◻    114

# A Comprehensive Overview of Electric Vehicle Charging using Renewable Energy

**Abdul Rauf Bhatti*,****, Zainal Salam*,***, Mohd Junaidi Bin Abdul Aziz**, Kong Pui Yee****
* Centre of Electrical Energy Systems
**Power Electronics and Drives Research Group, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Johor, Malaysia
***Insitute of Future Energy, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Johor, Malaysia
****Department of Electrical Engineering, Government College University Faisalabad, Faisalabad 38000, Pakistan

**ABSTRACT**

The integration of PV with the electric vehicle (EV) charging system has been on the rise due to several factors, namely continuous reduction in the price of PV modules, rapid growth in EV and concern over the effects of greenhouse gases. Over the years, numerous papers have been published on EV charging using the standard utility (grid) electrical supply; however, there seems to be an absence of a comprehensive overview using PV as one of the components for the charger. With the growing interest in this topic, it is timely to review, summarize and update all the related works on PV charging, and to present it as a single reference. For the benefit of a wider audience, the paper also includes the bries description on EV charging stations, background of EV, as well as a brief description of PV systems. Some of the main features of battery management system (BMS) for EV battery are also presented. It is envisaged that the information gathered in this paper will be a valuable one–stop source of information for researchers working in this topic.

*Corresponding Author:*

Zainal Salam,
Centre of Electrical Energy Systems,
Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Johor, Malaysia.
Email: zainals@fke.utm.my

## 1.    INTRODUCTION

The concern over the environment due to the greenhouse gases emitted by the conventional internal combustion engine (ICE) vehicles is the major factor that accelerates the growth of the electric vehicle (EV) industry at a sustainable level. On the other hand, the prospect of the EV has initiated the integration of the electrical power and the transportation systems in a way that has not been conceivable before. The main link between the two sectors is the charging of the batteries. Charging stations fall into four basic contexts:

### 1.1. Residential Charging Stations

The EV users plug in when they return home, and their car recharges overnight. A home charging station usually has no user authentication, no metering, and may require wiring a dedicated circuit. Some portable chargers can be wall mounted as a charging station.

### 1.2. Charging While Park

A commercial venture, offered in partnership with the owners of the parking lot. This charging may be slow or higher speed, and encourages EV users to recharge their car while they take advantage of nearby facilities. It can include parking stations, parking at malls and small centers.

### 1.3. Charging at Public Charging Stations

These chargers may be at rest stops to allow for longer distance trips. They may also be used regularly by commuters in metropolitan areas, and for charging while parked for short or longer periods.

### 1.4. Battery Swaps or Charging in Less than 15 Minutes

It is achievable with EV battery swaps and Hydrogen Fuel Cell vehicles. It intends to match the refueling expectations of regular drivers. This had been possible due to the reasons that battery capacity and the capability of handling faster charging are both increasing.

By fitting the charging stations that are roofed by PV arrays, the electrical power to charge the EV can be derived [1, 2]. In large number of instances, particularly during the daytime working hours, the EV is parked idly in the parking area under the exposure of the full sun. The application of PV to charge the EV has been further enhanced by the advancement in the power conversion technologies, battery management systems as well as the improved installation practices using proper design standards [3-5]. The increasing research interest in the field of EV charging using PV can be observed from Figure 1, which shows the statistics of articles published per year in reputed database [6].
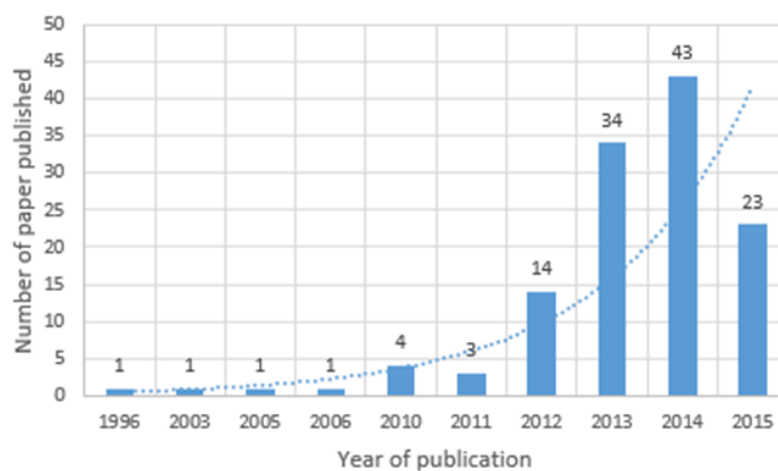


Figure 1. Number of published papers each year in the field of PV–EV charging (indexed in Scopus) [6]

Over the years, numerous EV charging methods using PV have been proposed. However, only two approaches appear to be viable: (1) using the combination of PV and the grid and (2) using only PV as the source. By far, former is the more popular; it uses the PV power whenever possible, but switches to the utility grid when the PV power is unavailable. For latter, the charging is carried out using the PV only, i.e. without any interconnection to the utility grid [7].

