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Design and Implementation of Real Time Charging Optimization for Hybrid Electric Vehicles

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ABSTRACT

Electric vehicle (EV) has gained incredible interest from the past two decade as one of the hopeful greenhouse gasses solution. The number of Electric Vehicle (EV) is increasing around the world; hence that making EVs user friendly becomes more important. The main challenge in usage of EV is the charging time required for the batteries used in EV. As a consequence, this subject matter has been researched in many credentials where a wide range of solutions have been proposed. However those solutions are in nature due to the complex hardware structure. To provide an unswerving journey an Android application based charging optimization is proposed. This application is aimed at giving relevant information about the EV's battery state of charge (SOC), accurate location of the EV, booking of the charging slots using token system and route planner. At emergency situations, an alternative service is provided by mobile charging stations. Route planner indicates the temperature by which prediction of reaching the destination can be done. In addition to that nearest places such as parks, motels are indicated. The estimated time and distance between the electric vehicle and the charging station is calculated by the charging station server according to which the parking lot is allocated. Vehicle to charging station communication is established for the time estimation of charging. This will help the EV users to know about charge status and charging station, which support fast charging method and availability of the station on the go and also when to charge their EV. The Arduino UNO board has been used for the hardware part. The hardware results are confirming the conceptual of the proposed work.

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1. INTRODUCTION

Traditional cars produce a lot of carbon dioxide (CO_2) emissions that are ejected into the atmosphere, causes pollution and greenhouse gases [1]. Today, electric vehicles (EVs) have received much attention as an alternative to traditional vehicles. The traditional vehicles are powered by internal combustion engines. The electric vehicle is developed because of the advancement in battery technology and motor efficiency. The secondary batteries are the main energy sources of the EV. Thus, energy management is the key factor in EV or Hybrid Electric Vehicles (HEV) [2] design. Moreover, the charge capacity of the battery will influence the endurance of electric vehicles. The main challenge in the HEV is the charging time required for the batteries and insufficiency of charging stations (CS) [3] and therefore charging within existing distribution system infrastructure is problematic. Up to now the HEV's CS is in the range of 100 km per charge due to the onboard energy which is need to be optimized. The second challenge for the EV's is their battery capacity which ranges from 8.6KWh to 15.2KWh. The consequent disadvantage is that the charging time for above mentioned size, in a level 1 household charger (120V, 50Hz, 15-20A) is more than 15 hours. Due to these constraints, the vendor (EV charging station supplier) needs a convenient distribution system to cater to customer demand as well as maximize benefits. A special attention must be given to the charging station [4]. In future, the number of electric vehicles will be increasing to a greater extent, these electric vehicles have to re-charge their battery in a place (i.e.) charging station, so there will be a growing need of public accessing charging stations. This will have a significant impact on the power systems like transformers, protection devices etc. With respect to the varying load, it will have an impact on the consumers and vendors due to the traffic at these station, waiting time for charging the vehicles will increase etc. Therefore to improve all these factors there should be a proper monitoring systems to monitor them, like the smart grid technologies monitoring the load on the power grids [5-8]. Therefore both the consumer and vendor will get assistance from a communication system which shares useful data regarding the charging station, whether the charging slots are free, rate at which charging is done, cost per unit etc. This is basically what is known as vehicle to grid communication (V2G).

The objective is to develop an application it connects the user and vendor. The added feature in the developed application is the vendor can sell their entity through the means of bidding process. It can be done by adding the charging station on an online GPS map, so that the viewer can choose the closest station based on the cost per unit.Kennel *et al*. [9] literature an energy management system for the smart grids including the Full Electric Vehicles (FEV) integration. Moreno-Muñozet*et al*. [10] literature the possible solutions to integrate the control, monitoring and the protection functions in the distribution automation functions. A synchronization technology was developed and tested by synchronization test and measurement test [11]-[12]. Gungor*et al*. [13] and Parikh *et al*. [14] literature some opportunities and challenges to the wireless sensor area in the smart grids. Sabbah*et al*. [15] literature a survey of this communication technology in the smart grids. There are research pointed in the MLI based PWM schemes and it may be extended in EV area by care the battery [35-36]. In the proposed idea the mobile application is used to show the details of the electric vehicle and it is communicated to the charging station server. The charging station server indicates the availability of the parking slots to the users so that they can prefer the charging stations. This helps the EV users to save their time. Outline of Electric Vehicle shown in Figure 1 and android application main modules and functionalities as shown in Figure 2.

