Smart Charging Infrastructure for Electric Vehicles

S.Swarnalatha[1], Gundra Bhargavi[2],B.Yasaswini[3]
[1]HCL technologies
[2]Dept. Of Electrical Engineering, JNTUA College of Engineering, Pulivendula,
[3]Tata Consultancy Services pvt limited
S.Swarnalatha[1], Gundra Bhargavi[2], B.yasaswini[3]
sswarnalatha887@gmail.com[1], gundra.bhargavilatha@gmail.com[2], yasaswinireddy99342@gmail.com[3]

***Abstract* - This paper discuss the pros and cons of various proposed techniques for EVs smart charging infrastructure and also compares different available technologies in the current scenario. This paper presents a novel smart bidirectional interface equipped with multilevel cascaded power converter with embedded strategies of reverse energy integration in order to keep stress on the power grid to minimum. Future research work is also mentioned in this paper for smart charging station.**

***Index Terms*— Electric Vehicles, Smart Grid, Smart Charging Station, Multilevel Power Converter, Efficient Energy Consumption.**

INTRODUCTION

Future vision of smart grid and smart cities envisages diffu- sion of electric vehicles running on electric power supply with either on-board or off-board charger . Embryonic charging infrastructure is great challenge for wide penetration of electric vehicles in the market because power demand by EVs will put strain on the power grid . A major component of charging station is Electric Vehicle Supply Equipment(EVSE) that supplies electric energy for recharging electric cars and includes socket outlets, connector, on-board or off-board charger depends onthe level of charging employed, charging levels and standards are explained in the proceeding section. Networked EV supply equipment with meters can perform a number of services including “smart grid” applications.

The paper is composed as follows: It gives comprehensive knowledge of different charging methodologies defined by SAE and ChAdeMo, it gives deep insight into traditional charging station architecture describing an overview of charging station with local energy storage system with evaluation of energy storage units, it discusses role of information and communication technology in the development and management of electrical load of charging station infrastructure, it is comprised of concerns related to siting of charging stations with a brief discussionon improving power factor of charging station, consequently it is dedicated to comprehensive discussion on local energy storage system based charging station with appropri- ate insight into ultra-capacitor based energy storage system. It presents and gives comprehensive look into the proposed approach vs. existing techniques and framework of the proposed architecture with simulation results and obser- vations. Finally, it concludes the paper outliningthe distinctive

features of the proposed scheme with future research directions.

CHARGING METHODOLOGIES OF EVS

Quality of service of a recharging station is measured in terms of how fast the vehicles’ battery is charged and discharged, provision of electric supply for recharging EVs, delay in accepting charging request by vehicle owner, long term effect on battery performance, and pricing. Charging capability of battery as defined in the SAE J1772 standardfor e-vehicles is as follows:

- Slow charging - Level 1: Supplying AC energy to the on-board charger of the vehicle of rating of 120V/16 Afor charging 1.92 kW battery with charging time of 10 hours
- Standard charging - Level 2: Implies AC energy to the on-board charger of the vehicle of voltage of 208-240 V and current of 12-80 A for 2.5-19.2 kW with chargingtime of 8 hours at most
- Fast charging - Level 3: Using DC energy from an off-board charger, in DC charging there is no minimum energy requirement but the maximum current may be 400 A and 240 kW with charging time of 20-30 minutes.

Level 1 charging may be suitable at homes where vehicles are normally parked for 8-10 hours during night through many of the electrical circuits near parking supply up to 120 Volt, a rate that is only required for level-1 charging. therefore, Level-1 charging is considered to be suitable at home garages. Electric vehicle can be easily plugged-in in the normal house socket as it requires normal AC supply. On the other hand fast charging may not be installed at home garages because of its special requirements of supply equipment and high current rating and safety measures. Level-2 electric vehicle supply equipment does operate on circuits with a capacity similar to those thatrun appliances, such as clothes dryers and electric ovens. It is suggested that EV drivers that travel long distances on regular basis and have high capacity batteries should use Level-2 charging station. However, installation costs can easily exceed the cost of the level-1 EV supply equipment itself. DC fast charging is different from Level-1 and Level-2 charging because of substantial difference in charging duration.