With the growing interest in this topic as shown in Figure 1, it is timely to compile all the related works, to update their status, and to present it as a single reference. Admittedly, it is very difficult to ensure a fair benchmarking for each method, as every researcher designs the charging system according to his own hardware, available EV and different environmental conditions. Furthermore, the control schemes or algorithms are tested on different PV system, i.e. power ratings, technologies, size, etc. Thus, this paper is not meant to be seen as an effort to rank the charging methods based on their merits and performance.

To facilitate the readers in going through the paper, the outline is given as follows. In first part, the background on the EV is briefly discussed. Then a brief overview of PV system is given. Then it includes various PV–grid and PV–standalone EV charging approaches with their salient features. Finally, some main features of battery management system (BMS) are also presented. In the conclusion of the paper, the future trends on PV charging are highlighted. It is hoped that the data collected in this paper will be an important one–stop foundation of information for researchers who wish to work in this area.

## 2.     EVOLUTION OF EV

EV is widely referred to an electrically driven vehicle which uses one or more electric motors for its propulsion. It may include an electric car, train, lorry/bus, motorcycles/scooters etc. In this paper, however, the

definition of EV is limited to the hybrid electric vehicle (HEV), plug–in hybrid electric vehicle (PHEV) and purely battery electric vehicle (BEV). A surprising fact which is not known to many is that the EV was built and driven much earlier than the internal combustion engines (ICE) vehicles [8]. The first EV was commissioned in 1828 and experienced the peak development in late 19th century. However, at the beginning of 20th century, with the advances in ICE with its longer driving range, shorter refueling time, good refilling infrastructure and cheaper gasoline price, contributed to a dramatic decline on the production of the EVs [9, 10]. In general the EV offers several advantages such as no vibration, smell, noises and ease of gear changes relatively to gasoline vehicle. The resurgence of the EV in the late 20th century is primarily due to the major concerns on the impact of the ICE to the global warming and the rapid upwards trend in the price of oil. With the recent technological advancement in battery technology, power electronics, converters, control and microelectronics, the EV is expected to make serious inroads to the motor industry.

## 3.  PV SYSTEM

Photovoltaic is the technology that uses solar cells or an array of them to convert solar light directly into electricity [11, 12]. The most widely used PV arrays/modules are based on poly– or mono–crystalline technology [13]. However, recently, thin film is getting more popular, especially for large PV systems [14]. Despite their lower efficiency, thin film cells are easier to manufacture, more cost effective and exhibit better performance at higher temperatures. Other technologies include the Hetero–junction with Intrinsic Thin layer (HIT) [15] and multi–junction cells [16]; but they are not used for general applications owing to their much higher cost. A typical commercial module is rated between 200–300W with an open circuit voltage of about 20–30 V. The modules are arranged in series strings to achieve the required working direct (dc) voltage; for EV charging applications, this voltage is in the range of 200–500 V, depending upon the type of EV. To increase the array power, several series strings are connected in parallel. The main impetus for the PV–based charging station is the consistent drop in the module price. This can be related to the fact that in a typical PV project, the module comprises approximately 60–70% of the total investment; thus, the overall cost is very vulnerable to the price of this component.

## 4.  PV–EVCHARGING APPROACHES

In this section, two PV charging concepts, namely the (1) PV–grid and (2) PV–standalone, are presented. The PV–grid charging has the advantage that during insufficient solar irradiance, the EV can be continuously charged by means of the utility (grid) supply [17]. It is also more flexible because in the absence of EV (to be charged) the PV power can be injected to the grid. On the other hand, the PV–standalone is more beneficial in remote areas for example islands or deserts where utility supply is not available or too costly [18, 19]. Its configuration is simpler due to less power conversion stages needed.

### 4.1. PV–Grid Charging

### 4.1.1. General

Invariably, EV charging imposes an additional loading to the electricity grid [20-22]. This is because the current drawn from the grid, particularly for fast charging EV, can be very large. Furthermore, if the charging takes place during peak hours, the owner may have to pay a high premium for the tariff. Because the grid is the principal dynamic entity in any electrical power system and hence its burden should be controlled by proper way [23, 24]. To offset this burden, a PV–grid charging system is proposed [25]. From the grid operator's perspective, the availability of PV power translates to reduced spinning reserve requirements and greater grid stability [26]. Due to its multi–purpose capability, the PV–grid charging stations are attracting more interest from the EV community [27].