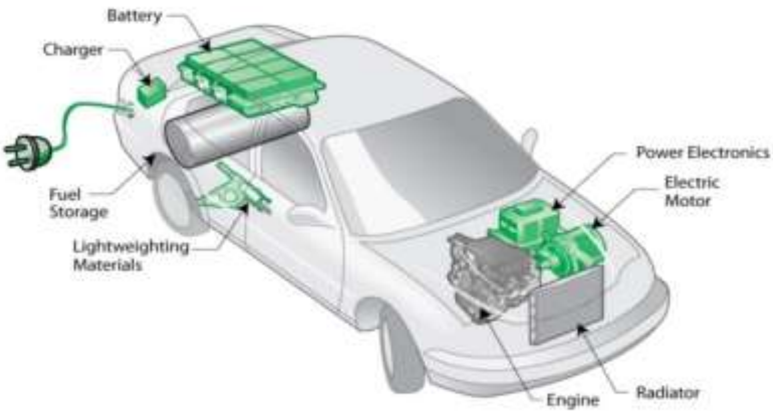

Figure 1. Outline of Electric Vehicle

2. HARDWARE ARCHITECTURE

The proposed system architecture is mainly developed for the convenience of the electric vehicle users. The main modules and functionalities are illustrated in Figure 3.

2.1. Battery Performance Analysis

The critical components of the battery are energy density, charging time, life time and cost. Of all these charging time has a stronger dependency on the battery performance. The control parameters of the charging process is voltage, current, temperature, input energy and output energy. The charging time and discharging time of a battery is calculated using the equation (1) and (2).

$$\text{Charging time} = \frac{\text{Battery rating}}{\text{Current}} \quad (1)$$

$$\text{Discharging time} = \frac{\text{Battery rating} * \text{Battery voltage}}{\text{Applied load}} \quad (2)$$

The discharging rate is also affected by the C-rate.C rate is the rate in amperes, while nC rate will discharge a battery in 1/n hours. For example, a rate of C/2 will discharge a battery in 2 hours, and a rate of 5C will discharge a battery in 0.2 hours. For a 2 Ah battery, the C/5 rate is 400 mA, while its 5C rate is 10 A. As mentioned before, C depends on battery discharge current rate according to Peukert’s equation. The peukert’s condition is that in which the discahrging of the batteries will be faster than estimated. The Peukert’s equation is shown in the equation (3).

$$\text{Usable pack size} = \text{Kw} * 0.80 * \text{Peukert'sConstant} \quad (3)$$

For a lead acid battery, the Peukert constant can range from 2.0 to 1.0 depending on manufacturing technology. Lithium ion batteries supports the charging temperature of 0˚C to 45˚C (32˚F to 113˚F) and discharging temperature of -20˚C to 60˚C (-4˚F to 140˚F). No charging is permitted below freezing point. There will be good charging and discharging performance at higher temperatures but the life of the battery will be affected.

