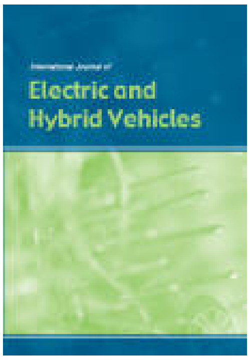

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Comprehensive review on charging solution of electric vehicle - an internet of things-based approach

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Comprehensive review on charging solution of electric vehicle – an internet of things-based approach

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Abstract: Electric vehicles (EV) are bringing in a new era in transportation by reducing emissions, noiseless operation, and the efficient consumption of energy compared to the internal combustion engine (ICE) vehicle, though EV has significant limitations in terms of battery capacity, lack of long-range travel, long charging time, and cost. A smart and optimised charging technique will help the consumer for the energy consumption of EV as per time of use as well as sharing of charge in the interest of charging cost reduction and increasing energy demand due to EV charging may affect the load balancing of the power system. The charging infrastructure development may increase the performance criterion. This paper includes a brief discussion about EV components which will help the researcher for a quick overview of EV and an improved charging solution for EV is proposed.

Keywords: electric vehicles; EVs; EV charging; charging strategies.

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1 Introduction

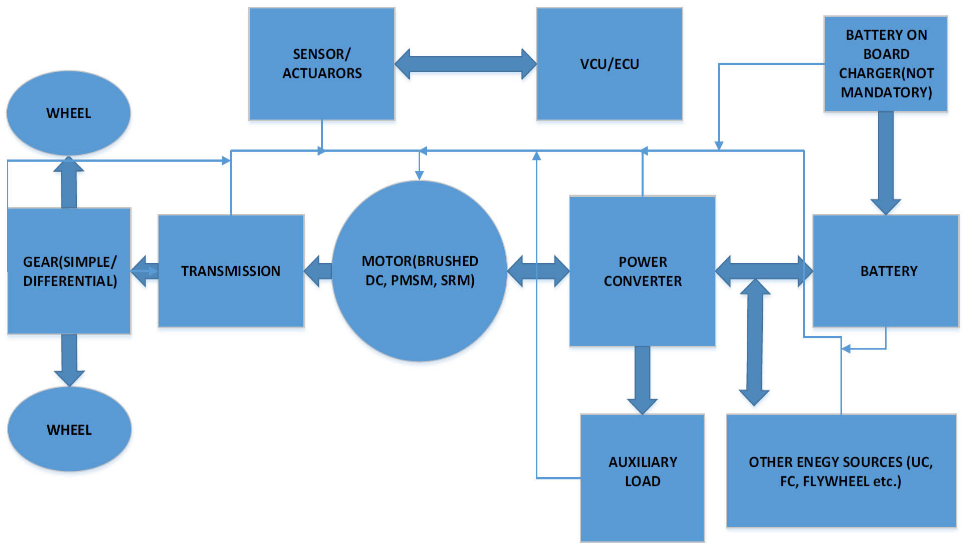
In this century, EV is the key attention of researchers, leading to intensive and extensive study because it is a green transportation tool and almost zero-emission device. After the development of EV the usage increases drastically within some time. It results in some new challenges about the safe operation of power systems due to the consumption of energy. Throughout the world, the usage of EV is increasing due to safe fuel, high power, safe, and comfortable riding. EV manufacturing companies are Tesla, BMW, Nissan, Chevrolet, Ford, Volkswagen, Kia, etc. EVs are the future of transportation due to their lower emission, noiseless operation, and can be used as power regulation. The three main limitations are the charging time, range anxiety, and cost. Battery development may reduce the problems and research is going on for the high-density low- cost battery. EV is full of components and these are interrelated so the design for each component should be proper because the power level of any component may be affected by the operation of another component. Charging of EV plays an important role due to its frequent requirement and power fed externally by a charger. The power demand level is growing for EV charging. A solar power-based charging station is helping to reduce the consumption of power at an available time.

A real-time battery-supercapacitor-powered HESS was developed and controlled by nonlinear control theory. The objective of the controller is to track the set speed of EV wisely that it can reduce battery usage. It is simulated under the UDDS cycle and a recorded city driving cycle to demonstrate its effectiveness (Zhang et al., 2019). SPHEV architecture has been modified using a planetary gear which made the system series or parallel hybrid mode but less efficient than THS. Hereby topology modification the new model has been proposed which is optimised by two methods GA and DP. Which of one is worsen and another is efficient (Kabalan et al., 2019). Power-split HEV has been formulated as a nonlinear and constrained optimal control problem and using MPC strategies power split between engine and battery has been optimised by simulation under multiple standards drive cycle which results in noticeable improvement of fuel economy (Borhan et al., 2012). New EMS optimised for a hybrid charging station for EV and fuel cell vehicle. The proposed system is to reduce the utilisation cost of ESS. Optimisation depends on a cost prediction system. Efficiency improved by the fuzzy controller and solve by PSO. Here results show that this charging model has better efficiency (+7.35%) (Garcia-Trivino et al., 2019). HESS suffers from the problem of battery longevity due to sudden power demand or fluctuation in charging/discharging. A Super-capacitor has a low capacity it cannot satisfy the power demand. Here time-series the forecasting method was used and then the T-S fuzzy modelling method was used and finally, the MPC power management problem was formulated. By simulation, it has been shown that 17.81% of battery life is prolonged (Hu et al., 2019b). Various challenges of power electronics for EV propulsion, charging and power accessories are explained here, its context with the comparison of EV and its body, motor, EV propulsion, charger, battery, ECU, power accessories. The development of power electronics technology will make the EV more efficient (Chan and Chau, 1997). EV research background includes charging, mathematical analysis and control strategies. Types of charging techniques are centralised pile charging, distributed pile charging, and battery replacement. BMS is the basis of EV and smart charging Technique has been developed. Advance charging control technology with nonlinear control theory, fuzzy, chaos control, etc. Wireless charging technique has been developed by electromagnetic induction, electromagnetic resonance, and high-frequency radio waves. Including PV systems used to enable renewable energy sources. Optimisation of the converter is required for high performance (Zhang et al., 2016). Optimal control systems and LQR are used for EV for minimum use of energy and maximum average speed with minimum operational cost. MATLAB model is simulated considering the slope, air/drag, rolling load under various driving conditions. Model-based design is used to solve the problem of managing multi-domain complexity. It results in that energy efficiency and average speed 0.0175 m/s faster (Wicaksono and Prihatmanto, 2015). Optimal Control of PMSHM drives using state feedback control and GWO technique. Using mathematical model developed state space model and GWO were applied to acquire weighting matrices in LQR optimisation. A penalty term is used to suppress overshoot and compare it with and without using the penalty term. It shows that the state feedback controller using the penalty term shows better results (Sun et al., 2019). IoT-based control algorithm has been proposed to get estimation, Indication of various parameter information alerts in smart devices. Estimate SoC vs distance travel and lifetime. Range estimation and crash detection also optimised in Sudheer et al. (2020). Smart charging stations were handled effectively by the grid-connected PV system and acted as UPS based on TOU tariff. Using Raspberry Pi and IoT the charging can be made optimum. MATLAB model shows the result of PEV charging data (Divyapriya and Vijayakumar, 2018). Braking energy is used to control the speed of the EV using a fuzzy logic controller. Using regenerative and frictional force braking safety and stability can be optimised. Using BLDC motor MATLAB model is simulated and results show the positive speed increasing after using FLC (Agrawal and Shrivastava, 2017). Object detection and recognition are used for vehicle detection and using the waterfall method validation and training completed. After Fourier transforms using a deep learning model object localised and recognised. Equalisation, median filter, feature extraction, cascade object detector and classification, recognition its results the detection (Mouna and Mohamed, 2019). A mathematical model and adaptive controller are shown here to solve the problem of an autonomous vehicle overtaking having the information of inter- vehicle position and orientation by the onboard sensor data. It is investigated as a tracking problem with desired polynomial virtual trajectories in real-time. Results show the time history of the vehicle parameters (Petrov and Nashashibi, 2014). Modelling and simulation of EV and HEV have been developed composing V-Elph having the electric motors, batteries, IC engine, and other components to create the drive train in MATLAB. Simulation results in the vehicle speed, torque, and current in both EV and HEV (Wicaksono and Prihatmanto, 2015). EV attributes to solve environmental pollution and get rid of petroleum resources. Having several types of charging methods are constant current charging, constant voltage charging, pulse charging. The main difficulties are cost, capacity, and security. Other than cycle life, dynamic performance, mileage is also a limitation. The energy management system of EVs has great scope to be developed. V2G technology can buffer power to a grid where the control strategy needs improvement to perform better. Impacts of load, capacity of power grid, and power charging time have the most important drawback. Hybrid technology has the key technology to reduce cost (Zhou et al., 2016). The nonlinearity of suppression, tier, and seat is analysed and the model has been built. The bifurcation and chaotic motion of the system under sinusoidal excitation considering the time delay between the front and rear tyres are studied here (Wu and Sheng, 2012).

