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Renewable Energy Sources Integration in Battery Electric Vehicles

Olaseinde David Olagbegi
Silesian University of Technology
oo300245@student.polsl.pl

Abstract— **An overview of all electric vehicle is presented. Range anxiety as a factor affecting the wide adoption of all electric vehicle is presented. Renewable energy sources of interest and the potentials are presented. Areas of further research for cost savings and range improvement in all electric vehicle are presented.**

I. Introduction

The quest for clean energy has been on the front burner in the 21st century as a result of the climate change resulting from the daily activities of the human civilization and the observable adverse effects that some of these human activities have on the environment. Historical data showed that during the 20th century alone, the world population increased from about 1.65 billion to 6 billion. The global human population growth rate is estimated at about 1.1% every year (worldometer data 2022) [1], this rate of increase also translates to an increase in Energy demand in the world. Energy availability has been one of the bedrocks of modern civilization. The International Energy Agency (IEA) projects an increase in demand for energy in the world due to the increase in the global population and several global developmental programs geared towards the improvement of living standards across the globe.

This increase in energy demand however, comes at a cost because, the main source of energy that powers the global development today is the fossil fuels; coals, crude oil and natural gas. According to a 2019 data by the world energy supply and consumption, it was estimated that 84% of the primary energy consumption in the world and 64% of electricity generation in the world is from fossil fuels [2]. The burning of fossil fuels accounts for serious environmental damage. Putting this into perspective, over 80% of the carbon dioxide (CO2) emission generated by humans is from the burning of fossil fuels. A major drive to cut the emissions of greenhouse gasses to a sustainable rate that preserves the earth's atmosphere from global warming is by substituting the conventional fossil energy sources with renewable energy sources like Solar energy and Wind energy for our daily energy needs in order to cut down our level of pollutants hence, improving the quality of live. Renewable energy sources are very clean non depletable energy sources. Their use does not produce adverse toxic byproducts like the greenhouse gasses that are extremely harmful to the environment.

A key to the reduction of the negative impact of the greenhouse gasses emission in the transportation sector is the adoption of all electric vehicle. However, a major factor slowing down the wide adoption of the battery electric vehicle (BEV) technology for private and commercial commute is the "Range Anxiety" [3]. This paper proposes some potential solutions to solving the myth of the range anxiety through the integration of renewable energy sources such as wind energy and solar energy in the BEV.

II. BEV Topology

The BEV are fully battery powered electric vehicles unlike the hybrid electric vehicles (HEV) which could be a combination of an electric power and an internal combustion engine (ICE). The main source of energy for the ICE is the gasoline while for a BEV, the traction battery pack provides the energy needed for the vehicle to function as intended. However, due to the present limitations in battery technologies, limited electric vehicle supply equipment (EVSE) infrastructure and the time it takes to charge up a depleted battery in comparison to the time it takes to fill up a completely empty ICE gas tank, these creates some constraints in the wide adoption of the BEVs amongst consumers.

The BEV are generally made up of the following parts [4]:

A. The Traction Battery Pack

The traction battery pack is about the heaviest and most expensive component in the all-electric vehicle. The traction battery pack is used to store the energy needed to drive the electric traction motor. These batteries are usually made up of lithium-ion cells. Depending on the manufacturer, they may come in different shapes (cylindrical, prismatic or pouch) and sizes but the cells are basically stringed together in series and parallel combination to achieve the desired voltage and current level needed by the vehicle.

B. Electric Traction Motor

The Electric traction motor is powered using the electrical power from the traction battery pack. The use of electric motors in EVs presents some very important advantages like; Higher efficiency than the ICEV, also the Torque generated by an electric motor is very quick and precise based on the advancement in drives control technology. Depending on the load conditions and the drive control technology deployed, the choice of the electric traction motor can either be DC powered motor or AC powered motors. The motor technologies that are most commonly used in BEVs are; DC motors, Permanent magnet motors, switched reluctance motors, Induction motors, Synchronous permanent magnet outer rotor motor, with each motor technology offering its unique advantages and disadvantages depending on the application [4].