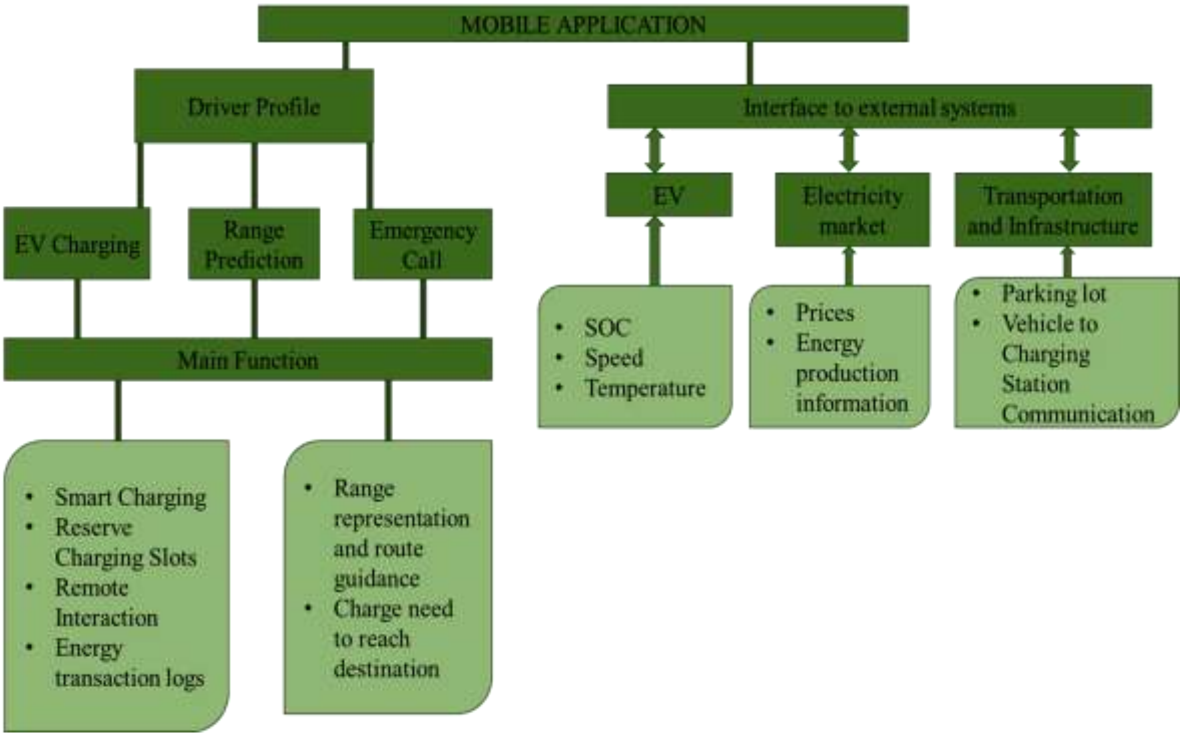

Figure 2. Android application main modules and functionalities

2.2. EV Charging Module

2.2.1. House- hold Charging point: This is a simple household charging point where the EV is plugged into standard socket in the residential building, the input varies from country to country for example 240 volts (in INDIA), 120volts (in USA). It takes more than 4-11 hours of charging with the expected power level of 1.4KW (12A) for a battery capacity of 5-15Kwh the EV to its full capacity, but when compared to other levels of charging this is easiest and cheapest way of charging the EV [16-20].

2.2.2. Public Charging Stations: This is best suited and normal way of charging the EVs, as these hasspecial equipment which provides a high level of safety. These used in public places to charge the EVs. They can be of two types either conductive or inductive. The conductive type is further classified in two butt type, pin and s sleeve types. For the level 2 charging the input is 400volts (in India), 240volts (in USA) and the expected power level is 4KW (17A). It takes about 1-4 hours for charging the battery with the capacity of 5-15KWh [17].

2.3. Range Prediction

It provides guidance to the CS with the possibility of reserving a charging slot using the range charging assistant function. Based on the battery state-of-charge (SoC) [20-25], and remaining distance, the system can calculate the minimum energy required in the batteries and it indicates the driver whether the destination can be reached or not with the present SOC. So that the users can make it possible to reach the desired destination or they can plan to reach the nearest CS. The range prediction can be estimated using the formula given in Distance estimation in Chapter 3.

2.4. Emergency Call

The Emergency call system paves the way to access the mobile charging station. It is accessed when the nearest charging station cannot be reached. When the EV's battery SOC is very low, the EV's location will be sent to the mobile charging stations. The SOC and DOD is defined by the following equations (4) and (5).

$$\mathrm{SOC} = \left(\mathrm{Q_{total}} - \mathrm{Q_{out}}/\mathrm{Q_{total}}\right) * 100 \tag{4}$$

$$\mathrm{DOD} = 1 - \mathrm{SOC} \tag{5}$$

Where Q_{total} is the charge available before discharging of the battery. $Q_{out}$is the charge during discharging of the battery. DOD is the Depth of Discharge

2.5. External Interface System

The Battery SOC, speed and the temperature must be communicated to the android application via Bluetooth. Bluetooth is preferred because it can communicate up to the distance of 100 meters. So that we can achieve the prediction of reaching the destination [26-28].