Increased number of PEV conventionally charged from G2V and for the energy back up it can be used as V2G also. For the emergency, the V2V charging is quite helpful as there is a lack of a charging station. Previously the portable charger is used to charge the V2V. Here multi-function EV charger is proposed and developed in MATLAB which needs only the V2V cable (having SAE J1772 socket) to charge. Here two H-bridge converter has been used one for constant DC-DC converter and the other one DC-AC and AC-DC converter operate in different control strategies as per requirement and have the capability to charge up to charger maximum power ratio otherwise it was limited to 325 W (Taghizadeh et al., 2020). A complete EV is developed by the researcher using two nos. 12 KW PMSM and two IGBT power electronic converters with a control board TMS320F28335DSP. Here the energy storage system has used the battery pack along with the UC with DC-DC buck-boost converter. Using the given data of the vehicle the required power to drive the motor is 11KW which does not exceed the motor rating. The mathematical model has been developed here behind the calculation. The battery has been charged using SMPS whereas the discharging is controlled by the PI controller to lengthen the battery life. A driving test is done in IM240 dynamometer and vehicle velocity and SOC of BP has presented here which successfully delivered power from the battery to load however acceleration may be improved (Park et al., 2016). EV is used to reduce pollution and produce efficient output for transportation. For proper evaluation of EV, a model is required so in this paper a model has been developed in Modelica which can be developed in multi-domain. Here synchronous motor has been used to drive the EV. The different sensor is used to get the value of current, voltage, SOC, velocity, etc. The simulation results show the SOC, variation of power, and mechanical torque for the NECD profile having a specified vehicle with a given parameter. It is a model-based design that gives way to better modification for efficient operation of EV (Guizani et al., 2016). Using the commercial software (i.e., MATLAB SimDriveline) the model of EV has developed by the researcher. Physical modelling is the exact presentation of the real-world object of EV which must satisfy the other objects parameter at the time of representation. Automated mechanical transmission is introduced to control heavy-duty applications. The battery pack and UC is managed by EMC as well as to improve the driving experience. Simulation under the USSD cycle shows the motor speed, torque, current, and UC voltage while shifting gear. This model allows simulation under different controllers to validate the design (Zhou et al., 2014). FPGA board and processor are used to communicate between MCU and plant. For a given vehicle work mode the motor torque, SOC, vehicle speed has been observed as well as the real car result also shown. This work is more realistic for EV power train optimisation for real-world experiments (Wang et al., 2015). To reduce the instant charging and discharging an IoT-based model has developed to obtain the nearest traffic, having GPS data can be optimised using a MPC Method which results in reduced discharging power (Hu et al., 2019a). Life cycle assessment of vehicle is reviewed in Tintelecan et al. (2020), which provide detailed data and comparison of different EV and its impacted speed control with stabilisation is achieved using the FLC at the time of stable or transient condition which achieves a better speed regulation. For the battery voltage, the speed has been regulated in a real-time digital power system simulator (Veysi et al., 2020). Hybrid EV efficiency is higher for the particular split of the energy for the ICE and the electric power. Generally, rule-based methods are implemented for the simple operation of EV. But for real-time, multiple domain optimisation different algorithm approaches are used, i.e., DP, GA, MPC, etc. Considering different driving conditions adaptive EMS control strategies are developed (Liu et al., 2019).

Intelligent hybrid EVs (IHV) use the concept of advanced driver assistance system (ADAS) which is generally used for the safety purpose but using this concept IHV significantly develops the eco-driving. Depending on the information flow the energy flow has been developed depending on the external constraints, i.e., traffic, geographical obstruction, etc. Using the electronically scanning radar (ESR) and the radar control unit (RCU) help to get the data from the external which processed and using the vehicle control unit VCU () the EMS is optimised and efficient driving range is fetched (Zhao et al., 2019). Fundamental of the HEV is to shift from one energy source to another energy source for the optimum operation. This shifting creates jerk and stress on the clutch which may discomfort the passenger. A cascade predictive method is used to control constraints of jerking and a PID-based controller is used to take care of the engine torque response (Fu et al., 2019). Importance of fault tolerance increases due to the electrification of the vehicle. Elaborately the fault tolerance is the ability to take care of the fault in the system and help the vehicle to stop safely. The passive and active fault is to be determined to optimise the fault and there must be some feature that can handle the situation. For presumed fault or minor fault, there must be an indication and for serious fault, some backup protective system is used to determine the fault. The fault hypothesis is determined from the previous survey of vehicle fault detection and diagnosis (Wanner et al., 2012). All-wheel drive EV has the possibility of the fault of a single motor in a fatal condition which may cause instability in running condition. The fault tolerance control system has been developed using a stability control algorithm which is distributed for the front and rear wheel separately. Several faults may occur, i.e., short circuit, open circuit, demagnetisation, torque overload, etc. Electronically stability control theory helps to withstand the fault. Simulation results show that using ESE serious instability can withstand and the system controls the situation (Lee and Lee, 2020). In EV, speed must be regulated and manage the power flow from the energy storage system subsequently. The controller is used to control the speed of the EV at the desired speed and also manage the power flow from the energy storage system and also manage the power balance between multiple energy sources (when it is a multi-energy storage system). As the real track of EV is not a linear system so the EV must follow the Lyapunov-based nonlinear controller to handle the nonlinear EV dynamics (Zhang et al., 2019). The cruise control system has the advantage to reduce the loss of power of the EV. Average speed cruising reduces the excess power consumption for heavy or moderated traffic conditions where higher speed can cause aerodynamic loss and reducing the speed by regenerative braking in average traffic speed may give a higher travel range. Using two-vehicle as host and another one as an experimental vehicle the analysis has been performed in the Cambridge Green Challenge using Nissan e NV200 (Madhusudhanan and Na, 2020).

Figure 1 Basic block diagram of EV powertrain (see online version for colours)



The basic block diagram of the EV power train is shown in Figure 1. ICE vehicles are conventional vehicle that uses IC Engine for the generation of mechanical power. Its drive train contains engine → clutch → transmission → differential gear → wheels. EVs are run by the electric motor which has different characteristics than the Conventional ICE. Different power trains are implemented for the EV drive train system. Several drive train system are discussed here, i.e.:

a conventional type: battery → converter → motor → transmission → differential gear → wheel

b transmission less type: battery → converter → motor → differential gear → wheel

c cascade type: battery → converter → joint motor on wheel

d in wheel type with reduction gear: battery → converter → in wheel type with reduction gear

e in-wheel direct drive type: battery → converter → in-wheel motor

f four wheel direct drive type: battery → converter → front and rear in-wheel motor.

Effects of EV are going to change the era of the ICE vehicle and help to transport in green environment. Though it will help to transport, decrease fuel charge, etc. it will have some impact on the power grid, economy, and human acceptance. From the literature survey, it is observed that there is a lot of development opportunity in EV development. To make EVs feasible in daily transportation some important development is required for ease of use.

Apart from all the discussions reported in the literature, the main findings are described below:

- EV charging techniques are developing for easy and fast charging. As per requirement various charging strategies for the optimum charging solution of electric vehicles are discussed.
- Charging of EV is directly related to the energy storage system so the knowledge of energy storage system is necessary. A comparative analysis of the various energy management techniques in an EV is established.
- For hybrid energy storage system and in case of charging and discharging process power converter is the key component. Power converter architecture for the solar powered hybrid charging vehicle is proposed for the future development of the charging infrastructure to get optimum power utilisation.
- To make the charging procedure easier the IoT connected vehicle with advance feature is necessary. As the EV charging process is lengthy in the fast life of human civilisation so there need to be more optimal way of charging that consumer can easily handle the charging process. An IoT-based charging infrastructure is proposed for EV charging which may lead to the optimal solution of charging/discharging of power and balancing process.

In this paper, the basic structure and equipment are discussed, and the main contribution to propose a charging infrastructure that leads to help the consumer for a smart charging facility where the battery charging will be optimal and using the IoT-based connected vehicle and charging station will communicate with each other that will reduce the communication rates in CAN bus. Security and safety in the charging station are achieved more and optimum charge for the battery helps to reach the rider to the destination. Using AI the charge level SOC optimisation is featured.

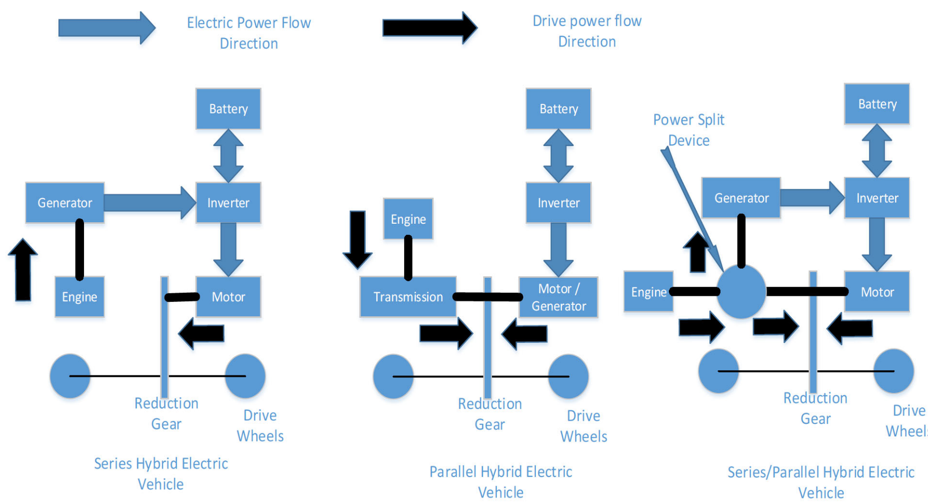
The remainder of this article is presented as follows: Section 2 represents the EV topologies and its working principle, Section 3 describes the overview of EV motor, Section 4 discussed the different energy sources of EV and reports the comparison of power and energy density, Section 5 establishes the power converter architecture for the optimal charging and discharging process, Section 6 represents the detailed overview of EV charging including PV charging station, solar powered EV, V2G, V2V, wireless charging and IoT base charging station, Section 7 reports the limitation of performance criterion of EV, Section 8 establishes the proposed strategies of EV charging and Lastly Sect 9 concludes the paper accordingly.