C. The Transmission (Gear box)

In contrast to the ICEVs, the BEV do not have the clutch system, however the gear system is present which is directly coupled to the traction electric motor. Some traction electric motor can rotate at speeds as high as 20,000 RPM depending on the load condition. In order to reduce this speed to a relatively safe levels for the BEVs, the complex gear systems are connected directly to the electric traction motor without need for any clutch system required in ICEVs for smooth power transfer, because the torque from the electric traction motor can be transferred smoothly without the stalling of the motor to the wheels of the vehicle in BEVs.

D. Power Electronics Converters and Controller

The DC/DC converters, DC/AC inverter and AC/DC rectifiers are integral parts of the power electronic controllers used in the BEVs.

Some electronic controllers in the BEVs might require the DC current from the traction battery pack to be increased to a higher level or decreased to a lower level for their efficient operation. The electronic converter used to increase the voltage level of the traction battery pack for such applications is known as BOOST converters while the BUCK converters are used to reduce the voltage level of the traction battery power pack for other applications withing the BEVs that requires very low voltage. If an AC electric traction motor is used, in order to convert the DC voltage from the traction battery pack to the AC voltage required by the electric motor, a voltage INVERTER is used in this regard. Also, the varying AC voltage produced during the regenerative braking process is converted to DC voltage using AC/DC rectifier.

In contrast with the power system of ICEVs which is made up of several parts like the internal combustion engine, fuel pumps, carburetor, air filter, ignition systems etc. the power systems in BEVs are basically made up of the power electronic controller and the motor.

The power electronic controller operates between the traction battery pack and the electric traction motor. It takes the power from the traction battery pack, supply it to the electric traction motor in a controlled way to match the load condition of the vehicle.

The controller converts the battery direct current into alternating current (for AC traction motors only) and regulates the energy flow based on the load demand. The controller is also responsible for the driving of the BEV in the reverse mode by changing the direction of rotation of space vector current into the electric traction motor. In regenerative braking application, when the motor acts as a generator during the deceleration the power electronics controller also plays the key role in using the generated electricity in charging the traction battery pack. Through the process called pulse width modulation (PWM), modern power electronic controllers adjust the speed and acceleration of the motor using switching devices like metal oxide silicon field effect transistors (MOSFET) or Insulated gate bipolar transistors (IGBT) or other semiconductor switches, by adjusting the on and off time of the switch (duty cycle) to suite the power requirement of the electric traction motor in meeting the desired load demand.

E. Onboard Charger

The charging system used in an electric vehicle make up a very important part of the electric vehicle service equipment (EVSE). The two broad mode of charging the depleted battery of an all-electric vehicle can either be through an onboard charger or an offboard charger.

The charging system is onboard when it is integrated into the electric vehicle and offboard when it is external to the electric vehicle. Electric vehicle could either be charged from an AC source or a DC source. According to [5], the chargers are often categorized in 3-levels depending on the type of electric current source used as described below:

AC Charging:
Level 1: 120V single phase, 2kW and below
Level 2: 208-240V, single phase, up to 20kW
Level 3: undefined, single or three phase
DC Charging:
Level 1: 200–450V, 20kW and below
Level 2: 200-450V, 20 to 80kW
Level 3: 200-450V, above 80kW

The most basic feature of the onboard charger used in the BEVs today is the lower rate of power transfer. The battery management system (BMS) which monitors the battery's state of charge (SOC) is also integrated into the onboard charging system. Onboard charging systems tend to add weight to the entire vehicle due to the high frequency transformer (HFT) which in turns increases the inertial of the vehicle. Below is presented a basic onboard charging system for a level 2 or 3 charging.

III. Challenges and Limitations of the Currently Available BEVs

There are several challenges slowing down the wide adoption of BEVs today. A qualitative data driven approach was used by [3] to investigate the reasons for the low adoptability by consumers in opting for the all-electric vehicles.

A. Cost of the Traction Battery Pack

The battery of used in the BEVs is at the center point of all the challenges facing the wide adoptability of the BEVs [6].