A typical PV–grid EV charging system (excluding the PV array and utility grid) has three main components, namely (1) an MPPT dc–dc converter (i.e. dc to dc power converter with a built–in MPPT), (2) a bi–directional dc charger and (3) a bi–directional inverter. A typical set–up for this configuration is shown in Figure 2 [28]. The dc common bus provides a convenient point for the integration of all associated components [29]. Its voltage varies for different systems, but 200–400 V range is typical. The MPPT dc–dc converter, which is usually based on the buck–boost or boost topology, is used to harvest the maximum power from the PV array. The PV voltage is further conditioned so that it can be transferred efficiently to the dc bus. The dc charger is used to control the voltage and current so that it suits the EV that is being charged. It also has bi–directional power flow capability.
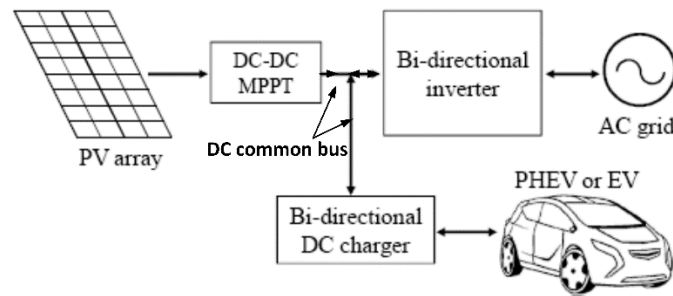
Figure 2. The PV–grid charging system for EV [29, 30]

The bi–directional inverter has dual functions: if the power on the dc bus is to be fed back to the grid, it behaves as a dc–ac converter (i.e. in inversion mode). On the other hand, if power needs to be drawn from grid to charge the dc bus, it has to be configured as an ac–dc converter (rectification mode) [31].

### 4.1.2. Practical PV–Grid Charging Systems

With the new features adopted by various researchers in charging schemes, the system becomes more flexible and is able to increase the battery lifetime [32]. This is achieved by introducing the battery management system, which is necessary to avoid the battery from overcharging and hence increasing battery life. Furthermore, with the expected proliferation of the smart grid topologies [1], the charger is  adaptable and can be integrated in the utility systems quite readily. There are also efforts to introduce the vehicle–to–vehicle (V2V) and vehicle–to–grid (V2G) concepts, as mentioned in [33-35]; whilst it may be useful for immediate or emergency charging, cautions have to be exercised with regards to the possible shortened battery life. Adding an additional battery storage unit in the system [17, 19] is also beneficial to reduce grid burden, but at the expense of initial investment and maintenance.

In [36, 37], the authors proposed a charging system where a dc–dc charger transfers the charging of EV from PV to grid during the last 20–30% of the charging phase to avoid the battery from experiencing unexpected PV output variations.

Another work in [2], proposedan extendable system having multiple charging ports with different levels (variable) of voltage output. Therefore, it can accommodate different types of EVs. The power control is done using the dc–dc converter and the algorithm unlike [37], which uses solid state relays for the same purpose. Grid tied dc–ac inverter and ac–dc rectifier are used instead of using bi–directional inverter[38].

On other place in [30], the authors used bi–directional dc–dc charger capable of operating in three modes. (1) mode 1: to charge EV battery only, (2) mode 2: to charge battery and support grid to control any variation in inverter's output and (3) mode 3: when battery is fully charged, the charger provides a support to grid to stable inverter output. Authors used single bi–directional inverter unlike using two converters as in [2].

The authors in [33, 34] proposed an intelligent fuzzy logic based smart charging system for parking lots. It manages energy in real time using forecasting models for PV output power and EV power requirement. For accurate prediction, hourly data, which have been collected over 15 years, are used. The system sets the charging priorities and the rate of charging. The charging priorities depend upon charging requirements of the EV like SOC and time of stay etc. While the charging rates depend upon predicted PV output power, EV power demand and grid energy price.

The reference [39] proposed a dc micro-grid consists of the PV, theand battery bank, and the grid. In the proposed system, the PV is coupled directly to the dc link without a static converter to reduce the control complexity. Also, a real-time rule-based algorithm is proposed to manage power among the PV, the battery and the grid. Here grid is taken as a backup and given last priority to charge the EV.

### 4.2. PV–Standalone Charging Systems

The PV–standalone charging refers to the charging of the EV solely by the PV power, i.e. without the involvement of utility (grid) [40, 41]. It is more efficient due to fewer power conversion stages [37, 42]. However, the PV array must be large enough to fulfil the charging requirement for the  designated number of EVs [43]. There are two ways to achieve the charging goals: (1) direct PV to the EV and (2) with an intermediate battery bank, placed in between the PV and the EV. The block diagrams for these two approaches are shown in Figures 3 (a) and (b), respectively. Both need a dc charge controller to ensure that the voltage suits the requirements of the EV. In the first approach, the power obtained from PV array is used directly to charge the EV battery. Clearly, the disadvantage is when the PV could not supply enough power to charge the

EV, and then the charging is compromised. Despite this fact, the set–up is simple; only one charge controller is needed – which is similar to the stand–alone PV system configuration. On the other hand, the intermediate storage battery bank approach enables the excess energy to be stored and to be utilized later when the PV power is unavailable because electrical energy is the lifeline of domestic, industrial, agricultural and approximately every field of life and should not be wasted by any cost [19, 44, 45]. Although this is more advantageous, the initial investment cost for the battery bank may not be feasible. In certain cases, battery storage is connected to in between the PV and the EV to filter the abrupt changes in the PV output power [46].