2 EV Topologies

EVs run using the storage energy of battery conventionally. But due to the requirement of optional power in different prospects, the combination of two or more energy sources is used to feed the motor of an EV. Depending on the combination the EV has been categorised as battery EV (BEV), hybrid EV (HEV), plug-in hybrid EV (PHEV) and fuel cell EV (FCEV).

Figure 1 shows the powertrain of a battery EV whether the source may be changed. Power is fed from the grid or renewable energy sources. A high-density battery is used in BEV for a longer range. Battery, motor, charging facility, control system should be developed for better efficiency which helps for consumer acceptance.

Figure 2 Block diagram of series hybrid EV, parallel hybrid EV, series/parallel hybrid EV (see online version for colours)



Source: Alamoudi et al. (2019)

ICE and electrical energy source have been combined here to run the vehicle. Some topologies are defined to characterise the minimum consumption of fuel and maximum efficiency as per requirement. One source work at a time and different combinations are discussed below:

a Series hybrid EV: here power flow is done in series. Generally, it is a basic battery EV where ICE is placed and works to charge the battery and therefore the battery fed the motor which is directly connected to the wheel. Converters are required to charge the battery and drive the motor. Figure 2 shows the diagram of a series hybrid EV.

b Parallel hybrid EV: ICE and the motor are coupled with the direct transmission and share the driving load. When ICE works the motor work as a generator and charges the battery and absence of ICE it works as a motor. A converter works to charge the battery and also run the motor.

c Series/parallel hybrid vehicle: it is a combination of both series and parallel. There is a switching phenomenon to shift from series to parallel and vice versa.

d Crankshaft mounted integrated stator/generator (ISG) system-based hybrid vehicle: parallel hybrid vehicle which can run ICE and battery separately or both at a time. For higher torque regions like start, hill climbing ICE is used and for constant running, electric motor works (Alamoudi et al., 2019). There are some others hybrid EVs, i.e., micro hybrid, mild hybrid, and full hybrid EVs.

3 Overview of EV motor

EV needs acceleration to catch the base speed that requires torque in the time of starting a movement of the vehicle and when it acquires base speed then constant low torque required for the cruising whereas the industrial motor requires the same phenomenon but the base speed is higher than the EV motor base speed because the operating range of the industrial application motor is wider within the starting torque. So the selection of the motor of the EV is important that provide the constant torque requirement for the acceleration time and power requirement for the time of the constant run. The motor speed and torque are very much related. Comparing the feature it can be summarised that permanent magnet BLDC is most efficient whereas the weight of the SRM is lower and the cost of the brushed DC motor is lower. But in the perspective of the EV SRM is the most suitable motor for the EV due to the cooling, extended speed operation, fault tolerance capability, and reliable, lower weight.

Due to the higher cost of the motor, the overall cost of the EV cannot reduce and there is a need for a more efficient operation of the motor that can improve the range of the vehicle. Several developments are going on in the motors of the EV. The current review as per Wang et al. (2021) says that PMSM is one of the best motors for the EV due to its high torque and high power density. Having construction change the cost of PM can be reduced in PMSM which reduces the overall cost. IM is PM less and low-cost motor but due to less efficiency, this is not adopted. The cost of SRM is lower than the PMSM but due to low torque and other problems like torque ripple and noise, it uses in some vehicles only, example, Tesla Model 3 (2020) use PMSM of 211–340 kW motor, Mercedes-Benz EQC (2019) uses IM 150 kW $*$ 2 (Wang et al., 2021). Power density increment with cost reduction is the optimal solution for the development of EV motor. Stator and rotor development for the machine reduces the harmonic losses and reduced the torque ripple. Driving cycle oriented motor development may result in efficient performance for energy consumption. Novel topologies are used to derive the efficient motor, i.e., stator PM machine, flux memory and hybrid excitation machine, multiphase machine, magnetic gear machine, reconfigurable winding machine, etc. which have special configuration and working principle which give efficient output for EV (Shao et al., 2020).

4 Different energy sources of EV

Energy management systems play an important role in the context of EV development. After 1960 step by step evolution of battery, motor makes the road wider for the EV.

EMS plays a vital role for the EV power so predictive maintenance, parameter sensing, safety should be indulged (Aruna and Prabhu, 2019). EVs should have a high power density and high energy density storage system. From the consumer perspective fast charging, long battery life, a higher life cycle is required which create a challenge to the researcher.

a Battery: energy density, power density, lifetime, cycle life, price, operating temperature, charging time, fast charging, self-discharge, maintenance all are important phenomena for a battery. In an EV battery is the primary source of energy fed to the motor and other accessories of the EV. There is a lot of battery used in EV, i.e., lead- acid, NiMH, Li-ion, Ni-Zn, Ni-Cd, etc. All these batteries have their pros and cons regarding cost, weight, life cycle, maintenance, etc. Tesla S model uses a Li-ion battery in an 85 kWh pack. In the battery pack for keeping voltage in balance different equaliser is used to maintain the voltage, i.e., resistive equaliser, capacitive equaliser, basic inductive equaliser, etc. Li-ion batteries are using every place due to their high energy density, good performance, and lower weight. But the cost is not much budget-friendly so researches going on for improving cost efficiency (Loganathan et al., 2019).

b Ultra capacitor: it consists of two electrodes and works like the capacitor having a voltage rating proportional to the battery SoC. For different road conditions, the sudden change in power and for the terrain (positive or negative) the sudden change of energy is balanced by the UC. It is placed parallel to the battery with a controller.

c Fuel cell: using electrochemical reaction the FC creates electricity which is fed to the motor of EV. It uses hydrogen which is oxidised in the electrode to create electron movement. It is noiseless, low emission but high cost. UC is used with fuel cells for better performance and FC and battery combination is also used.

d Flywheel is used as a prime mover for spinning and keeps rotating using kinetic energy whether there is a sudden change in power. It can absorb power more efficiently from regenerative braking. Though multiple energy sources are used in today's EV. Table 1 shows the comparison of energy and power density of a different storage system.

Table 1 Comparison of energy and power density of different storage system

Storage	*Energy density*	*Power density*
Battery	High	Low
Ultra capacitor	Low	High
Fuel Cell	High	Low
Fly Wheel	Low	High

Source: Un-Noor et al. (2017)

The power management in EV is a new era of findings because multiple source energy storage devices are used for the efficient operation of EV. So there are various energy sources, i.e., fuel cell, battery, super capacitor, PV cell, flywheel, etc. They may place separately or a combination of two or more. Li-ion battery and super capacitor pack are used here (Hu et al., 2019b) and the power management is rule-based which is simple fuzzy logic. The super capacitor pack helps to reduce the discharging of the battery during sudden load change as a result the battery SoC is improved.

Fuzzy logic-based two-HESS system has proposed by Eckert et al. (2020) which consist of one single motor for the rear with differential gear and for the front wheel two separate motors is used which is connected with different HESS. Generally, the HESS system has developed for the combinational power flow of two or more sources and also the optimisation of the power split division using GA. It increases the driving range of the vehicle. The use of the two HESS reduces the battery size and the ultra-capacitor which is used is suitable for fast charging (Eckert et al., 2020).

5 Power converter architecture for hybrid charging system

Power converters are power electronic devices that convert the electrical energy from DC to AC and AC to DC as per the required magnitude. These devices are made by GTO, BJT, MOSFET, IGBT, static induction transistor, static induction thyristor, etc. Depending on the voltage, current rating, switching frequency the power electronic devices must be selected and research is going on to find the optimum converter for the use of requirement of fast charging of EV. PWM inverters are used for the feeding of the battery. From the last decade, different switching scheme has been developed for better utilisation of DC voltage link. The discrete pulse modulation scheme is used for converter betterment (Chan and Chau, 1997).

Power and signal multiplexing technique is proposed in Zhang et al. (2020) for the communication between the charging point and the EV where it reduces the communication complexity and wire requirement. A three-phase multilevel inverter is proposed which is a cascade inverter for the motor speed adjustment and battery balance system and controlled by PWM and communication channel used in parallel with the frequency shift keying (FSK) approach.

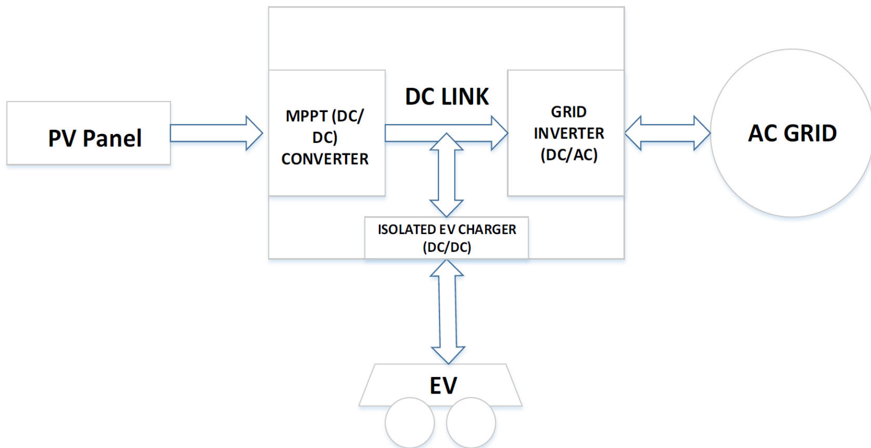
The multilevel inverter is implemented on EV charging operations and is also used for the PV MPPT operation. In Dhanamjayulu et al. (2021), a 53-level inverter has been proposing using the cascade connection of the switched capacitor (SC). For various road conditions, the higher level inverter is implemented for the simple use of operation for various voltage levels. MLI reduces the cost and the size of the inverter is reduced due to the reduction of switches.