According to [6] the battery cost was responsible for more than half (57%) of an electric vehicle production cost in 2015. In 2010, the average price of one kilowatt hour of battery capacity was estimated as $1160. The material composition of the battery is the major factor responsible for the high cost of the batteries [7] as shown in figure 5. Through research and development in battery technologies, this price has been driven down by more than 85% to around $157 for one kilowatt hour battery capacity in 2019. Projection by Bloomberg shows continued declining in battery cost as shown in the figure 6. It is forecasted that the cost of one kilowatt hour battery capacity would be below $100 by the year 2024 [8]. With the reduction in battery cost, the prices of BEVs are going to be reduced hence the possibilities of wide adoptability as a result of more competitive pricing between the BEVs and the ICEVs.

B. Charging Time of The Traction Battery Pack

In ICEVs, the main source of energy is from the fossil fuel in the gasoline tank. However, for BEVs, the traction battery pack is the main source of energy needed to power the electric traction motor. Just like the gasoline in the ICEVs get depleted with use and are topped up at gas stations, the energy in the traction battery pack also gets depleted with use and need to be top up through the process of charging. Currently, there are a lot of gas station infrastructure available across major cities making it easier to fill the gasoline tank of an ICEV, however, limited number of charging stations (EVSE) for electric vehicle makes it more challenging to top up a depleted battery pack in an all-electric vehicle. The EVSE infrastructure deficit could cause what is known as "RANGE ANXIETY" in all-electric vehicles drivers due to the uncertainty of where next to top up the battery, and the compatibility of these EVSE with the particular model of vehicle [9].

The major difference in this regard between the ICEVs and the BEVs is the time required to top up the depleted energy used in powering the vehicles. Typically, it takes less than 10 minutes to fill the gasoline tank of an ICEV from empty to full capacity. In BEVs, the time taken to charge the fully depleted traction battery pack varies with the size of the battery pack, the level of charging power supported by the model of the vehicle, the available EVSE for the charging of the vehicle. As an example, a 60kWh battery can take as much as 8 hours to charge from empty to full capacity using a 7kWh EVSE charging point [9]. Some major factors affecting the charging time of an all-electric vehicle traction battery pack according to [10] are:

- The Size of the battery: The bigger the battery capacity in kWh, the longer time it will take to charge. A 60kWh battery pack will take less time to charge than a 100kWh battery pack.
- State of Charge of the Battery (empty vs. full): It take more time to charge a fully depleted battery than it will take to topping up the battery pack from say a 50% SOC.
- Maximum Charging rate of the Vehicle: Vehicle manufacturers often set the maximum charging rate for an electric vehicle. Charging the battery pack of the vehicle above the manufacture's preset rate could damage the battery pack. In most cases for example, a 7kW maximum charge rate vehicle cannot be charged faster from a 30kW rated charging point. The higher the maximum charge rate of the vehicle the faster the battery can be charged using high rated power EVSE without damage to the vehicle.
- Maximum Charging rate of EVSE Charge point: The charging time of the battery pack will also be affected by the rated power of the EVSE charging point. If the BEV is rated at 30kW charging rate and it is plugged to a 7kW rated charging point, the vehicle will only charge at the rating of the EVSE charging point irrespective of the vehicle's rated 30kW charging rate.
- Environmental factors: Environmental factor like temperature plays a key role in the time it takes for a battery pack to be charged. The lower the temperature, the longer it takes for the battery to be charged.

C. The Driving Range of The Vehicle

The driving range of an electric vehicle is the distance the vehicle can travel on a fully charged battery pack before it runs out of electrical energy. The average range of an ICEV generally depends on the fuel economy of the car in miles per gallon (mpg), that is the efficiency of the energy conversion process and the size of its gasoline tank. Similarly, the average range for a BEV is a function of its energy economy in miles per kWh as well as the size of the traction battery pack. According to [10], the average range of an all-electric vehicle is 327km this is in contrast to the 460km average range for ICEVs [11]. Below are some different ways to increase the range of the all-electric vehicle;

- By increasing the battery capacity: this will translate to a more costly all-electric vehicle and also increase the weight of the BEVs.
- By Improving Energy efficiency: improving the energy efficiency of the BEVs through the battery management systems (BMS) by improving energy usage efficiency can also improve the range of the BEVs.
- Renewable energy sources Integration: the integration of renewable energy sources like Wind energy and Solar energy can also be used to improve the range of all-electric vehicle.