TRADITIONAL CHARGING STATION ARCHITECTURE

Current power grid is not able to support increase in power demand by EVs charging stations. A concept of energy storage system in smart recharging stations with capability of storing excess power from the grid has been introduced, sustaining grid stability. If 5 % of EVs, expected to be in 2018, are charged at the same time using fast charging level, there will be 5 GW increase in total power demand. Thus, it is necessary to avoid failures or outages due to unexpected risein power demand by EVs charging stations. Based on some observations following points are concluded:

- charging station need constant power from the grid to meet high demand, a local energy storage system is introduced as a component of smart charging station
- when the charging station is idle, all available power from the grid will be used to charge the local energy storage devices

The core idea of energy storage system is that the power demand by EVs can be either supplied by the utility or througha local energy storage unit. It is worth mentioning that only excess power from the grid is employed to charge energy stor- age devices which in turn is used to support timely high loadson the charging station.

A. Ultra-capacitor Based Energy Storage System

In order to ensure a reliable charging facility for e-vehicles, a concept of fast charging station with an ultra-capacitor based energy storage system has gained wide attention of research community. A fast charging station with ultra-capacitor energy storage system offers reduced charging time without putting stress on the grid. Charging time may be reduced by supplying high rate of power transfer i.e. increasing the charging voltage and current. According to SAE J1772 standards Level-3 DC; 400V and 200A, charging may be employed to rechargeEVs in around 20 minutes using off board charger with required supply equipments. In this scenario the power is delivered by directly transferring from the charging station to the battery without an on-board vehicle rectifier. However high energy demand and high power rate may burden the grid and require additional generation and distribution infrastructure. To overcome this issue energy may be stored during low demand hours in order to utilize it at during peak demand hours . This strategy would not only save extra investment on energy production but it will also enhance efficiency of the system at economical prices.

There are many energy storage systems such as batteries, ultra capacitors and flywheel. Evaluating different technologies on the basis of their advantages and disadvantages, ultra-capacitor energy storage system prevails and considered to be the best suitable for rapid charging station because of its high charge/discharge time, huge life cycles,high power density result in high operating efficiency as shown in Fig. 1 .

Ultra-capacitor is considered to be the best choice for energy storage, because a large voltage drop is observed when ultra-capacitor discharges, so range of applicable voltage will be around 50%. It means if 50% energy is useable then therewill be almost 75% energy accessible i.e. if the capacity is 20 kWh, then 15k Wh is useable. Power usability limitation for ultra-capacitor is due to limitation of power electronics as ultra-capacitors can be discharged at high rates. On contrary, batteries have low durability in case of high charging and discharging cycling which results in limited lifetime of the battery if used for charging station. Additionally, batteries operate in small range of temperature to avoid any further decrease in lifetime and performance. Some other concernsrelated to batteries are; it has regular maintenance requirement and replacement expenses make batteries less economic and hence less attractive energy storage system. Considering fly- wheel as an energy storage system may be better than batteries but its limitations include low recharge/discharge cycle rateand less reliability.

B.ICT AND CHARGING INFRASTRUCTURE

To support e-vehicles' smooth driving, provision of recharg- ing facility on-time on-place with high quality of service with the lower delay needs to be ensured. Vehicles are needed to be equipped with new navigation and infotainment devices as well as with wireless communication technology to support Vehicle to charging station Infrastructure (V2I) and charging station Infrastructure to Vehicle (I2V) communication pro- vided by 3G and future 4G cellular networks. Updated on- board information about the status and location of a charging station in terms of number of available free plugs and average waiting time at the station is likely to be provided in future electric vehicles' network. In this way such communicationinfrastructure optimize electric mobility with reduced search time for charging station, price information depending on the power demand for better economy with reduced trip time. An effective communication infrastructure may help cooperate

