge can be reduced by using active rectifiers (Singh et al., 2004; Beretta, 2010).

On the technical evaluation of the impacts of EVs with special emphasis on the economic, environment, and power grid effect, the examination is in a double perspective which includes the utility power Grid and EV owners. The overall economic and environmental analysis of EVs would consider electricity generation mix when charging is completely reliant on fossil fuel-based power units as negative. The challenges associated with integration of EVs to power networks are: increase in load profile during peak hours, over loading of power system components, transmission losses, voltage deviations, phase unbalance, harmonics and system stability issues that reduce the power quality and the reliability of the power system.

In developing countries therefore, there must be a sponsored bill/policies in place to reduce numbers of conventional cars by provision of enabling infrastructure to encourage potential customers. However, currently that is not the case because there is no constant supply of power in the country, i.e. Nigeria stepped down a bill on the promotion of EVs because the lawmakers knew of the impending infrastructural and financial cost challenges. This is also true for most countries in Africa. This means the anticipated alternative to charge this EVs may be back to fossil fuel. Otherwise there might be a need to consider an alternator or alternative designs for replenishing EV batteries, or to upgrade the electricity generation and supply as well as improving the efficiency and life of the battery once charged. This process must also be cost efficient. Apart from direct cost implications of EVs, sustaining mobility is based on charging. There are three charging levels. (De-soussa et al., 2010; Morrowa et al.2008) stated that around 500 - 880USD installation cost is required for Level 1 charging method. Expectedly, this charging level will be combined with EV in near future. According to technical study (Tuttle & Baldick, 2012), around 1000 USD-3000 USD installation cost is needed for Level 2 charging process and cost of 2150 USD for residential unit infrastructure (Morrowa et al., 2008). Charging power level 3 requires an execution cost between USD 30000 and USD 160000 (Thomas, 2009). Other details on power charging levels are highlighted in table II below.

4. HEALTH, SAFETY, COSTING AND CHARGING CODES STANDARDS

The principal components of EVs includes the dc/dc converters, electric motor driving inverter, high voltage battery, and the charging module which is connected to the power grid. A power transformer is major equipment between the EVSE and the existing grid system. The body of EV must be earthed in case of both on-board and off-board charging processes. A technicality which calls for close isolation monitoring when electrical separation is not present for the EV charger (Tell et al., 2014). There is no galvanic isolation present for low frequency methods at the DC/DC converter stage. For larger frequency arrangements, high frequency transformers are used to provide galvanic isolation in the dc/dc converter stage. Transformers design plays a vital role to have a reduction in various notable parameters which includes size, losses and cost. High frequency transformers are used to provide galvanic isolation in the dc/dc converter stage for larger frequency arrangements. The design of transformers plays a vital role to have a reduction in various significant parameters including size, losses and cost. The main benefits and issues in providing isolation by high frequency transformers includes better control by regulating voltage, compactness, protection for load apparatus. For level step-down or step-up operation (i.e. 208 to 240V), from level 2 to level 1 or 3, respectively, therefore, the cost of isolating a transformer which is between 7200$ to 8500$ (Yilmaz & Krein, 2013), must be born. The main concern of a system is to lessen the issues of electric shock for safety of owner during the charging process of EVs.

On safety, a wireless charging system (WCS) technology enhance operational safety as applied to EVs with an absence of high voltage cables or power outlets exposures, significant research has been conducted (Onar et al., 2013) to examine the EMF issues with human electromagnetic exposure limits. Irritation, surface electric-charge impacts, the stimulation of both primary and secondary nervous tissues, and faint flickering of the retina (ICNIRP, 2010). There is a possibility of inducing high field strengths and heating in nearby human bodies (human body as a conductor of electric fields), implanted medical devices, small animals, and metals by the EMF. These common exposure limits are those published by the Institute for Electrical and Electronic Engineers (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

The limit on general public exposure to electric fields by ICNIRP is set to be 83 V/m. Also, regarding the magnetic fields, the tissue has the same magnetic flux density with that of the external field. The recommended limit on general public exposure to magnetic fields is 27 IT as at 2010, as an update to the 6.25 IT limit set in 1998 which is still commonly in use. Furthermore, suitable user-friendly infrastructure as in electric vehicle supply equipment and software (EVSEs) with international standards and charging codes must be deployed for expansion and appropriate operation of EVs in near future. This will aid the analysis of wider range of technical issues of EVs by such implemented international standards and the safety codes. The cost of charging infrastructure is also linked to the hardware standards of EVs (Folley et al., 2010). This may be much expensive at some charging levels (i.e. 2 and 3) according to the National Electrical code (Quincy, 1999) as the cables and connectors are being expected to be de-energized before they are plugged in to the vehicle. This is an outright added cost to EVSEs.