IV. Renewable Energy Sources of Interest

In this paper, two renewable energy sources of interest with possibilities of integration into the BEVs are the Solar energy and Wind energy.

A. Solar Energy Integration

Since the amount of energy generated from the solar source of renewable energy is a function of the area on which the solar ray is incident. This implies that conventionally, more solar energy can be generated from a larger surface area than a smaller surface area under the same solar conditions. Technological improvements are still being made in Solar energy conversion. However, considering a full-size sedan with an estimated 5.57m^2 available surface area suitable for solar panel installation.

Typical Area of a solar cell = 0.016m^2

This implies that about 348 solar cells can be fitted in this area on the full-size sedan.

These solar cells can be stringed together into a photovoltaic module in a particular order of serries and parallel connections. For the purpose of this study, assuming the following:

$$Series\ PV\ cells = 58\ cells$$

$$Parallel\ PV\ cells = 6\ cells$$

For a solar cell with the following respective open circuit voltage and shut circuit current 0.525V/cell and 3.5A/cell, the above arrangement will therefore yield the following results:

$$58\ series\ cells = 30.45V$$

$$Series\ cells\ resistance = 8.7\Omega$$

$$\text{Combined}\ panel\ resistance = 1.45\Omega$$

$$6\ Parallel\ cells = 21A$$

$$Power = 639.45Watts$$

This implies that assuming optimum solar conditions of 1000W/m^2 at 25^{0}C for a 9hour period, about 5.755kWhr of energy can potentially be generated from this renewable energy source to boost the energy need of the BEV.

B. Wind Energy Integration

The kinetic energy present in the wind as a result of wind displacement from the motion of vehicles can be put to a good use by converting this energy to electrical energy. The integration of wind turbine in the BEVs does not eliminate the need for the traction battery. Wind energy integration is rather considered in the scope of this project as a means of improving the range of the traction battery pack by either putting generated energy as a result of the vehicle motion back into the battery or using the generated energy to power other energy intensive devices in the vehicle thus shedding load from the traction battery pack and ultimately improving the range of the BEV.

The general equation for the calculation of the energy that can be generated by a wind turbine is given as:

$$Wind\ Turbine\ Power = \frac{1}{2} * A * V^3 * \rho * C_p(\lambda, \beta)\ [Watts]$$

Where;

A is the turbine blade swept area

V is the wind velocity

ρ is the air density

λ is the tip speed ratio (TSR)

β is the pitch angle

C_p is the power coefficient of the turbine (a constant)

For the purpose of simplicity, assuming a unity power coefficient, this implies that the power generated will be only a function of the swept area of the turbine, the wind velocity which is also the vehicle speed, and the air density. Thus, for a vehicle traveling at the speed of 90km/hr., the following power can be potentially generated from the turbine.

$$V = 90km/hr \ \equiv 25m/s\ at\ R\ = 0.25m$$

$$Power = \frac{1}{2} * 0.2 * 25^3 * 1.225 = \mathit{1914\ Watts}$$

This implies that for a period of 9hours the potential energy the vehicle will be able to generate is going to be about 45.94kWhr. while traveling at this speed.

V. Conclusions

The average daily commute is estimated to be around 66km/day. This put the average energy usage by the BEV at 13.86kWhr/day. From the estimated power output from the renewable energy source and the available energy for a 9hours period, it can be seen that the energy need of the BEV can easily be meet from the renewable energy sources proposed in this paper.

However, a lot of research needs to be carried out on the potential of integrating these renewable energy sources into the BEVs for the alleviation of the range anxiety associated with the low adoption of electric vehicle technology due to the low energy density of the current lithium-ion battery technologies. The potentials in the integration of renewable energy sources in electric vehicle also helps in the reduction of energy cost that may be associated with the use of electric vehicle.

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