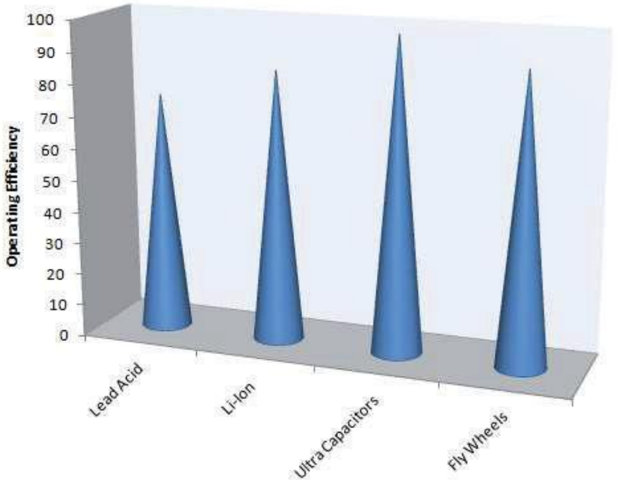

Fig. 1. Energy storage devices

within network of EVs to utilize electric power charging infrastructure efficiently. Authors explore the role of modern communication technologies as an integral part of smart grid for effective demand side management while matching supply and load on the power grid with reflection of real-time dynamic pricing signal.

A. Communication Based Load Management of EVs

As e-vehicles need power from electric grid, so load on the grid should be managed to avoid transients and failures in the electric network. In this regard communication based load management scheme has been introduced . In the proposed scheme, utilities provide certain amount of energy based on the predicted demand level. For this, there must be effective communication bridge among vehicles, smart charging station, Substation Control Center (SCC) and utility center. When a vehicle is plugged in into a smart charging station a request for energy demand is sent to SCC, which decides based on the available energy from utility and either accepts the request or reject it. Performance of this kind of load management is measured in terms of delay, delivery ration and jitter. As a matter of fact EVs may be charged at any time of a day depending on requirement to top their batteries even during peak demand hours. Increasing load on the grid during peak hours may require extra power generation through any source which may increase the cost and greenhouse gases emission. Coordination among all nodes of the grid and smart charg-ing stations help reduce strain on the grid and improve stabilityof the grid. Appropriate communication channel between vehi- cles owner and smart charging station may urge vehicle drivers to recharge their vehicles during off-peak hours at low pricing period. Communication based optimization is flexible than solely optimization based strategies because in communication based infrastructure decision can be taken dynamically on the current state of the smart grid whereas in optimization based schemes state of load and capacity of the grid is supposed to beknown ahead but grid condition and load demand may change in real time. In this way, in addition to improved grid stability, charging expenses on EVs may also be reduced if charging is done during off-peak hours. In this scenario, smart charging station may be considered. Mesh Points which communicate with the substation sending a packet for charging request when EV is plugged in. Substation makes decision based on the availability of energy either allowing or rejecting the charging request. Smart charging station need to communicate with EV in order to be updated about state of charging SOC and tariffs. The load management scheme is depicted in the Fig.2