For the requirement of high power and efficiency, a multi-source charging station is shown in Figure 3, three converters are needed to complete the operation. The PV-connected hybrid energy charging station needs one unidirectional DC-DC Converter for the PV panel, one bidirectional DC/AC grid inverter which is a 3-phase inverter that operates with DC link, and one bi-directional DC-DC converter for the charging of EV. Silicon-based power electronics devices are used to get high switching frequencies. Generally, the expected operation is grid to EV charging and when Solar power available it may be PV to EV or combined operation of grid and PV to EV. Otherwise, the power-sharing of EV flows from EV to the grid. In the absence of an EV, the PV panel power is fed to the grid. The power balance equation is given in equation (1).

$$P_{ac} = P_{ev} - P_{pv} + P_{loss} \tag{1}$$

where the P_{ac} is grid power which fed the EV power demand P_{ev} and P_{pv}, P_{loss} are the PV panel output power and the converter losses respectively (Mouli et al., 2018).

Figure 3 PV connected hybrid energy charging station using three converter (see online version for colours)



Source: Mouli et al. (2018)

Bidirectional AC/DC converter: generally the use of AC/DC converter is increasing due to the wide range of applications of charging purpose and drives control. Greater firing angle is increased the power factor and introduces lower order harmonics. IGBT or MOSFET is the best choice for the converter where the bi-directional scheme completely depends on the operation of the switches. For the same converter, the rectifier mode generates DC output for battery charging whereas the inverter mode generates the AC power fed to the grid.

Bidirectional DC/DC converter: DC-DC converter is used for the wide range of the operation of the driving in EV. It is efficient to operate in higher efficiency. Buck-boost operation is created to charge and discharge the battery. In the case of the unidirectional DC/DC converter, the power flow is in one direction generally used to cultivate power from the PV array (Singh et al., 2020).

6 Detailed overview of EV charging

EV charging is the most important era for the researcher due to its requirement of several developments. EV charging is categorised into three types, constant voltage charging, constant current charging, and pulse charging. Constant voltage charging maintains the voltage across the battery which increases the charging time for constant current charging where the value of current is constant. In pulse charge, the battery is fed using different pulse which helps to fast charging depending on the pulse feeding (Zhou et al., 2016). There are various AC and DC charging systems used that has different configurations. Several charging standards are used, i.e., IEC 61851: conductive charging system, SAE J2293: energy transfer system, SAE J2344: EV safety guidelines, etc.

EV charging stations are categorised in different ways. For the mobility of the vehicle several charging stations are required. These charging stations are also categorised in fixed, mobile and contactless charging process. Generally fixed charging stations are home charging, public charging, AC charging, and DC (fast) charging. In AC and DC charging there are three and two level of charging respectively which is categorised depending on the power level. Depending on the availability of power, constructability the stations are constructed, i.e., PV connected charging stations are useful in remote places rather than urban area. Security of the charging is necessary for unexpected loss of power. Different connecters are used to connect the EV among them CHADEMO DC fast charger is secured because it remain locked during the charging process. Commercial analysis for the setup of charging station has been discussed in Pal et al. (2016). Battery swapping may be solution for the instant charging of EV but due to lack of reliability and availability it has less practical feasibility. Two types of charging methods are used. ON board charging: for battery EV charging circuit is on the vehicle and its use for less energy. It uses J 1772 and the charger is an additive weight for the vehicle and OFF board charging: it is placed in the charging station and used for the higher KW. It reduces the weight of the EV and fast charging facility is available.

Real-world data have a lot of difference from the experimental data so the actual performance of EV has experimented with in Flanders living lab. The EVA and iMore are the platform of the Flanders lab and generate GPS data, charging data, power measurement with the value of voltage and current along with the tank-to-wheel energy that is consumed. Using standard cycle the simulation has done which results in Nissan Leaf shows 60–80% power to the wheel from a 100% grid power (De Cauwer et al., 2015).

The need for fuel for an EV is fast charging. Compared to the conventional gasoline vehicle the refuelling time is higher for normal charging. So the fast and especially extremely fast charging is necessary due to the need of the consumer as they are habituated for instant filling of the fuel. The proposed extreme fuel charging technology in Tu et al. (2019) needs a solid-state transformer and an advance power converter topology. DC fast charging ABB Tera HP can charge up to 350 kW which is the maximum till now which can give enough fast charging in 10 min (minimum). An alternative way of wireless fast charging is deployed but lower efficiency due to the lower susceptance. Fast charging DC cables are available with the highest capability of 175 kW (IEC 62196-3) in a 1,000 V supply. AC and DC extreme fast charging station is proposed in which the AC is a better solution from all aspect but DC has better efficiency in lower cost (Tu et al., 2019). Fuzzy logic-based rule developed here for three charging infrastructure, i.e., distributed, battery swapping, and fast charging. Battery swapping and fast charging is required in the daytime where there is a rush and the distributed charging is available all the time and if the consumer is aware of the cost efficiency he/she will charge the vehicle at peak load time at a lower energy cost. From the cost curves, it is determined that a rule-based charging infrastructure can be more economical (Sachan and Mortka, 2020).

AC charging systems are used for charging the EV because EV needs DC voltage that can be feed from the household supply using an AC-DC converter. There are different levels of the conversion of energy. Where in DC charging there is the arrangement of DC power using power cable and fed to the battery of EV which has the fast charging capability. On-board, charging has been used to get rid of the charger (Un-Noor et al., 2017).

There are three charging levels of EV, i.e., level 1, level 2 and level 3. Level 1 is for slow charging at 120 V/15 A. Where level 2 is for both 120 V and 240 V having a higher charging rate compare to level 1. Level 3 is a fast-charging scheme of 480 VAC. Using supervised and unsupervised learning the charging procedure may be classified by the prediction from previous data. Due to the lack of the datasheet of public charging, the finding moves towards cluster analysis (Shahriar et al., 2017).

Charging model: for charging model has been developed here,

1 Charging by constant current where the battery has been kept in series, as a result, it prolonged the time of charging and due to the nonlinearity; the battery life may be shortened.

2 Charging by constant voltage where the charging time is fast but due to the high initial current, may reduce the battery life.

3 Fast charging using the concept of the pulse helps to depolarise the battery and make fast charging.

4 Stage-wise charging at first constant current charging to meet the terminal voltage then constant voltage charging for fast operation. This is combination charging which helps comparatively fast charging and keeps the battery healthy (Zhang et al., 2016).

In advance charging model control the control strategies are used for the charging of the battery. The battery has several nonlinear parameters so keeping all this into account the battery charging can be optimised by different control theory, i.e., chaos control, fuzzy logic, etc.

AC-DC converter is used to charge the EV generally but always it will not meet the required value of the current. So DC-DC converter is used to convert the required voltage and current level of the EV.

Due to the increasing demand for EVs, the charging facility needs to be developed. EV generally charged from fixed charging station, mobile charging station, and wireless charging station. Fixed charging stations are the main source of EV charging which is developed at a different point and wireless charging technique research is going on. But mobile charging station is discussed in Afshar et al. (2020) where the charging has mobility nearer to the EV. It may reduce the anxiety of the consumer from a distance range. Mobile charging stations are portable, truck mobile and V2V charging. Battery swiping is an easy charging procedure instantly though it is not so much efficient due to the battery degradation the truck charging station concept is better for the emergency need of the charging. The charging truck maybe with battery storage or without the battery storage increases the availability of charging.

Charging stations are mainly three types domestic, public and commercial. A public charging station is needed for future use of the EV. Domestic charging is not possible for all purposes and this will increase the demand for public charging. EV public charging station includes the energy management unit which communicates with the grid for the power requirement. Multiple charging points decided on the EV charging procedure. For the V2V infrastructure, it is also communicating with other vehicles and decides to fetch or deliver power as per the requirement with cost estimation. Decision making for the vehicle is to get the right and optimum charging for the on-board or the grid-connected charging station (Hariri et al., 2018).

For inter-vehicle or V2C and G2V charging, multifunctional charger is required with is capable of bi-directional charging. AC-DC converter is used here for the PWM converter and VSI for the power consumption and the power fed to the grid. Generally, a DC-DC converter is used for the optimum charging voltage for each vehicle (Suhara et al., 2018).

Various charging techniques and architectures for reliability and efficiency in energy storage systems are as follows:

a PV charging station

For the environmental concern, the use of renewable energy sources is increasing day by day and it has an impact on EV also. For green transportation, the conventional vehicle is transformed into an EV and the EV power is fed from the grid. But the use of solar charging stations may reduce the use of grid power when it is available. Nowadays the development of solar panel it fetch the better amount of power. Solar charging stations have a grid supply if the need for the vehicle does not meet the EV then the grid will serve the power and at night time. Battery backup is used for the absence of both PV and grid which is rare. Mainly the battery is used to supply the auxiliary load for the charging station.