2.6. Points of Interest

Information related to points of interest (POI) is preloaded on the system, such that the driver can perform a quick search for any desired POI near the present location. This information is also used for guidance to FEV battery charging points that remain at a predefined distance [29-30].

2.7. Parking Places

Information associated with available parking places and remote reservation of EVs battery charging slots [30-34]. And the nearest parks and motels are also indicated.

3. RESULTS AND DISCUSSIONS

3.1. Monitoring the Battery Voltage

Hardware implementation includes the connection of battery with the Arduino UNO board and then monitoring the voltage of the battery. In this the battery is connected to one end of the voltage divider and the other end of the voltage divider is connected to the pin A_0 of the Arduino UNO board.

The ground pin is connected to the negative terminal of the battery. In this the voltage of 9V battery is measured and it is displayed in the PC using the serial port which has the baud rate of 9600. The voltage measured is 4.85V for a 9V battery. The battery voltage is measured using the voltage divider rule. Then the battery SOC is measured. The SOC is measured using the coulomb counting method. This method is easy and accurate. The connection of 9v Battery to the Arduino UNO is shown in the above Figure 3. The Battery's Voltage is measured using the equation

$$\mathrm{VR_2} = \left(\frac{\mathrm{R_2}}{\mathrm{R_1}+\mathrm{R_2}}\right) * \mathrm{V_{in}} \tag{6}$$

$$\text{Ratio} = {}^{V_{in}}/{}_{V_{out}} \tag{7}$$

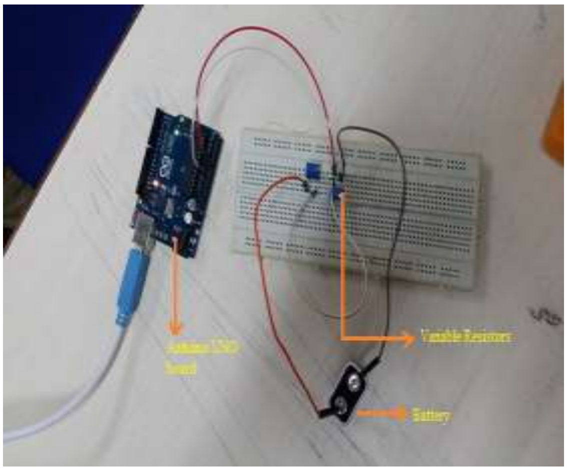

Figure 3. Monitoring the battery voltage

Figure 4. Battery SOC-Display

3.2. Arduino-Bluetooth Interface

The Figure 5a shows the interfacing ofthe Bluetooth Module to arduino for receiving the battery voltage from the arduino to android mobile.The key pin of the Bluetooth module is connected to the 3.3V of the arduino board, the VCC pin is connected to the 5V pin of the arduino. The TX pin of the Bluetooth module is connected with the RX pin of the arduino board. The RX pin of the Bluetooth module is connected with the TX pin of the arduino board. The battery SOC is communicated to the android via the Bluetooth module. The Bluetooth module used here is HC-05. It supports the baud rate 9600. The SOC is then displayed in the android is shown in Figure 5b.