Figure 3. PV–standalone charging system (a) without battery, (b) with battery

### 4.2.1. Charging Operation

The main component of the standalone PV charging system is the charge controller. Basically it is a dc–dc converter with MPPT capability, with a special role to regulate the PV voltage so as to ensure the charging current is optimized [47-50]. Whilst different researchers propose various types of charge controller circuits, the primary components are shown in Figure 4 [51]. It comprises of two parts: (1) a voltage comparator which determines the magnitude of current that is appropriate for a proper charging operation [52] and (2) the MPPT block to extract the maximum power from the PV. The current reference generated by the voltage control loop is dynamically limited to have an upper value equals to the MPP current.



Figure 4.  Main building block of a PV–standalone charge controller

The dc–dc converter can be thought of as a controlled current source that injects a given amount of current i into the battery. The injection depends on the deviation in the battery voltage from a set reference value $V_{batt,ref}$. The MPP current referred to the output (inductor) side of the dc–dc converter is dynamically calculated by the MPPT algorithm as a function of the instantaneous irradiance, temperature and battery voltage. It is important to note that the voltage control loop will produce a large reference current due to the accumulation of error at normal operation under MPPT due to its integral action.To prevent output windup when the over–voltage control action starts, an anti–wind up is implemented to reset the integral output. For a

more sophisticated charge controller, intelligent battery management system is included to improve the charging mechanism.

**4.2.2 Practical PV–Standalone Charging Systems**
    To avoid the charging system from overloading and to synchronize the charging load with the availability of PV energy, the authors in [53], proposed a first–in–first–out (FIFO) algorithm to manage the charging queue in the parking lot. In another work [54], the authors introduced an adaptive PV–standalone system to utilize maximum available solar energy. To compensate for the partial shading and to avoid the problems arising from it, they use flexible switching matrix (FSM), Flexible String (FST), Flexible PV Module (FPVM) and Adaptive String (AST). The switching methods are controlled by an intelligent system that dynamically changes the interconnections of the system by sensing the shading conditions on the PV array.
    In [18] an additional battery bank is included in the system similar to the one shown in Fig. 3 (b). This bank consists of a second–hand partially degraded lithium batteries. The purpose of using second life batteries is to keep the system's cost lower. To make proper and optimal use of these second life batteries, a Battery Management System (BMS) is also included. The roles of BMS shall be described in the next section.
    An innovative EV charging system using hybrid energy storages is introduced in [21]. It includes batteries, super–capacitors and fuel cells. By utilizing more energy sources, the availability of energy and thus reliability of the system can be improved [18, 55]. The authors used two control algorithms; the first is used to interface between batteries and fuel cells, while the second manages the power between super capacitors and batteries.

## 5.    BATTERY MANAGEMENT SYSTEM (BMS)
    When an EV is plugged–in for charging, its battery's SOC is checked and continuously monitored to avoid overcharging. This is carried out by the battery management system (BMS). If charging system has V2G capability [33, 34], then over–discharging is also monitored using BMS. In addition, the SOC data can be used to forecast the remaining battery capacity; the results are used to predict the distance that can be covered by the EV. In the PV–grid charging system, the BMS controls the switching between the grid and the battery bank for charging the EV when the PV has insufficient power as demonstrated by [17, 56]. In the PV–standalone charging, the BMS can be used to regulate the battery voltage and to disconnect the battery from the PV when the latter produces current more than allowable maximum charging current [18, 57].
    Obviously, the energy capacity of a single battery cell is inadequate to drive the traction motor. The EV battery commonly needs thousands of single cells, packed in series/parallel connections, to form a battery module[58]. Since the Li–ion cells are sensitive to charge and discharge, they can neither be overcharged nor over discharged. Overcharging of batteries causes the temperature of different cells to rise unevenly which leads to the difference of voltage among each cell (cell imbalance). This increases its temperature. If not controlled, the available capacity of battery is decreased and its life–time is shortened. Figure 5 shows the location of the BMS in the EV system and its key operational parameters. The voltage, the current and the temperature are the key operational parameters that are continuously monitored to protect the cells [59, 60]. The BMS comprises of sensors, switches and controllers.
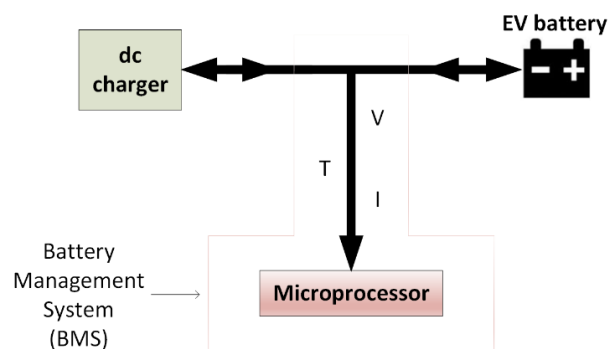