Combination of PV cell, battery, grid all there is connected for a charging station. MPPT and PID controllers are used for the DC-DC converter to maintain the terminal voltage and power. Current control bi-directional converter is used for the battery because when a load of EV charging is not available then the PV cell power sends to the battery and in absence of solar power the battery is used to work for the charging of the EV. For the power demand of the EV, the combination of PV, grid, and battery will be a necessity to charge the vehicle as well as reduce the rise of the grid power demand curve along with backup power (Biya and Sindhu, 2019).

b Solar powered EV

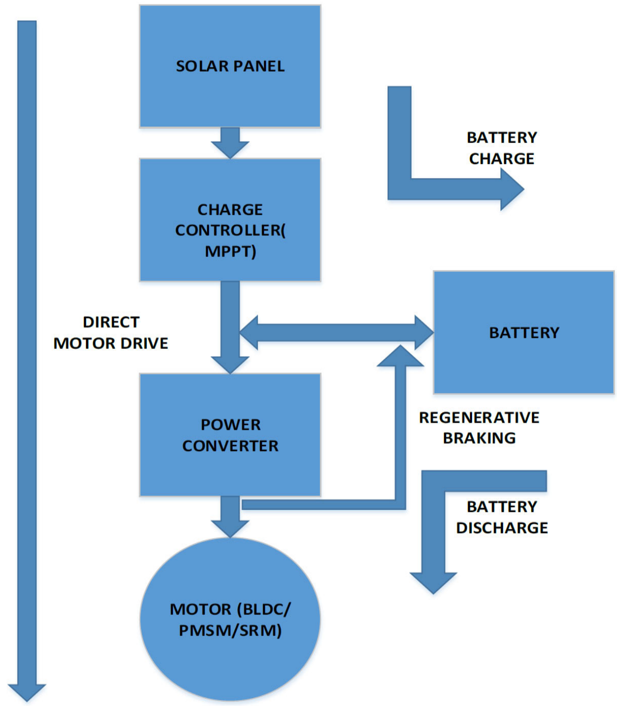
Solar power is one of the renewable energy sources that can be fed as an energy source in EV. PV cell is the source of electrical energy in presence of the sun. Solar power is not certain so a battery is used as storage to give power in the absence of the sun. A charger/charge controller is needed for the maximum power point tracking from the PV panel. It’s designed by MPPT algorithm and it maintains the balance between PV cells, battery, and motor/load. In presence of sunlight, the PV cell serves the energy to the motor or combinational energy serve by the battery and PV cell. But in the absence of sunlight, the motor is run by the battery only. Figure 4 shows the block diagram of a solar-powered vehicle (Blaga and Kovacs, 2014).

Hybrid energy storage is used for solar-powered EVs. Where super capacitor is used to give power for the sudden change of the load while solar power is absent and also in the presence of solar power the super-capacitor helps to withstand the voltage fluctuation of the PV array. This needs a control circuit and individual DC-DC converter for each purpose (Porselvi et al., 2019).

PV cell on the top of the EV is used to fetch the power of solar energy to the EV battery or motor. The effective area is calculated for the PV cell to cultivate more energy with the angle tilt. Depending on the tilt angle and the orientation of a single

PV cell has been optimised and then total series-parallel combination has been calculated depending on that cell (Schuss et al., 2019).

Figure 4 PV fed battery EV block diagram (see online version for colours)



Source: Blaga and Kovacs (2014)

For mono-crystalline solar panels the efficiency is 21% and capture up to 300 W power in a 1.6 m^2 area. The parking lot is the space where the shades are already used. Installed PV cells on the roof of the parking lot and the building also can cultivate green energy and use it as the charging power of the EV. Solar power is not available all the time so it is needed to have an arrangement for the backup power and optimised control is used for the co-operation of the charging process maintain continuously (Anna et al., 2018).

Power flow between the EV and the EV to the grid has been handling in the parking of a car. In the parking time, the optimal charging and discharging procedure have been developed using a flow chart. This parking holds the grid connection along with a storage device and panel control scheme for the consumer to use as a charging and discharging scheme. The parking information is monitored through a Wi-Fi enable system and the fee for the charging and parking will be calculated and paid by the consumer (He et al., 2018). The charging of EV is one of the most important phenomena to bring the EV to commercial and public usage levels. So the proposed architecture can be developed in the prototype-based and then it can be applied for the bigger usage of more number of entities of the EV charging. A Lyapunov-based optimisation algorithm is used for this MCS availed charging procedure of EV (Chen et al., 2018).

It is a multiple power source charging station where not a single power is fed for the charging. Hydrogen fuel cell, grid connection, battery energy storage, and PV cell are connected to form the charging station. The advantage of the charging station is that it will help to supply power continuously. The PV is kept as a main power source for the EV but as it may not fulfil the demand always the hydrogen fuel cell is used to serve the power and that needs energy management system (EMS) to balance the demand. The grid is connected to the secondary supply if demand is not fulfilled. The battery storage system has been used for the long-term period of charging as backup power for the charging station (Garcia-Trivino et al., 2019). Breakthrough of the EV technology increases the demand for the power to feed the battery of the EV which creates a huge impact on the power system. So the recent EV integration with the power grid needs classification to reduce the stress of power demand. Optimal charging of EV can reduce the stress of the power demand and may fetch economic incentive (Patil and Kalkhambkar, 2020).

EV charging load has several impacts on the power grid, i.e., power quality deterioration due to the use of power electronic converter it generates the harmonics, voltage fluctuation which causes voltage instability. Transformer life is going to reduce due to the constant stress. Stability, supply-demand balance, harmonics increase of the power grid has to be taken into consideration. But above all EV gives a green environment which reduces the use of non-renewable energy and gets rid of the emission (Garwa and Niazi, 2019).

c Vehicle to grid technology (V2G)

Vehicle to grid technology helps to reduce the power demand and helps to utilise the power plant more. The growing demand for power due to the EV may cause a higher load demand which directly has an impact on generating stations. The consumer will charge the vehicle at a low-cost power consumption period and able the EV battery connected to the grid and use as a power supply unit. This will have a good impact on the power generating station because it will help to adjust the consumption and demand respectively. Though the use of power electronic devices, it may cause the generation of harmonics so it will issue about the power quality. Power quality must be improved for this case using high voltage charging and discharging and also use the harmonic suppression and reactive power device (Zhou et al., 2016).

d Vehicle to vehicle technology (V2V)

Convention charging is from grid to vehicle is used and the reverse procedure that is vehicle to the grid has been discussed earlier which helps the grid to use the vehicle as a storage unit point. Now the new development of vehicle to vehicle charging has been proposed here. Instead of a portable charger, a cable with an SAE J1772 socket only transfers the power from one vehicle to another vehicle using of vehicle multifunctional charger. This charger enables the EV to get power from the charging station and also charge at the time of the vehicle to vehicle charging (Taghizadeh et al., 2020).

Integrated on-board chargers are essential for the V2G, G2V, and V2V operation. Enhanced topology increases the charging efficiency and reliability. The charger enables to connect to the charging station and other vehicles and capable of delivering power as per requirement. Optimisation of the charger for the power feeder and receiver is through communication.

Time of usage: the huge demand for charging creates stress on the grid so the optimised charging may relieve the grid from stress and fluctuation also. The Monte Carlo method is used to check and simulate the power demand of different vehicles and the vehicle response ratio is defined under different time of usage prices. Identifying the fluctuation of the grid for different vehicle charging the maximum satisfaction index is optimised and solves using the NSGA-II algorithm which results in a significant improvement in the grid voltage quality (Shi et al., 2018).

e Wireless charging

Wireless power transfer is using to charge the EV battery without any contact. There is no need for a cable to charge the EV. It is in R&D stage and due to the safety concern till now it is not used in commercial EV. Several wireless charging techniques are invented, i.e., inductive power transfer, capacitive power transfer, PM coupling power transfer, resonant inductive power transfer, etc.

Wireless charging is the solution for the vehicle's quick charging and helps to get power in the time of running condition. The dynamic charging station can be placed anywhere on the road though it is not suitable for every condition. But this procedure can reduce the range anxiety and for the heavy EV, it helps to reduce the battery size and weight. In the case of V2V charging, the dynamic wireless charging helps to transfer power at any instant just only the vehicles are placed to each other. There needs a lot of development for the wireless charging of the EV which indulges the future EV more accomplished (ElGhanam et al., 2020).

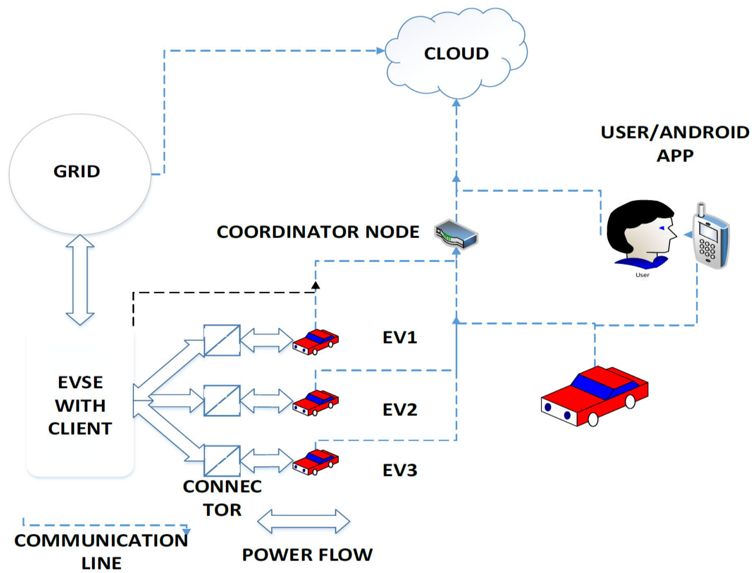
f IoT-based EV charging station

The demand for the charging of the EV can easily operate using IoT communication and the mobile charging station. Fixed charging stations have several drawbacks for on-road vehicle charging due to space, power consumption, etc. IoT devices are used to communicate with the base station which has all the data of the charging requirement and has the mobile charging station, as a result, the EV may be in the parking lot or road it can be get charged easily.