(a) (b)

Figure 5(a) Arduino-Bluetooth Interface, (b) Output Display on Android Application

Table 1. Comparison Table for SOC

Theoretical				Test Work Bench			
Battery Present Voltage	Charging Time	SOC	Voltage	Battery Present Voltage	Charging Time	SOC	Voltage
0	15	1.27%	0.06	0	15	1.20%	0.04
0	13	1.08%	0.05	0	13	0.90%	0.02
0	10	75.76%	3.79	0	10	74.90%	3.3
0	9	73.41%	3.67	0	9	72.6%	3.1
0	3	100%	5	0	3	99.98%	4.85

3.3. Algorithm for Route Prediction

Charging Station Selection server (CSS) traces the instantaneous location of a vehicle and taps the range available with it. It proposes all the charging stations covering the limit.CSS communicates with other vehicles to determine the road traffic and gives an approximate time and charge remaining, until a specific charging station is reached. It also suggests an alternate route to the nearest charging station in case of heavy traffic. The driver chooses the charging type and blocks a slot considering least waiting time. The CSS uses mobile network to communicate with the vehicle and CSs. It also proposes the current metering scheme at particular CS and compares with other CS price. It also can be done through a demand based metering system where EVs will be charged according to peak time and peak load.

3.4. Distance Estimation

Speed, Battery pack KW rating, driving conditions, aerodynamics, vehicle weight, hills, temperature, driving styles and several others play a vital role in the distance perdiction. Here the Batttery pack KW rating and the speed is considered for the distance estimation. The equations (8), (9) and (10) are used for the distance estimation.

$$\text{Distance} = \frac{\text{Battery pack size (KW)}}{\text{Watt}-\text{hour}/_{\text{mile}}} \tag{8}$$

$$\text{Watt} - \text{hour}/_{\text{mile}} = \text{Volts} * \left(\text{Ampere draw}/_{\text{Mile per hour}}\right) \tag{9}$$

$$\text{Battery Pack Size (KW)} = \text{Pack Voltage} * \text{ Amp} - \text{Hour Rating} \tag{10}$$

4. CONCLUSION

The main aim is to develop an android application for the electric vehicle users. It mainly concentrates on measuring the battery state of charge. After measuring the SOC it must be communicated to the android application via the Bluetooth module (HC-05). An algorithm must be developed in order to predict whether the destination can be reached with the current state of charge in the electric vehicles battery. And to evaluate this Google maps are integrated with the temperature according to that also the prediction of reaching the destination can be done. The charging station serves the electric vehicles based on the token system so requesting for the token in the charging station is also included in the android application. Mainly the android application was developed for the convenience of electrical users. For the future implementation the bidding process can be used in the allocation of parking lot to the electrical users.

REFERENCES

[1] A.Y. Saber and G.K. Venayagamoorthy, "Plug-in vehicles and renewable energy sources for cost and emission reductions", *IEEE Trans. Ind.Electron*., vol. 58, no. 4, pp. 1229–1238, Apr. 2011.
[2] M.A. Hannan, F.A. Azidin, A. Mohamed, "Hybrid Electric vehicles and Their Challenges", Renewable and Sustainable Energy Reviews 29 (2014) 135–150.
[3] Arancibia, A. and Strunz, K., *"Modeling of an Electrical Vehicle Charging Station for Fast DC Charging*", Proc. IEEE Int. Elect. Veh.Conf. (IEVC), pp. 1-6 2012.
[4] Praveen Kumar and Kalyan Dash, "Potential Need for Electric Vehicles, Charging Station Infrastructure and its Challenges for the Indian Market", *Advance in Electronic and Electric Engineering.* ISSN 2231-1297, Volume 3, Number 4 (2013), pp. 471-476.
[5] Wenbo Shi, Eun-Kyu Lee, Daoyuan Yao, Rui Huang, Chi- Cheng Chu, and RajitGadh, *"Evaluating Microgrid Management and Control with an Implementable Energy Management System"*, Smart Grid Energy Research Center University of California, IEEE International Conference on Smart Grid Communication 3-6 November-2014.
[6] M. Verbrugge, D. Frisch, and B. Koch, "Adaptive Energy Management of Electric and Hybrid Electric Vehicles", *Journal of Power Sources*, 2005.
[7] Minghao AI, Linhai QI, "Orderly Charging Based Electric Vehicle Charging Stations' On-Line Monitoring System", CIRED Workshop - Rome, 11-12 June 2014

[8] Wenbo Shi, Eun-Kyu Lee, Daoyuan Yao, "Evaluating Micro grid Management and Control with an implementable energy management system", Smart Grid Energy Research Centre USA, ALBERTA, 27-31 July 2014.