Figure 5. Key operational parameters in BMS

    The microcontroller algorithm executes various functions, namely (1) to determine the battery's SOC, (2) to perform cell balancing and (3) thermal management. An accurate estimation of SOC is very important to prevent from unintentional depletion [61]. The extremely high or low SOC may lead to permanent damage

in the battery. Since no direct method is available to measure SOC, it is estimated from the current, the voltage and the temperature measurements [61]. Several algorithms are used for the estimation, namely the Open Circuit Voltage (OCV) [62], Coulomb–counting (or A–h counting), Battery Model–Based [63], Neural networkand Kalman filtering methods [64].

The problem of imbalance among the cells worsens with time as the weak cells charge less effectively while the stronger cells charge faster [65]. The cell–balancing of the BMS functions to protect the cells by performing charge equalization among the cells. The most common approach is to interrupt the charging and discharging process, in order to avoid the battery cell from reaching its maximum and minimum allowable state of charge. The three main methods are (1) End of charge method, (2) Active method and (3) Passive method.

The cell imbalance phenomenon and the open circuit voltage of cells are usually varied in accordance to the temperature difference. Hence, the temperature of the battery should be continuously monitored and regulated to prevent the damage of the cells.

## 6. CONCLUSION AND FUTURE WORK

This paper is written to provide an overview on the technology, the operation and the status of the available PV charging methods. With the expected high incursion of EV into the grid system, the issue of PV–grid integration with the charger will be more demanding. It is envisaged that more sophisticated energy management system is required to manage the charging stations for large number of EVs. The main issue is to avoid grid interruptions when several EVs are simultaneously plugged into the system during very short period of time. At the same time, it is important to optimize the EV charging based on the availability of the PV power, real time electricity demand and tariff structures. Furthermore, the safe charging procedures using battery management system need to be maintained to ensure long life of the EV batteries. The integration of various energy sources (besides the PV), for example fuel cell, wind turbines and stand–by battery to the smart grid is also a possible area to be investigated. Although this integration increases the capital cost, it may be economical when long term running cost is considered. These are interesting topics that provide exciting further research opportunities in this area.

## REFERENCES

[1] F. Locment, M. Sechilariu, and C. Forgez. *Electric vehicle charging system with PV Grid-connected configuration*. in 2010 IEEE Vehicle Power and Propulsion Conference (VPPC). 2010; pp. 1-6.

[2] G. Gamboa, C. Hamilton, R. Kerley, S. Elmes, A. Arias, J. Shen*, et al. Control strategy of a multi-port, grid connected, direct-DC PV charging station for plug-in electric vehicles*. in 2010 IEEE Energy Conversion Congress and Exposition (ECCE) 2010; pp. 1173-1177.

[3] K. Branker, M. J. M. Pathak, and J. M. Pearce. A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews.* 2011*;* 15(9): 4470-4482.

[4] A. Iqbal, M. S. B. Arif, S. M. Ayob, and K. Siddiqui. Analysis of a solar PV/battery/DG set-based hybrid system for a typical telecom load: a case study. *International Journal of Sustainable Energy.* 2015: 1-18.

[5] R. Liaqat and A. R. Bhatti. *Management and conservation of electrical energy in industrial units*. in Proceedings of the International Conference on Power Generation Systems Technologies. 2011.

[6] *http://www.scopus.com/ [accessed 20.09.15].*

[7] S. J. Chiang, S. Hsin-Jang, and C. Ming-Chieh. Modeling and Control of PV Charger System With SEPIC Converter. *IEEE Transactions on Industrial Electronics.* 2009*;* 56(11): 4344-4353.

[8] M. Alonso Abella, M. A. F. ChenloAbella, and F. Chenlo. *Photovoltaic charging station for electrical vehicles*. in Proceedings of 3rd World Conference on Photovoltaic Energy Conversion. 2003; pp. 2280-2283.

[9] S. Li and C. Zhang. *Study on Battery Management System and Lithium-ion Battery*. in International Conference on Computer and Automation Engineering. 2009; pp. 218-222.

[10] C. C. Chan. An overview of electric vehicle technology. *Proceedings of the IEEE.* 1993*;* 81(9): 1202-1213.

[11] R. Anusuyadevi and S. Pandiarajan. Maximum Power Point Tracking of DC To DC Boost Converter Using Sliding Mode Control. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2013*;* 3(3): 321-327.

[12] V. J. Chin, Z. Salam, and K. Ishaque. Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review. *Applied Energy.* 2015*;* 154: 500-519.