IoT level 5 generally used multiple nodes concerning a coordinator node wherein IoT level 6 consisting of multiple independent nodes. In Figure 5 the IoT level 5-based coordinator node sends the data to the cloud and the user can access the data or processed it to the database. Each EV client device fetches the data of battery state to the user, nodes, and nearby vehicle. Client devices are used to measure the data parameter and share the information to the nearest node and control the charging/discharging operation. User ID with a unique identification number is embedded in the memory of the EV client that cannot be changed. The coordinator node gets the data from the cloud of the nearby vehicle and after the computational algorithm, it decides the schedule for V2G charging (Chamola et al., 2020).

In Kharade et al. (2020), the charging slot availability is proposed which reduces the hazard for the consumer. Due to the unavailability of an EV charging station, the proposed IoT-based system guide the user to the nearest charging station and also gives the data for the availability of the charging slot and also the time.

Figure 5 IoT-based general architecture for the charging of EV (see online version for colours)



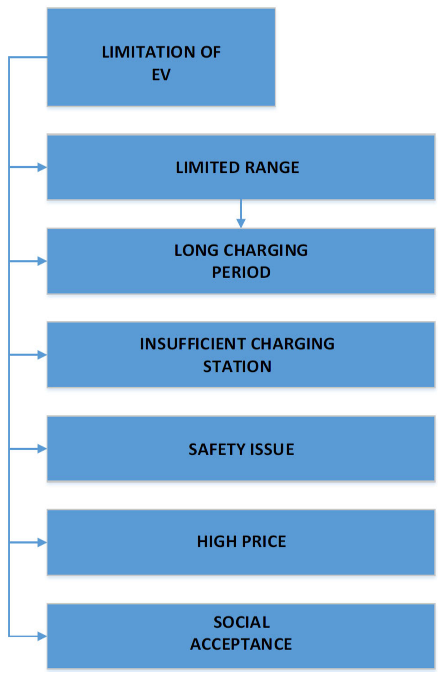
7 Limitations on performance criterion of EV

Research and development are going on to overcome the limitations of the EV. From social acceptance to lack of charging infrastructure, all these are affirmative. But the main concern is about battery development and fast charging with good charging infrastructure which may reduce all the problems because the development of battery, EV charging, motor, drivetrain, and optimisation may reduce the cost of the EV, which help for social acceptance. Hybrid vehicle is more convenient than conventional EV. Battery power management (SoC optimisation) is one of the most important phenomena in EV for more efficient operation. Charging of EV becoming fast enough due to more powerful converter and smart technique used to enhance for ease of operation. The electric motor of EV is power-full, efficient, robust, and fully controllable for precise control. Monitoring of the vehicle parameter through smart devices is useful for efficiency, safety, and smooth operation. V2G technology is used for future EV power operating systems. Speed control is operated by ECU which uses different control theories for better efficiency. Vehicle detection techniques are used for safety and smooth operation. Bifurcation and chaotic theory are used to study the mechanical nonlinearity (i.e., tyre, seat, etc.). Figure 6 shows the limitations of the EV. The following developments may overcome the limitations

- battery development for higher density but the lower cost is very much required
- the energy storage system is to be developed for efficient energy consumption
- charging procedure is the most important domain that has to be developed (easy charging solution)
- charging must be fast enough and optimised

- V2G charging is necessary for power balancing
- V2V charging is important for emergency services
- fault prediction is most important for the safety and operability
- the driving strategy should be developed for more efficiency and power optimisation
- IoT-based connected vehicles should be developed more for easy use
- AI may be used for charging and discharging procedure for efficient daily operation.

Figure 6 Limitation of the EV (see online version for colours)



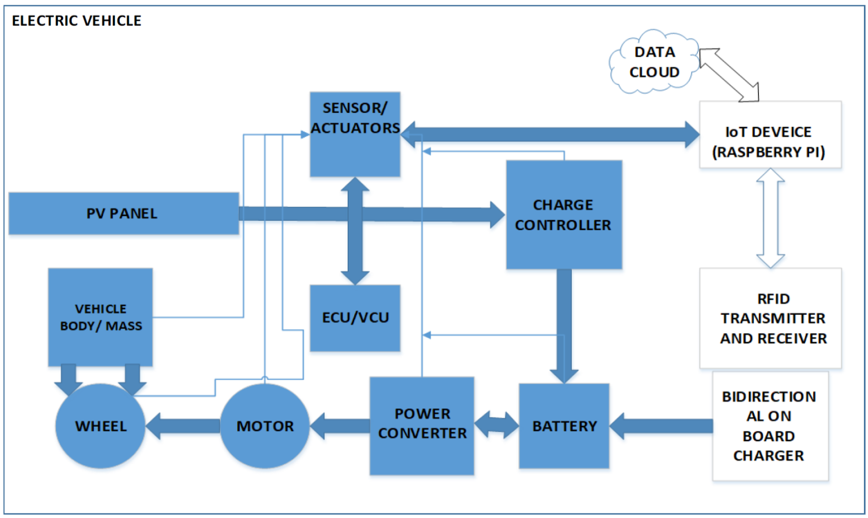
8 Proposed strategies of charging of EV

The following block diagram is given where the proposed model of the charging infrastructure has been presented.

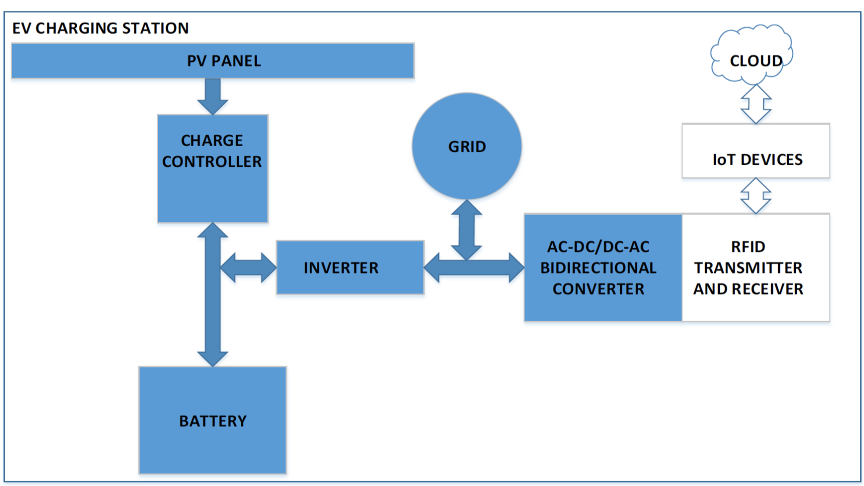
In Figure 7(a), the proposed block diagram of EV is presented. The EV will be connected using an IoT device and the RFID tag of the EV will share the information and confirmation of the presence of EV before the charging/discharging process is started, For V2V the RFID will also help to share information and the data against the charge sharing will not be charged at a price directly. It will be stored as data for a particular period and then it will be charged after all charging and discharging processes. In discharging process the cost will reduce from the account. Including the parking, charge waiver grows interested to share the charge. Figure 7(b) shows the block diagram of the hybrid charging station, which includes the PV panel to cultivate energy in the daytime.

The cost of the charging and discharging must be set in a way that consumers will be enthusiastic to charge in the low peak period and share the charge in the high peak period. Optimal charging and discharging procedures will be deduced by some AI algorithm approach which may be helpful for the consumer that how much energy should be shared or consume.

Figure 7 Overall block diagram of the proposed work (white blocks), (a) block diagram of proposed EV (b) block diagram of proposed charging station



(a)



(b)

Design an IoT (cloud)-based battery charge monitoring and tariff system for each vehicle and charging station which optimised the charging and discharging by AI technique (may have zero fuel cost). For vehicle, it contains an RFID-based (unique address) IoT device which is swiped whenever the charger port is connected or for V2V charging and charged and discharged data is stored in the cloud. For charging station, RFID receiver with IoT connected cloud which does the same as the vehicle. V2V charging both of them swiped by each other RFID and store data to the cloud by the usage. Solar parking lot or normal parking lot with cloud-based charging station (may have zero parking charge).

Benefit:

- no fixed charging time (car may be charged for 5 min or whole day)
- get rid of tariff payment at each time
- increasing load on power grid maybe retained
- usage of solar power may increase
- users may get more charging station and less fuel cost.

9 Conclusions

To defeat the environmental pollution EVs have a good feature to reduce the pollution in the transportation sector and may be the biggest solution in the future for saving the Earth from greenhouse gases and global warming. EV will be the best alternative in future to reduce the emission and protect the environment for the sustainable development. Using the non-conventional energy for the power of EV gives a greener environment by the smart technology of power handling. In this paper EV powertrain, architecture, energy sources, power converter, charging of EV have been discussed. The main components and sustainable development of EV technology are reviewed and precise discussion on them is presented here. Solar power EV and charging station may give a promising solution of alternative power supply in EV. The limitation of the current EV has been forecasted and the development possibility to overcome these limitations is discussed here. The charging solution of EV is focused and a detailed discussion is presented and a new charging architecture is proposed. The IoT-based proposed smart charging station/parking lot technology gives the solution for the consumer for more smart charging that they can share the charge as per costing rate which is fixed by the time of usage and IoT cloud will store all the data and charged once waving the parking fee, neither every time of charging nor at the time of charge sharing. The power grid will be stressed less at the peak load time and at the off-peak period the power consumption will increase. In the future charging solution will be a promising way to get rid of the long-distance anxiety and lack of a charging station. From the zero to complete evolution of ICE vehicles to EV needs a lot of charging infrastructure.