Meanwhile, the manufacturer' specification is to put an interlock which controls the EVs from being driven at the time of charging. Several international organizations and groups working on standards and charging codes of EVs includes the Society for Automobile Engineers (SAE), which standard for supply equipment includes J1772: On conductive connectors and charging methods for EV, J2894: on power quality, J2836/2847/2931: On communication objectives (Bayram & Papapanagiotou, 2014), J1773: On coupled inductive charging, J2293 standards for energy transfer systems in relation to EVs and EVSE requirements by the International Energy Agency (IEA). Standards by National Fire Protection Association (NFPA), NFPA 70: On safety management, NEC 625/626: on EVs charging systems, NFPA 70E: On safety, NFPA 70B: On electrical equipment maintenance. Standards by International Working Council (IWC) and Institute of Electrical and Electronic Engineering (IEEE), IEEE 2030.1.1: On fast DC charging for EVs, IEEE P2030: Interoperability/Switch-ability of smart grid, IEEE P2690: On charging network management and Vehicle authorization, IEEE P1809: On electric transportation guide, IEEE 1547: On interconnecting electric system with Tie Grid/distributed resources, IEEE 1901: On provision of data on vehicle charge rate overnight. Table I highlights some existing international safety standards by SAE.

Table I: Stand-alone Safety Standards for EVs

S/N	Technical Codes	Breakdown
1	SAE J-2344	Defines the policies for EV safety
2	SAE J-2464	Standard describes the safety rules for the recharge energy storage systems (RESS)
3	SAE J-2910	Electrical safety standards for buses and test hybrids of electrical trucks
4	SAE J-2929	Safety standards of propulsion battery system.
5	ISO 6469-2:2001(IEC)	Standard to ensure electrical hazard protection
6	ISO 6469-1:2009 (IEC)	Ensure standard is related to EVs on roads, to on-board RESS, within and outside protection of a person
7	ISO 6469-2:2009 (IEC)	Safe operation standard of EVs for protection against internal failures
8	IEC TC 69/64	Relates EV ty, infrastructure safe, electrical installations and shock prevention.
9	NFPA 70/70E	Relates workplace, charging system and branch circuit standards.
10	UL 225a	Prescribes protection policies on components i.e. plugs, couplers, receptacles, etc.
11	UL 2202	Relates safety standards on charging system.
12	UL 2231	Relates safety standards on supply circuit
13	DIN V VDE V0510-11	Relates safety regulations for battery installations

5. SYSTEM CHARGING AND BATTERY TECHNICALITY

The EV charging is by energy transfer which includes; the conductive charging, Inductive charging and Battery swapping network systems. The conductive systems need a physical linkage between the supply network and the EV. The energy transfer by conductive system mode is through a cable between a connector between EV and the charging inlet point. The connector is a cable conductor which connects the established power outlet from any power level (i.e. Level 1, 2 or charge station Level 3) to the electronic equipment. They are used as on-board chargers for slow charging or off-board chargers for fast charging techniques of EVs. A typical battery charging station is shown in figure II.

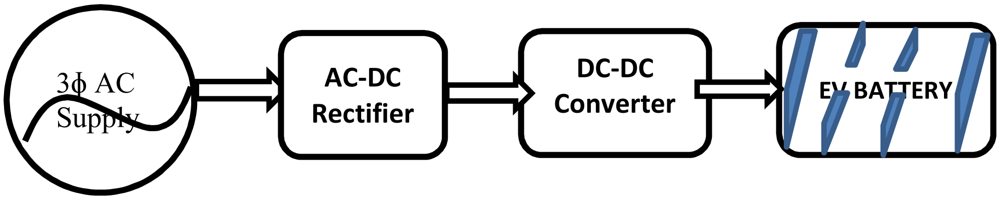

Figure II: Block Diagram of the Battery Charger Station

The inductive charging system uses the electromagnetic field through inductive coils as means of power transfer to the EV battery, so does not need a physical link. The battery swapping method is one in which the owners of EVs can swap partially or completely discharged batteries with fully charged ones.

TABLE II: SAE Charging Power Levels, Emphasis on BEV (SAE, 2010).

S/N	Power Level	Charge rating	Charge time	Remark	Interface for Energy Supply
1	AC level 1 (Convenient)	120 V, 1.4 kW (12 A)120 V, 1.9 kW (16 A)	BEV: 17 h. The State of Charge (SOC) –20% to full.	Single Phase, On-board Charging	Any Convenient Outlet
2	AC level 2 (Main)	240 V, up to 19.2 kW (80 A)	For 3.3 kW charger: BEV: 7 h (SOC–20% to full) For 7 kW charger: BEV: 3.5 h (SOC–20% to full) For 20 kW charger: BEV: 1.2 h (SOC–20% to full)	Single Phase/ Three Phase, On-board Charging	Electric Vehicle Supply Equipment (EVSE)
3	AC level 3 (Fast)	> 20 kW, single phase and three-phase	Yet to be determined	Yet to be determined	Electric Vehicle Supply Equipment
4	DC level 1	200–450 VDC, up to 36 kW (80 A)	For 20 kW charger: BEV: 1.2 h (SOC–20% to full)	Off-board charger	Electric Vehicle Supply Equipment
5	DC level 2	200–450 VDC, up to 90 kW (200 A)	For 45 kW charger: BEV: 20 min (SOC–20 to 80%)	Off-board charger	Electric Vehicle Supply Equipment
6	DC level 3	200-600 VDC, up to 240 kW (400 A)	For 45 kW charger: BEV (only):	Off-board charger	Electric Vehicle Supply Equipment