[13] A. H. Fanney, B. P. Dougherty, and M. W. Davis. Short-Term Characterization of Building Integrated Photovoltaic Panels. *Journal of Solar Energy Engineering.* 2003*;* 125(1): 13-20.

[14] J.-H. Song, Y.-S. An, S.-G. Kim, S.-J. Lee, J.-H. Yoon, and Y.-K. Choung. Power output analysis of transparent thin-film module in building integrated photovoltaic system (BIPV). *Energy and Buildings.* 2008*;* 40(11): 2067-2075.

[15] O. Vetterl, F. Finger, R. Carius, P. Hapke, L. Houben, O. Kluth*, et al.* Intrinsic microcrystalline silicon: A new material for photovoltaics. *Solar Energy Materials and Solar Cells.* 2000*;* 62(1–2): 97-108.

[16] M. Yamaguchi, T. Takamoto, K. Araki, and N. Ekins-Daukes. Multi-junction III–V solar cells: current status and future potential. *Solar Energy.* 2005*;* 79(1): 78-85.

[17] G. Preetham and W. Shireen. *Photovoltaic charging station for Plug-In Hybrid Electric Vehicles in a smart grid environment.* in Innovative Smart Grid Technologies (ISGT). 2012; pp. 1-8.

[18] S. J. Tong, A. Same, M. A. Kootstra, and J. W. Park. Off-grid photovoltaic vehicle charge using second life lithium batteries: An experimental and numerical investigation. *Applied Energy.* 2013*;* 104(0): 740-750.

[19] S. Mesentean, W. Feucht, H. G. Kula, and H. Frank. *Smart charging of electric scooters for home to work and home to education transports from grid connected photovoltaic-systems.* in 2010 IEEE International Energy Conference and Exhibition (EnergyCon). 2010; pp. 73-78.

[20] M. D. Galus and G. Andersson. *Demand Management of Grid Connected Plug-In Hybrid Electric Vehicles (PHEV).* in IEEE Energy 2030 Conference. 2008; pp. 1-8.

[21] M. Benaouadj, A. Aboubou, M. Becherif, M. Y. Ayad, and M. Bahri. *Recharging of batteries/supercapacitors hybrid source for electric vehicles application using photovoltaic energy in a stand-alone point.* in 2012 First International Conference on Renewable Energies and Vehicular Technology. 2012; pp. 161-166.

[22] A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, and K. P. Yee. A critical review of electric vehicle charging using solar photovoltaic. *International Journal of Energy Research.* 2015*;* 40(4): 439-461.

[23] A. R. Bhatti, Y. Saleem, A. G. Bhatti, F. Hayat, and T. Izhar. On-Line Operational Database System for UET Power Plant. *Journal of Faculty of Engineering & Technology.* 2013*;* 20(1): 55-62.

[24] A. R. Bhatti, A. G. Bhatti, R. Liaqat, S. Noreen, E. Rehman, and Z. Salama. Selection of Power System on the Basis of Best Combination of Power Source and Busbar Scheme. *International Journal of Electrical and Electronics.* 2013*;* 118(I): 160-165.

[25] C. Hamilton, G. Gamboa, J. Elmes, R. Kerley, A. Arias, M. Pepper*, et al. System architecture of a modular direct-DC PV charging station for plug-in electric vehicles.* in IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society. 2010; pp. 2516-2520.

[26] Makena Coffman, Paul Bernstein, and A. Mann, "Statewide and Electricity-Sector Models for Economic Assessments of Hawai'i Clean Energy Policies," 2012.

[27] N. Naghizadeh and S. S. Williamson. *A comprehensive review of power electronic converter topologies to integrate photovoltaics (PV), AC grid, and electric vehicles.* in 2013 IEEE Transportation Electrification Conference and Expo (ITEC) 2013; pp. 1-6.

[28] A. R. Bhatti and Z. Salam. *Photovoltaic (PV) Charging of Electric Vehicle (EV).* Electrical Engineering Research Colloquium For Electronics, Power, Instrumentation & Control And Communication (EERC-2013). 2013*;* 1; 102-103.

[29] J. Traube, L. Fenglong, and D. Maksimovic. *Electric vehicle DC charger integrated within a photovoltaic power system.* in Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition. 2012; pp. 352-358.

[30] J. Traube, L. Fenglog, and D. Maksimovic. *Photovoltaic power system with integrated electric vehicle DC charger and enhanced grid support.* in Power Electronics and Motion Control Conference 2012; pp. 1-5.

[31] S. A. Khan, M. I. Hossain, and M. Aktar. Single-Phase PFC Converter for Plug-in Hybrid Electric Vehicle Battery Chargers. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2012*;* 2(3): 325-332.

[32] D. B. Richardson. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. *Renewable and Sustainable Energy Reviews.* 2013*;* 19(0): 247-254.