[9] F. Kennel, D. Görges, and S. Liu, "Energy management for smart grids with electric vehicles based on hierarchical MPC," *IEEE Trans. Ind. Informat*., vol. 9, no. 3, pp. 1528–1537, Aug. 2013.

[10] A. Moreno-Muñoz, V. Pallarés-López, J.J.G. de la Rosa, R. Real-Calvo, M. González-Redondo, and I.M. Moreno-García, "Embedding synchronized measurement technology for smart grid development", *IEEE Trans. Ind. In format,* vol. 9, no. 1, pp. 52–61, Feb. 2013.

[11] V. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, and G. Hancke, "Smart grid technologies: Communications technologies and standards", *IEEE Trans. Ind. Infor000mat*., vol. 7, no. 4, pp. 529–539, Nov. 2011.

[12] G.A. Shah, V.C. Gungor, and O.B. Akan, "A cross-layer QoS-aware communication framework in cognitive radio sensor networks for smart grid applications", *IEEE Trans. Ind. Informat.*, vol. 9, no. 3, pp. 1477–1485, Aug. 2013.

[13] V.C. Gungor, B. Lu, and G.P. Hancke, "Opportunities and challenges of wireless sensor networks in smart grid", *IEEE Trans. Ind. Informat.*, vol. 57, no. 10, pp. 3557–3564, Oct. 2010.

[14] P.P. Parikh, T.S. Sidhu, and A. Shami, "A comprehensive investigation of wireless LAN for IEC 61850-based smart distribution substation applications", *IEEE Trans. Ind. Informat.*, vol. 9, no. 3, pp. 1466–1476, Aug. 2013.

[15] A. Sabbah, A. El-Mougy, and M. Ibnkahla, "A survey of networking challenges and routing protocols in smart grids", *IEEE Trans. Ind. Informat.*,vol. 9, no. 1, pp. 1551–3203, Feb. 2013.

[16] J.C. Ferreira, V. Monteiro, J.L. Afonso, and A. Silva, "*Smart electric vehicle charging system",* in Proc. IEEE IVS Intell. Veh. Symp, Baden-Baden, Germany, Jun. 2011, pp. 758–763.

[17] P. Simonik, A. Havel, M. Hromjak, and P. Chlebis, "Active Charging Stations for Electric Vehicles Charging", Progress In Electromagnetics Research Symposium Proceedings, KL, MALAYSIA, March 27-30, 2012, pp. 995-998.

[18] Haiying Wang, Yang Liu, Hang Fu and Gechen Li, "Estimation of State of Charge of Batteries for Electric Vehicles", *International Journal of Control and Automation*, Vol. 6, No. 2, April, 2013.

[19] J.C. Ferreira, A. Silva, and J.L. Afonso, "EV-cockpit—Mobile personal travel assistance for electric vehicles", Microsystems for Automotive Applications. Smart Systems for Electric, Safe and Networked Mobility, Berlin, Germany: Springer, 2011, pp. 247–257.

[20] Ganta Naveen, Tony Ho-Tung Yip, Yuyu Xie, "Modeling and Protection of Electric Vehicle ChargingStation".

[21] Mostafa Majidpour, Charlie Qiu, Ching-Yen Chung, Peter Chu, RajitGadh, "Fast Demand Forecast of Electric Vehicle Charging Stations for Cell Phone Application", Smart Grid Energy Research Center USA, ALBERTA, 27-31 July 2014.

[22] Melike Erol-Kantarci, Hussein T. Mouftah, "Wireless Sensor Networks for Cost-Efficient Residential Energy Management in the Smart Grid", *IEEE Transactions on Smart Grid,* vol. 2, no. 2, june 2011.

[23] SeokJu Lee, GirmaTewolde, Jaerock Kwon, "Design and Implementation of Vehicle Tracking System Using GPS/GSM/GPRS Technology and Smartphone Application", IEEE World Forum on Internet of Things (WF-IoT) 2014.

[24] Pankaj Verma, J.S Bhatia, "Design and Development Of Gps-Gsm Based Tracking System With Googlemap Based Monitoring", *International Journal of Computer Science, Engineering and Applications (IJCSEA)* Vol. 3, No. 3, June 2013.