Above the smart charging optimised and autonomous charging and charge sharing will help to resolve the problem of the power sector which should the future of the charging solution. The proposed solution gives a basic concept of the development of charging solutions for the need of further research.

References

Afshar, S., Macedo, P., Mohamed, F. and Disfani, V. (2020) 'A literature review on mobile charging station technology for EVs', *IEEE Transportation Electrification Conference & Expo (ITEC)*.

Aghabali, I., Bauman, J., Kollmeyer, P., Wang, Y., Bilgin, B., Emadi, A. (2020) '800V EV powertrains: review and analysis of benefits, challenges, and future trends', *IEEE Transactions on Transportation Electrification*, Vol. 99, No. 3, p.1.

Agrawal, S. and Shrivastava, V. (2017) 'Speed control of EV using fuzzy logic controller', *International Conference on Information, Communication, Instrumentation and Control (ICICC)*.

Alamoudi, Y.A., Ferrah, A., Panduranga, R., Althobaiti, A. and Mulolani, F. (2019) 'State-of-the-art electrical machines for modern EVs', *Advances in Science and Engineering Technology International Conferences (ASET)*.

Anna, Z., Mikolaj, S. and Andrzej, B. (2018) 'Cooperation of the process of charging the EV with the photovoltaic cell', *Applications of Electromagnetics in Modern Techniques and Medicine (PTZE), IEEE Conference*.

Aruna, P. and Prabhu, V.V. (2019) 'Review on energy management system of EVs', *2nd International Conference on Power and Embedded Drive Control (ICPEDC)*.

Baggio, A. and Grimaccia, F. (2020) 'Blockchain as key enabling technology for future electric energy exchange: a vision', *IEEE Access*, Vol. 8, pp.205250–205271.

Biya, T.S. and Sindhu, M.R. (2019) 'Design and power management of solar powered EV charging station with energy storage system', *3rd International conference on Electronics, Communication and Aerospace Technology (ICECA)*.

Blaga, C. and Kovacs, E. (2014) 'Some myths and facts of electric road vehicles', *International Symposium on Power Electronics International Symposium on Power Electronics Electrical Drives, Automation and Motion*.

Borhan, H., Vahidi, A., Phillips, A.M., Kuang, M.L. and Kolmanovsky, I.V. (2012) 'MPC-based energy management of a power-split hybrid EV', *IEEE Transaction on Control System Technology*, Vol. 20, No. 3, pp.593–603.

Chamola, V., Sancheti, A., Chakravarty, S., Kumar, N. and Guizani, M. (2020) 'An IoT and edge computing based framework for charge scheduling and EV selection in V2G systems', *IEEE Transactions on Vehicular Technology*, Vol. 69, No. 10, pp.10569–10580.

Chan, C.C. and Chau, K.T. (1997) 'An overview of power electronics in EVs', *IEEE Transaction on Industrial Electronics*, Vol. 44, No. 1, pp.3–13.

Chen, H., Su, Z., Hui, Y. and Hui, H. (2018) 'Dynamic charging optimization for mobile charging stations in internet of things', *IEEE Access*, Vol. 6, pp.53509–53520.

Das, U., Biswas, P.K. and Sain, C. (2020) 'A noble control approach for brushless direct current motor drive using artificial intelligence for optimum operation of the electric vehicle', *Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles*, pp.17–47.

De Cauwer, C., Maarten, M., Heyvaert, S., Coosemans, T. and Van Mierlo, J. (2015) 'EV use and energy consumption based on real world EV fleet trip and charge data and its impact on existing EV research models', *World EV Journal*, Vol. 7, pp.436–446.

Deng, R., Liu, Y., Chen, W. and Liang, H. (2019) 'A survey on electric buses-energy storage power management, and charging scheduling', *IEEE Transaction on Intelligent Transportation System*, Vol. 22, No. 1, pp.9–22.

Dhanamjayulu, C., Padmanaban, S., Ramachandaramurthy, V.K., Holm-Nielsen, J.B. and Blaabjerg, F. (2021) 'Design and implementation of multilevel inverters for EVs', *IEEE Access*, Vol. 9.

Divyapriya, S. and Vijayakumar, A.R. (2018) 'Design of residential plug-in EV charging station with time of use tariff and IoT technology', *International Conference on Soft-computing and Network Security (ICSNS) IEEE*.

Duan, B., Xin, K. and Zhong, Y. (2019) 'Optimal dispatching of EVs based on mart contract and internet of things', *IEEE Access*, Vol. 99, p.1.

Eckert, J.J., Silva, L.C.A., Dedini, F.G. and Correa, F.C. (2020) 'EV powertrain and fuzzy control multi-objective optimization, considering dual hybrid energy storage systems', *IEEE Transaction on Vehicular Technology*, Vol. 69, No. 4, pp.3773–3782.

ElGhanam, E.A., Hassan, M.S. and Osman, A.H. (2020) 'Deployment optimization of dynamic wireless EV charging systems: a review', *IEEE International IoT, Electronics and Mechatronics Conference (IEMTRONICS)*.

Fu, Z., Su, P., Song, S. and Tao, F. (2019) 'Mode transition coordination control for PHEV based on cascade predictive method', *IEEE Access*, Vol. 4, No. 99, p.1.

Garcia-Trivino, P., Torreglosa, J.P., Jurado, F. and Ramirez, L.M.F. (2019) 'Optimised operation of power sources of a PV/battery/hydrogen-powered hybrid charging station for electric and fuel cell vehicles', *IET Renewable Power Generation*, Vol. 13, No. 16, pp.3022–3032.

Garwa, N. and Niazi, K.R. (2019) 'Impact of EV on integration with grid system – a review', *8th International Conference on Power Systems (ICPS)*.

Guizani, A., Hammadi, M., Choley, J-Y., Soriano, T., Abbes, M.S. and Haddar, M. (2016) 'EV design, modelling and optimization', *Mechanics and Industry*, Vol. 17, No. 4, p.405, EDP Sciences.

Hariri, A.O., El Hariri, M., Youssef, T. and Mohammed, O. (2018) 'A bilateral decision support platform for public charging of connected EVs', *IEEE Transactions on Vehicular Technology*, Vol. 68, No. 1, pp.12–140.

He, T., Zhu, J., Zhang, J. and Zheng, L. (2018) 'An optimal charging/discharging strategy for smart electrical car parks', *Chinese Journal of Electrical Engineering*, Vol. 4, No. 2, pp.28–35.

Hu, X., Han, J., Tang, X. and Lin, X. (2021) 'Powertrain design and control in electrified vehicles: a critical review', *IEEE Transactions on Transportation Electrification*, Vol. 7, No. 3, pp.1990–2009.

Hu, Y., Chen, C., He, J., Yang, B. and Guan, X. (2019a) 'IoT based proactive energy supply control for connected EVs', *IEEE Internet of Things Journal*, Vol. 6, No. 5, pp.7395–7405.

Hu, Y., Chen, C., He, T., He, J. and Guan, X. (2019b) 'Proactive power management scheme for hybrid electric storage system in EVs: an MPC method', *IEEE Transaction on Intelligent Transportation System*, Vol. 21, No. 12, pp.5246–5257.

Jia, J., Shi, B., Che, F. and Zhang, H. (2020) 'Predicting the regional adoption of EV (EV) with comprehensive models', *IEEE Access*, Vol. 8, pp.147275–147285.

Kabalan, B., Vinot, E., Yuan, C., Trigui, R., Dumand, C. and El Hajji, T. (2019) 'Efficiency improvement of a series-parallel hybrid electric powertrain by topology modification', *IEEE Transaction on Vehicular Technology*, Vol. 68, No. 12, pp.11523–11531.

Kharade, J.M., Gaikwad, M.P., Jadhav, S.P., Kodag, P.D., Pawar, S.P. and Yadav, S.T. (2020) 'IoT based charging slot locator at charging station', *Fifth International Conference on Communication and Electronics Systems*.

Lee, K. and Lee, M. (2020) 'Fault-tolerant stability control for independent four-wheel drive EV under actuator fault conditions', *IEEE Access*, Vol. 8, pp.91368–91378.

Lee, Z.J., Pang, J.Z.F. and Low, S.H. (2020) 'Pricing EV charging service with demand charge', *Electric Power Systems Research*, Vol. 189, No. 2, p.106694.

Liu, C., Chau, K.T., Lee, C.H.T. and Song, Z. (2021) 'A critical review of advanced electric machines and control strategies for EVs', *Proceedings of the IEEE*, Vol. 109, No. 6.

Liu, T., Tang, X., Wang, H., Yu, H. and Hu, X. (2019) 'Adaptive hierarchical energy management design for a plug-in hybrid EV', *IEEE Transactions on Vehicular Technology*, Vol. 68, No. 12, pp.11513–11522.

Loganathan, M.K., Tan, C.M., Mishra, B., Snyman, L.W. and Msagati, T.A.M. (2019) 'Review and selection of advanced battery technologies for post 2020 era EVs', *IEEE Transportation Electrification Conference (ITEC-India)*.

Madhusudhanan, A.K. and Na, X. (2020) 'Effect of a traffic speed based cruise control on an EV's performance and an energy consumption model of an EV', *CAA Journal of Automation Sinica*, Vol. 7, No. 2, pp.386–394.

Mao, T., Zhang, X. and Zhou, B. (2019) 'Intelligent energy management algorithms for EV-charging scheduling with consideration of multiple EV charging modes', *Energies, MDPI, Open Access Journal*, Vol. 12, No. 2, p.265.