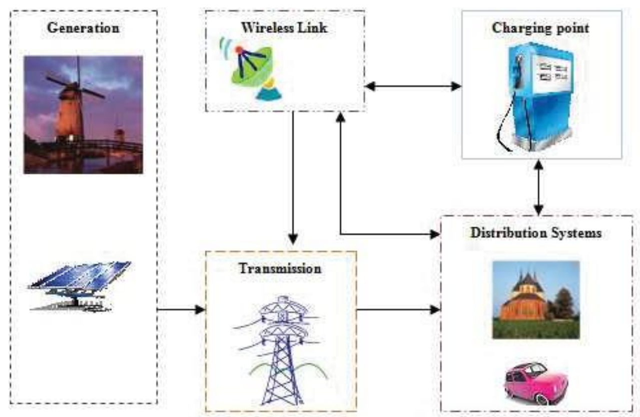

Fig. 2. Communication bridge among all nodes of the system

Locating Charging Stations

It has been recognized that it is essential to site the charging stations in such a way that it could support the transportation while drawing power from the utility grid. In this regard, a two-stage stochastic program based site for locating charging stations has already been proposed . Renewable energy coupled with recharging stations may cope with the challenges like variability of renewable energy resources and expected increase in power demand due to power utilization by EVs. However, a recharging station supplied by a stand-alone PV power generation can be located at homes or public places. Installing PV on top roofs is becoming popular and is consid- ered to be an optimal solution to power up electric vehicles at very low cost. Small scale renewable power generation can play vital role in acceptable popularization of electric vehicle without affecting utility grid while offering better economy. A crucial aspect of power charging stations from renewable power source is to build exchange stations at such locations which are convenient for the both- EVs and the grid without employing additional conventional power generation capacity. In a two-stage stochastic program based model, first- stage decisions are made by fore estimating the future demand for power that where to site the stations and number of batteries required to be equipped at each station. Second stage decisions are taken after the situation of power demand is realized, either to feed EVs or the power grid, by employinga certain number of batteries .

A charging station employing high power factor PWM in-verter is considered a key technology to support popularization of electric vehicles. Traditional charging stations use diode rectifier bridges with capability of one way power transfer from grid to load with disadvantage of absorbing reactive power from the grid. Three-phase PWM rectifier topology for smart charging station has also been introduced which is capable of charging battery in rectifier mode i.e. transferring power to vehicle from the utility grid.

THE PROPOSED SMART CHARGING STATION

From previous sections it is evident that most of the researchers have paid attention to equip a charging station with energy storage system but as a matter of fact the performed simulation results in Fig. 5 show that, having local energy storage system based charging station may get too expensive to afford even than conventional vehicles' fuel consumption cost. On the other hand communication based load management has been given much attention for sustainability of charging infrastructure, in fact it may be useful to an extent, but it may not be a solid strategy to support electric vehicles' electric load because it does not deal with the problem that how to feed EVs if a certain number of vehicles require recharging during peak hours. The presented idea for recharging station is that a smart charging station which is connected to smart grid should be made a bidirectional interface capable of either recharging electric vehicles or to use them as power source. The proposed smart bidirectional recharging station is to be equipped with robust and effective communication infrastructure. As communication among the power supplier, vehicle driver, recharging station, SSC and other nodes of the network is a key issue in making the recharging infrastructure smart and reliable with instant reflection of availability of power and dynamic pricing to the vehicle owner. . In view of communication technologies for recharging infrastructure, wireless mesh network is found to be the most suitable communication technology for coordination between electric vehicle owner and the nearest charging point for exchanging information about power demand either by EV or the facility depending on load on the power grid and price information.Mesh network offers fair enough data rate, self-healing, capability of self-configuration, high scalability services and low deployment cost. Additionally, wireless mesh network can be a good option for extended coverage where a vehicle driver does not find any recharging point in nearby area . On the other hand cellular networks can be useful for communication among the nodes which are not so near to each other such as recharging point and the utility control center . Cellular networks are advantageous because of having developed existing infrastructure and it will not require the companies to build new infrastructure and cellular networks provide sufficient bandwidth for such applications. Where, it is important to mention that supplying DC power to rechargean electric vehicle, which offers quick recharging, a DC bus based system may be more convenient if a charging station is directly powered up by a stand-alone renewable power generation system. In fact, DC bus based system has many advantages over AC system such as, it involves a few stages of power conversion with reduced losses and hardware costs. This paper proposes that a solar carport based charging point can be supplied by DC power for efficient and quick recharging of electric cars. A charging station supplied by stand-alone DC power generation through PV renewable resource offer few power conversion requirement and hence gives economical recharging facility.