[33] M. Tan, A. Mohamed, and O. Mohammed. *Optimal charging of plug-in electric vehicles for a car park infrastructure.* in 2012 IEEE Industry Applications Society Annual Meeting. 2012; pp. 1-8.

[34] T. Ma and O. Mohammed. Optimal Charging of Plug-in Electric Vehicles for a Car Park Infrastructure. *IEEE Transactions on Industry Applications.* 2014*;* 50(4): 2323 - 2330.

[35] F. Islam and H. Pota. V2G technology to design a smart active filter for solar power system. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2013*;* 3(1): 17-29.

[36] H. C. Lamb, E. K. Stefanakos, T. Smith, B. Krakow, C. Hernandez, R. Rodriguez*, et al. Efficient photovoltaic charging of electric vehicles.* in Southcon/94. Conference Record. 1994; pp. 47-52.

[37] M. Vaidya, E. K. Stefanakos, B. Krakow, H. C. Lamb, T. Arbogast, and T. Smith. *Direct DC-DC electric vehicle charging with a grid connected photovoltaic system.* in Photovoltaic Specialists Conference, 1996., Conference Record of the Twenty Fifth IEEE. 1996; pp. 1505-1508.

[38] B. Arif, M. Saad, and S. Md Ayob. *A novel single phase five-level photovoltaic based grid-connected inverter.* in 2014 IEEE Conference on Energy Conversion 2014; pp. 325-330.

[39] F. Locment and M. Sechilariu. Modeling and Simulation of DC Microgrids for Electric Vehicle Charging Stations. *Energies.* 2015*;* 8(5): 4335-4356.

[40] A. Abu-jasser. A stand-alone photovoltaic system, case study: A residence in gaza. *Journal of Applied Sciences in Environmental Sanitation.* 2010*;* 5(I): 81-91.

[41] A. R. Bhatti, Z. Salam, M. J. B. A. Aziz, K. P. Yee, and R. H. Ashique. Electric vehicles charging using photovoltaic: Status and technological review. *Renewable and Sustainable Energy Reviews.* 2016*;* 54(1): 34-47.

[42] N. A. Kelly and T. L. Gibson. Solar photovoltaic charging of high voltage nickel metal hydride batteries using DC power conversion. *Journal of Power Sources.* 2011*;* 196(23): 10430-10441.

[43] D. P. Birnie Iii. Solar-to-vehicle (S2V) systems for powering commuters of the future. *Journal of Power Sources.* 2009*;* 186(2): 539-542.

[44] A. R. Bhatti, A. G. Bhatti, M. Amjad, Y. Saleem, T. Izhar, and F. Hayat. A Comparison of Output Waveforms of Different Alternating Current Sources and Uninterruptible Power Supplies of Various Brands. *Life Science Journal* 2012*;* 9(4): 637-642.

[45] A. G. Bhatti, A. R. Bhatti, I. A. Chaudhary, and M. N. Javed. Energy crisis in pakistan, adaptation and mitigation measures. *Journal of Faculty of Engineering & Technology.* 2012*;* 19(1): 67-82.

[46] J. Mossoba, M. Kromer, P. Faill, S. Katz, B. Borowy, S. Nichols*, et al. Analysis of solar irradiance intermittency mitigation using constant DC voltage PV and EV battery storage*. in 2012 IEEE Transportation Electrification Conference and Expo 2012; pp. 1-6.

[47] J. Ahmed and Z. Salam. A Maximum Power Point Tracking (MPPT) for PV system using Cuckoo Search with partial shading capability. *Applied Energy.* 2014*;* 119: 118-130.

[48] J. Ahmed and Z. Salam. An improved perturb and observe (P&O) maximum power point tracking (MPPT) algorithm for higher efficiency. *Applied Energy.* 2015*;* 150: 97-108.

[49] J. Ahmed and Z. Salam. A critical evaluation on maximum power point tracking methods for partial shading in PV systems. *Renewable and Sustainable Energy Reviews.* 2015*;* 47: 933-953.

[50] M. F. N. Tajuddin, M. S. Arif, S. M. Ayob, and Z. Salam. Perturbative methods for maximum power point tracking (MPPT) of photovoltaic (PV) systems: a review. *International Journal of Energy Research.* 2015*;* 39(9): 1153-1178.

[51] S. G. Tesfahunegn, O. Ulleberg, T. M. Undeland, and P. J. S. Vie. *A simplified battery charge controller for safety and increased utilization in standalone PV applications*. in Clean Electrical Power (ICCEP), 2011 International Conference on. 2011; pp. 137-144.

[52] N. Amin, M. A. Azim, and K. Sopian. *Development of cost effective charge controller with data acquisition options for PV powered sensor nodes*. in 33rd IEEE Photovoltaic Specialists Conference. 2008; pp. 1-4.