Metwly, M.Y., Abdel-majeed, M.S., Abdel-Khalik, A.S., Hamdy, R.A., Hamad, M.S. and Ahmed, S. (2020) 'A review of integrated on-board EV battery chargers: advanced topologies, recent developments and optimal selection of fscw slot/pole combination', *IEEE Access*, Vol. 8, pp.85216–85242.

Moghaddam, Z., Ahmad, I. and Habibi, D. (2017) 'Smart charging strategy for EV charging stations', *IEEE Transactions on Transportation Electrification*, Vol. 4, No. 1, pp.76–88.

Mouli, G.R.C., Kefayati, M., Baldick, R. and Bauer, P. (2018) 'Integrated PV charging of EV fleet based on energy prices, V2G and offer of reserves', *IEEE Transactions on Smart Grid*, Vol. 10, No. 2, pp.1313–1325.

Mouna, B. and Mohamed, O. (2019) 'A vehicle detection approach using deep learning network', *International Conference on Internet of Things, Embedded Systems and Communications (IINTEC)*.

Pal, R., Chavhan, S., Padmanaban, S., Ahmed, S.S. and Khan, B. (2016) 'A comprehensive analysis of EV charging station infrastructure in an urban area', *IEEE Access*, Vol. 4, No. 13, p.2396.

Park, S.H., Lee, J.J., Lee, Y.I., Park, S.H., Lee, J.J. and Lee, Y.I. (2016) 'Development of EV powertrain: experimental implementation and performance assessment', *18th International Middle East Power Systems Conference (MEPCON)*.

Patil, H. and Kalkhambkar, V.N. (2020) 'Grid integration of EVs for economic benefits: a review', *Journal of Modern Power System and Green Energy*, Vol. 9, No. 1, pp.13–26.

Petrov, P. and Nashashibi, F. (2014) 'Modeling and nonlinear adaptive control for autonomous vehicle overtaking', *IEEE Transaction on Intelligent Transportation System*, Vol. 15, No. 4, pp.1643–1656.

Porselvi, T., Nisha, J., Thendral, K. and Devi, P.V. (2019) 'Solar PV fed electrical vehicle charging system with hybrid energy storage system', *International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*.

Sachan, S. and Mortka, M.Z. (2020) 'Fuzzy logic triggered charging infrastructures for EVs', *IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC)*.

Sain, C., Banerjee, A. and Biswas, P.K. (2020a) 'A comprehensive study on various topologies of permanent magnet motor drives for electric vehicles application', *Artificial Intelligent Techniques for Electric and Hybrid Electric Vehicles*, pp.207–217.

Sain, C., Banerjee, A. and Biswas, P.K. (2020b) 'Design and optimization of a fuzzy-PI controlled modified inverter based PMSM drive employed in light weight electric vehicle', *International Journal of Automation and Control*, in press.

Sain, C., Banerjee, A. and Biswas, P.K. (2020c) 'Modelling and comparative dynamic analysis due to demagnetization of a torque controlled permanent magnet synchronous motor drive for energy-efficient electric vehicle', *ISA Transactions*, Vol. 97, pp.384–400.

Sain, C., Banerjee, A., Biswas, P.K. and Padmanaban, S. (2020d) 'A state-of-the-art review on solar-powered energy-efficient PMSM drive smart EV for sustainable development', *Advances in Greener Energy Technologies. Green Energy and Technology*, pp.231–258, Springer, Singapore.

Schaltz, E. (2011) *Electrical Vehicle Design and Modeling*, IntechOpen, Denmark.

Schuss, C., Fabritius, T., Eichberger, B. and Rahkonen, T. (2019) 'Calculating the output power of photovoltaic cells on top of electric and hybrid EVs', *IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*.

Shahriar, S., Al-Ali, A.R., Osman, A.H., Dhou, S. and Nijim, M. (2017) 'Machine learning approaches for EV charging behaviour: a review', *IEEE Access*, Vol. 8, pp.168980–168993.

Shao, L., Karci, A.E.H., Tavernini, D., Sorniotti, A. and Cheng, M. (2020) 'Design approaches and control strategies for energy-efficient electric machines for EVs – a review', *IEEE Access*, Vol. 8, pp.116900–116913.

Shariff, S.M., Alam, M.S., Ahmad, F., Rafat, Y., Asghar, M.S.J. and Khan, S. (2019) 'System design and realization of a solar-powered EV charging station', *IEEE Systems Journal*, Vol. 14, No. 2, pp.2748–2758.

Shi, Z., Zhu, N. and Yu, J. (2018) 'The EV time-of-use price optimization model considering the demand response', *MATEC Web of Conferences EECR*.

Singh, V.K., Sahu, Y., Mishra, P.K., Tiwari, P. and Maurya, R. (2020) 'Charging of EVs battery using bidirectional converter', *International Conference on Electrical and Electronics Engineering*.

Sreejith, R. and Singh, B. (2020) 'Sensorless predictive control of SPMSM driven light EV drive using modified speed adaptive super twisting siding mode observer with MAF-PLL', *IEEE Journal on Emerging and Selected Topics in Industrial Electronics*, Vol. 2, No. 1, pp.42–52.

Sudheer, K., Kumar, K.H., Puneethkumar, N. and Reddy, K.V.V. (2020) 'IoT based intelligent smart controller for EVs', *6th International Conference on Advanced Computing & Communication Systems (ICACCS)*.

Suhara, E.M., Nandakumar, M. and Mathew, K. (2018) 'Adaptive hysteresis based multifunctional EV charger with a single feedback loop controller', *IET Journal*, Vol. 2018, No. 8, pp.714–720.

Sun, X., Hu, C., Lei, G., Guo, Y. and Zhu, J. (2019) 'State feedback control for a PM hub motor based on grey wolf optimization algorithm', *IEEE Transactions on Power Electronics*, Vol. 35, No. 1, pp.1136–1146.

Taghizadeh, S., Hossain, M.J., Poursafar, N., Lu, J. and Konstantinou, G. (2020) 'A multifunctional single-phase EV on-board charger with a new V2V charging assistance capability', *IEEE Access*, Vol. 8, pp.116812–116823.

Tintelecan, A., Constantinescu-Dobra, A. and Marți, C. (2020) 'Literature review – EVs life cycle assessment', *ELEKTRO*.

Tu, H., Feng, H., Srdic, S. and Lukic, S. (2019) 'Extreme fast charging of EVs: a technology overview', *IEEE Transactions on Transportation Electrification*, Vol. 5, No. 4.

Uiterkamp, M.H.H.S., Gerards, M.E.T. and Hurink, J.L. (2021) 'Online EV charging with discrete charging rates', *Sustainable Energy, Grids and Networks Elsevier*, Vol. 25, p.100423.

Un-Noor, F., Padmanaban, S., Mihet-Popa, L., Mollah, M.N. and Hossain, E. (2017) 'A comprehensive study of key EV (EV) components, technologies, challenges, impacts, and future direction of development', *Energy Storage Systems and Power Conversion Electronics for E-Transportation and Smart Grid*.

Veysi, M., Aghaei, J., Shasadeghi, M., Razzaghi, R., Bahrani, B. and Ryan, D.J. (2020) 'Energy-efficient speed control of EVs: linear matrix inequality approach', *IEEE Transactions on Vehicular Technology*, Vol. 69, No. 10, pp.10469–10483.

Wang, H., Yuwen, Z., Fang, Y., Qiao, Y. and Li, Z. (2015) 'Development of pure EV powertrain controller based on hardware in the loop platform', *6th IEEE International Conference on Software Engineering and Service Science (ICSESS)*.

Wang, Z., Ching, T.W., Huang, S., Wang, H. and Xu, T. (2021) 'Challenges faced by EV motors and their solutions', *IEEE Access*, Vol. 9, pp.5228–5249.

Wanner, D., Trigell, A.S., Drugge, L. and Jerrelind, J. (2012) 'Survey on fault-tolerant vehicle design', *World EV Journal*, Vol. 5, No. 2, pp.598–609.

Wicaksono, A. and Prihatmanto, A.S. (2015) 'Optimal control system design for EV', *4th International Conference on Interactive Digital Media (ICIDM)*.

Wu, G. and Sheng, Y. (2012) *On Chaos and Bifurcation in Nonlinear Driver-Vehicle System Probabilistic Dynamics*, SAE International by University of California Berkeley.

Zhang, F., Zhang, X., Zhang, M. and Edmonds, A.S.E. (2016) 'Literature review of EV technology and its applications', *5th International Conference on Computer Science and Network Technology (ICCSNT)*.

Zhang, L., Ye, X. and Xia, X. (2019) 'A real-time energy management and speed controller for an EV powered by a hybrid energy storage system', *IEEE Transactions on Industrial Informatics*, Vol. 16, No. 10, pp.6272–6280.

Zhang, Y., Chen, G., Hu, Y., Gong, C. and Wang, Y. (2020) 'Cascaded multilevel inverter based power and signal multiplex transmission for EVs', *CES Transaction on Electrical Machine and System*, Vol. 4, No. 2, pp.123–129.

Zhao, S., Wu, Y., Zhai, Y., Chen, C., Wu, J. and Sun, B. (2019) 'An integrated control strategy for eco-driving of intelligent hybrid vehicles', *IEEE International Conference on Smart Manufacturing, Industrial & Logistics Engineering (SMILE)*.

Zhou, J., Shen, X. and Liu, D. (2014) 'Modeling and simulation for EV power train controls', *IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)*.

Zhou, X., Zou, L., Ma, Y., Gao, Z., Wu, Y., Yin, J. and Xu, X. (2016) 'The current research on EV', *28th Chinese Control and Decision Conference (CCDC)*.