[25] Lin Ch T, Wang J P and Chen Q S, Methods for state of charge estimation of EV batteriesand their application, Battery Bimonthly, 2004, vol. 34, no. 5, pp. 376-378.

[26] Pooja Sathe, "Gprs Based Routing & Tracking of Mobile VehiclesUsing Arm*", International Journal of Engineering Research and Applications (IJERA)* ISSN: 2248-9622 www.ijera.com Vol. 2, Issue4, July-August 2012, pp. 1088-1090.

[27] Daniel Chang, Daniel Erstad, Ellen Lin, Alicia Falken Rice, Chia Tzun Goh, An-An (Angel), Tsao, "Financial Viability Of Non-Residential Electric Vehicle Charging Stations", August 2012.

[28] Strnad, D. Skrlee, and T. Tomisa, "A Model for the Efficient Use of Electricity Produced from Renewable Energy Sources for Electric Vehicle Charging", 978-1-4673-5556-8/13/$31.00 ©2013 *IEEE.*

[29] P. Goli, W. Shireen, "PV powered smart charging station for PHEVs", Renewable Energy 66 (2014) 280e287.

[30] Shamna PV, Beena M Varghese," State-of-Charge Estimation of Lithium-Ion Batteries Combining Current and Voltage Based Estimation", *International Journal of Engineering and Innovative Technology (IJEIT)* Volume 2, Issue 12, June 2013ISSN: 2277-3754 pp 128 – 137.

[31] J.C. Ferreira, P. Trigo, A. Silva, H. Coelho, and J.L. Afonso, *"Simulation ofelectrical distributed energy resources for electrical vehicles charging processstrategy"*, in Proc. IEEE Comput. Mag. Dedicated 2nd Brazilian Workshop Social Simul. (BWSS 2010), Oct. 2010, pp. 82–89.

[32] Jia Ying, Yong, Vigna K. Ramachandramurty, Kang Miao Tan, and Atputharajah A, *"Modelling of Electric Vehicle Fast Charging Stationand Impact on Network Voltage"*, 2013, IEEE conference on CleanEnergy and Technology (CEAT).

[33] Xiaona WU,Yunwei DONG, Hongbin ZHAO, *"A High Reliable Communication Technology in Electric Vehicle Charging Station",* Seventh International Conference on Software Security and Reliability Companion, 2013.

[34] Wenbo Shi, Eun-Kyu Lee, Daoyuan Yao, Rui Huang, *"Integration of V2H/V2G Hybrid System for Demand Response in Distribution Network",* IEEE International Conference on Smart Grid Communications (Smart Grid Comm '14), Venice, Italy, 3-6 Nov. 2014.

[35] C. Bharatiraja, Harshavardhan Reddy, N. Sri Ramsai, and Sunkavalli Satya Saisuma "FPGA Based Design and Validation of Asymmetrical Reduced Switch Multilevel Inverter, *International Journal of Power Electronics and Drive System (IJPEDS)*, Vol. 7, No. 2, pp. 340-348, June 2016.
[36] C. Bharatiraja, S. Jeevananthan, S,R. Latha, and V. Mohan, "Vector selection approach-based hexagonal hysteresis space vector current controller for a three phase diode clamped MLI with capacitor voltage balancing," *IET Power Electron.*, vol. 9, no. 7, pp. 1350-1361, June 2016.
[37] C. Bharatiraja, S. Jeevananthan, J.L. Munda, and R. Latha, "Improved SVPWM vector selection approaches in OVM region to reducecommon-mode voltage for three-level neutral point clamped inverter," *International Journal of Electrical Power & Energy Systems*., vol. 79, no. 1, pp. 285–297, Oct. 2014
[38] C. Bharatiraja, S. Jeevananthan, and R. Latha, "FPGA based practical implementation of NPC-MLI with SVPWM for an autonomous operation PV system with capacitor balancing", *International Journal of Electrical Power & Energy Systems.*, vol. 61, no. 1, pp. 489–509, Oct. 2014.