Practically, AC system has been in use since many years and it has developed infrastructure-standards and technologies. However, direct DC supply line is much feasible to integrate renewable power resources, in particular, supplying DC power to a charging station via stand-alone renewable power generation.Moreover, DC system may be more effective, economical and efficient than that of AC system because it does not employ more power conversion states unlike AC supply system. Therefore, we propose DC system as a quick charging method. On the other hand certain parameters need to be taken into account while supplying DC power from the central power grid; where voltage is transmitted at the rating of tens of kilovolt. In general, the higher the amount of power transfer the higher the voltage rating and current rating is kept lower. Whereas, in case of DC charging method, voltage supply should be as low as 100V and if DC supply voltage to the vehicle charger is kept higher, the charge would be required to be equipped witha DC/DC converter for matching voltage level which will make the structure of the charger complex and will also cause increase in hardware cost. Therefore, the proposed quick charging station equipped with multilevel power converter, directly powered by PV based renewable DC power generation, achieving the desired level of voltage. The proposed charging station architecture is depicted in Fig. 4.DC transmission does not suffer from skin effect so thinner conductors can be used with better utilization of conductor. Another important factor is the energy storage system, as mentioned above in the section of state-of-the-art techniques, for recharging station in order to make it reliable ensuring smooth operation of electro-mobility.

In this regard, the performed simulation for comparing conventional approach of charging station with the proposed charging station facility based on the parameters cost vs. quality of service (QoS,), the later measured in terms of continuity of power supply to EVs, delay in accepting charging request, supplying electric power to e-vehicles with required voltage and current levels. It is worth noting that, during low power generation hours, electric cars are used as an auxiliary

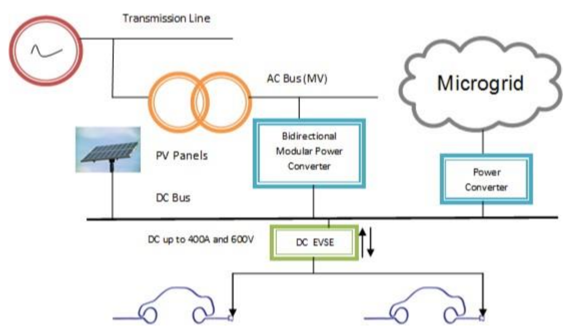

Fig. 4. The proposed charging station architecture

power sources removing the need to employ high cost energy storage units. Here, we consider another important aspect regarding the size of energy storage systems. It is well noted fact that, average power demand is much lower than the power demand at peak hours, so it is not rationale that auxiliary power source should be able to supply 100% peak power demand. Rather, utilizing electric vehicles as power sources may serve better up to great extent to satisfy the mean power demand at economical cost.

The proposed concept is about to develop a bidirectional intelligent interface between electric vehicles and charging infrastructure mounted with modern communication technology with market-based energy flow management; that EVs can be discharged to electric grid during peak demand hours, acting as power source. It is considered a potential mechanism in dealing with intermittency and fluctuating nature of renewable energy sources. Utilizing EVs as energy storage devices could help stabilize power grid. Using electric vehicles as a power source, when the stored power is not needed by some vehicles, during peak load hours helps in demand side management of EVs load. A smart charging station with bidirectional multilevel power converter involves vehicle driver's participation in electricity market by selling extra stored energy in the vehicle, when not needed, back to the charging station during peak hours for better economy with efficient use of energy. Moreover, the specifically designed multilevel power converter can ensure electric network stability. The future work includes the design of appropriate bidirectional cascaded multilevel converter topology for realization of smart charging station with effective demand side management and predictive control for enhancing network stability, while preserving the amount of stored energy necessary for car operation.