[53] P. Kadar and A. Varga. *PhotoVoltaic EV charge station*. in 11th International Symposium on Applied Machine Intelligence and Informatics 2013; pp. 57-60.

[54] M. Alahmad, M. A. Chaaban, and L. Chaar. *A novel Photovoltaic/Battery Structure for Solar Electrical Vehicles [PVBS for SEV]*. in 2011 IEEE Vehicle Power and Propulsion Conference (VPPC) 2011; pp. 1-4.

[55] D. M. Robalino, G. Kumar, L. O. Uzoechi, U. C. Chukwu, and S. M. Mahajan. *Design of a docking station for solar charged electric and fuel cell vehicles*. in 2009 International Conference on Clean Electrical Power. 2009; pp. 655-660.

[56] P. Goli and W. Shireen. PV powered smart charging station for PHEVs. *Renewable Energy.* 2014*;* 66(0): 280-287.

[57] P. Raman, J. Murali, D. Sakthivadivel, and V. S. Vigneswaran. Opportunities and challenges in setting up solar photo voltaic based micro grids for electrification in rural areas of India. *Renewable and Sustainable Energy Reviews.* 2012*;* 16(5): 3320-3325.

[58] L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang. A review on the key issues for lithium-ion battery management in electric vehicles. *Journal of Power Sources.* 2013*;* 226(0): 272-288.

[59] Electropaedia. Battery Management System (BMS). *Woodbank Communications Ltd, UK.* 2005.

[60] R. Passarella, A. F. Oklilas, and T. Mathilda. Lithium-ion Battery Charging System using Constant-Current Method with Fuzzy Logic Based ATmega16. *International Journal of Power Electronics and Drive Systems (IJPEDS).* 2014*;* 5(2): 166-175.

[61] B. P. Divakar, K. W. E. Cheng, H. J. Wu, J. Xu, H. B. Ma, W. Ting*, et al. Battery management system and control strategy for hybrid and electric vehicle*. in 3rd International Conference on Power Electronics Systems and Applications. 2009; pp. 1-6.

[62] M. Dubarry, V. Svoboda, R. Hwu, and B. Y. Liaw. Capacity loss in rechargeable lithium cells during cycle life testing: The importance of determining state-of-charge. *Journal of Power Sources.* 2007*;* 174(2): 1121-1125.

[63] G. Lijun, S. Liu, and R. A. Dougal. Dynamic lithium-ion battery model for system simulation. *IEEE Transactions on Components and Packaging Technologies.* 2002*;* 25(3): 495-505.

[64] P. Singh, R. Vinjamuri, X. Wang, and D. Reisner. Design and implementation of a fuzzy logic-based state-of-charge meter for Li-ion batteries used in portable defibrillators. *Journal of Power Sources.* 2006*;* 162(2): 829-836.

[65] C. Pascual and P. T. Krein. *Switched capacitor system for automatic series battery equalization*. in Twelfth Annual Applied Power Electronics Conference and Exposition. 1997; pp. 848-854.

**BIOGRAPHIES OF AUTHORS**

Abdul Rauf Bhatti received the B.Sc. and M.Sc. degrees in Electrical Engineering from the University of Engineering and Technology (UET), Lahore, Pakistan, in 2004 and 2008, respectively. He is currently pursuing his Ph.D. degree in Electrical Engineering from Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia.
He was a Lecturer at Government College University Faisalabad, Pakistan, for 9 years. He got best teacher award for the years 2009-2010. His research interests include Photovoltaic (PV) prediction modeling, energy management with special focus of charging the electric vehicles (EV), electrical machines, Matlab simulations and intelligent control.

Zainal Salam received the B.Sc. degree in electronics engineering from the California State University, Chico, CA, USA, the M.E.E. degree in electrical engineering from the Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia, and the Ph.D. degree in power electronics, from the University of Birmingham, Birmingham, U.K., in 1985, 1989, and 1997, respectively.
He is currently the Professor in power electronics and renewable energy at the Faculty of Electrical Engineering UTM. Since 2011, he has been the Editor of IEEE Trans. Sust. Energy. He represents the country as the expert for the International Energy Agency (IEA) PV Power Systems Task 13 Working Group, which focuses on the reliability and performance of the PV power system.

Mohd Junaidi Abdul Aziz received his B.S. and M.S. in Electrical Engineering from the Universiti Teknologi Malaysia (UTM), Malaysia, in 2000 and 2002, respectively, and his Ph.D. in Electrical Engineering from The University of Nottingham, U.K, in 2008.
He has been with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Malaysia Since 2008, where he is currently a Senior Lecturer. His research interests include power electronics and electric vehicles with a special focus on battery management systems.

Kong Pui Yee received the B.Eng. degree in electrical engineering from Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia in 2011. She is working towards M.Sc. degree at UTM. She is currently a Research Assistant in the Department of Electrical Power Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia. Her research interests include ac-dc converter, control and power electronics.