6. PROSPECTS AND CHALLENGING OF EVS

The development and deployment of EVs is no doubt a good resolution and promising approach towards environmental, economic and power gird impact issues. The electrification of transportation system is an alternative to address sudden change in climate, fossil fuel depletion and rising prices of crude oil. The technology of EVs is much energy proficient and cleaner in approach when compared with conventional ICE vehicles due to zero CO_2 emissions. Nevertheless, several challenges and limitations still need to be addressed and overcome before the efficacious employment of EVs in the market (Table III below). The key designs and technological challenges with future trends for widespread employment of EVs are stated below:

❖ **Initial Cost**: The price of an EV is still much higher in comparison with conventional ICE vehicles due to higher cost of EV batteries.

❖ **Battery Limitation**: Though there is a remarkable advancement in battery technology, the present charging technologies are yet to be fully developed. The limitations of the present Li-ion batteries are due to lower energy density and minimal life cycle. Maintenance is required in the first two years due to limited life cycle. Moreso, the size and weight of the batteries are approximately one-third of the vehicle. The experimental stage (not fully matured) indicates that a good performance can be achieved from few battery technologies.

❖ **Improved Design Development**: Efficient battery management systems is needed to achieve optimal performance of batteries. The design method involved in sizing the battery subsystems needs improvements for high performance, maximum range and greater life cycle of batteries.

❖ **Smart Grid Connector Development**: The present charging technology for EVs has certain constraints in relation to V2G technology. The battery connecting chargers are unidirectional chargers, which are not fully matured for V2G deployment in smart grid environment (advance bidirectional chargers are needed for standardized V2G implementation).

❖ **Energy Management Studies**: The V2G can accelerate the integration of RES. However, V2G concept requires the involvement of EV owners. Technical studies on energy based management techniques and reward-based schemes for should be implemented for EV owners to majorly participate in V2G.

❖ **Power network Development:** Existing infrastructure may not be effectively designed and up to date to sufficiently cater for massive and necessary demands of EVs. This may require high investment to update the conventional power infrastructure, especially for developing countries of the world. Moreso, the excessive cycling process of batteries may diminish the energy and increase conversion losses. Hence, advanced research and planning methods are necessary for deployment of such complex infrastructure.

TABLE III: The Merit and Harmful Impacts with Corresponding Benefits and Remedial Measures

S/N	Merit and Harmful Impacts	Merit and Remedies
1	V2G Technology	▪ It is an alternative source of energy at peak hours, increases reliability and reduces the overall cost of the system (Salman et al., 2015), minimizes line losses and voltage drops in the distribution network, and Power quality issues are minimized. Reduces frequency fluctuations, Ancillary Services
2	Environmental	CO_2 emissions and other pollutants are reduced.
3	Economic	The fuel and operating cost are reduced. Users can get benefits by supporting V2G concept.
4	Power Quality Issues	Requires and recommends a harmonic control such as: EN 50160:2000, IEEE 519-1992, IEC 61000-3-12/2-4. Employs PCU compatible with smart grid for coordinated charging, uses voltage source inverters and current control to improve harmonic issues, employs harmonic filter at supply side, uses smart appliances having banks of passive filters and Smart grid environment for load management approach.
5	Transformer overloading	Use smart load management techniques (K-factor derating method).
6	Increase in Power Losses	Uniformly distributed charging through coordinated control charging.
7	Increase in Peak Demand	Smart and controlled charging by Valley Filling approach and Smart multiagent metering system.
8	Voltage Instability	Reduce fluctuations with tap changing transformer Wide area control method.

7. CONCLUSION

This paper briefly highlights the constraints of power grid integration, health, safety, cost effects and standards, inductive charging, conductive charging and battery swapping networks, prospects and challenges as well as beneficial and harmful impacts of EVs. A friendly usage, expansion and appropriate operation of EVs in nearest future as a result of established new international standards and charging codes, reward-based initiatives, customer sensitization, suitable infrastructure, smart, efficient and suitable chargers as well as improved battery technology will get the attention of utility operators and EV owners in the nearest future. It is to be noted that the engine block is the major component replaced with an electric motor in EVs, other components such as the air-conditioning systems, transmissions through the propeller shaft for heavy vehicles, etc. are yet to be replaced like the conventional vehicles

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