A. Results

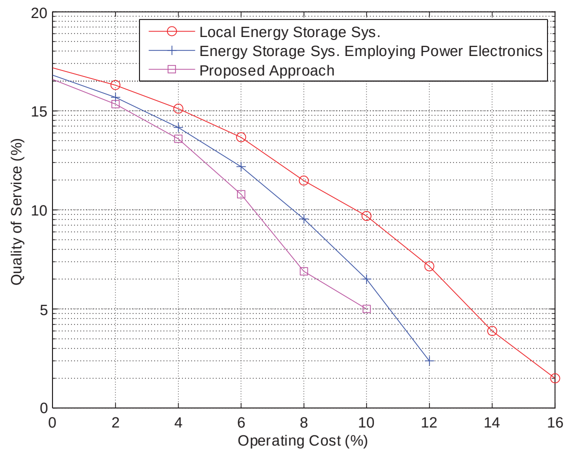

Fig. 5. Performance comparison between Cost and Quality of Service for SOTA and the proposed technique

A study on the proposed approach architecture have been conducted and presented the development of smart charging infrastructure under various settings of the simulation parameters, but the most important parameter which is of prime consideration in the development charging station and where we take into account, in the proposed approach, is Cost vs. Quality of Service, where QoS is determined in terms of: quality of continuity of power supply to EVs, recharging time, delay in accepting charging request, supplying electric power to e-vehicles with required voltage and current levels. This presents basic simulation results performed on the basis of two parameters Cost and Quality of Service comparing State-of-the-Art technologies and the proposed approach in order to make a clear understanding and prevailing feature of the proposed architecture.

TABLE I
QUALITY OF SERVICES VS. COST

	Charging Station with Energy Storage and Energy Storage System Employing Power Electronics	Proposed Approach
Quality of Service (%)	19.4 15 10 5 and 19 15 10 5	19 15 10 5
Cost (%)	16, 7.2, 14, 13–and– 12, 11.5, 11, 6	10, 8, 5, 2.5

Observation: Table-Quality of Services Vs. Cost presents the cost gain vs. gain in QoS. It is observed that cost gain is 4 - 6% higher in case of conventional charging station architecture than that of the proposed architecture for smart charging infrastructure.

TABLE II
MATRIX-COST VS. QUALITY OF SERVICE

Quality of Service (%)	Charging Station with Energy Storage and Energy Storage System Employing Power Electronics Cost (%)	Proposed Approach (%)
20 - 15	16 - 7.2 and 12 - 6	10 - 8
15 – 10	7.2 - 13 and 6 - 12	8 - 5
10 – 5	13 - 14 and 12 - 11	5 – 2.5

Observation: Table-Matrix- Cost Vs. Quality of Service presents the matrix between cost gain and quality of service gain. It becomes obvious from table that cost of charging station with energy storage units is 4 % -5% higher on same quality of service level than that of the proposed approach.

CONCLUSIONS

The proposed smart charging station prevails over state-of-the-art-techniques due to its overwhelming distinctive features. This paper identifies different flaws in the conventional techniques and methodologies, and performed simulation in which it is shown that the proposed architecture of recharging station gives better quality of service relatively at lower cost than that of conventionally proposed charging station with local energy storage system. The paper proposes mesh network and cellular network as an optimal wireless communication technologies for communication bridge among various nodes of the system. The specifically designed bidirectional multilevel cascaded H-bridge power converter will operate at low frequency with SHE reducing the need of power filter . The designed power converter with high power efficiency removes the need of bulky transformers. The proposed topology ensures better control of two-way energy flow using third generation component e.g. SiC and GaN. Using electric vehicles as an energy storage devices facilitate integration and sustainability of renewable energy resources. High power multilevel power converter becomes best suitable for quick recharging method- level 3 fast charging. It helps grid stabilization, optimum power factor control and reduces harmonic content. The proposed scheme offers full exploitation of V2G operation with sophisticated control of reverse flow of energy. It offsets the high cost of energy storage devices for traditional recharging stations and micro grids. Moreover, it supports greater expansion of renewable power generation resources with consumer's participation in the electricity market at better economy

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