

Energy Efficient Route Planning for Electric Vehicle

*Thesis submitted in partial fulfillment of the requirements for the award
of degree of*

Master of Engineering
in
Computer Science and Engineering

Submitted By
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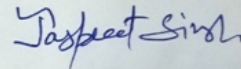
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PATIALA – 147004

June 2019

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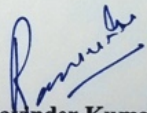
I hereby certify that the work which is being presented in the thesis entitled, "*Energy Efficient Route Planning for Electric Vehicle*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar Institute of Engineering and Technology, Patiala, is an authentic record of my own work carried out under the supervision of *Dr. Ravinder Kumar* and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.



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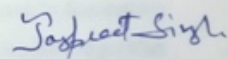
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ACKNOWLEDGEMENT

First of all, I would like to thank almighty, who has always guided me to work on the right path in my life.

I would like to express my sincere gratitude to my guide Dr. Ravinder Kumar for the continuous support of my research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me all the time of research and writing of this thesis. I could not have imagined having a better guide and mentor for my research work. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. His feedback and editorial comments were also valuable for writing this thesis.

I am also very thankful to Mr. Shubham Goel for his direct-indirect help and cooperation during my research work.


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ABSTRACT

In recent years electric vehicles have gained significant attention of world leaders due to growing concerns of the pollution caused by exhaust emissions of conventional Internal Combustion Engines & depletion of fuel reserves. Enforcement of strict emission norms for conventional vehicles will not help much because of the ever increasing demand for more vehicles has balanced the effect. Electric vehicles are propelled by electric motors that uses electricity as a fuel which is stored in the form electric charge in batteries. Conventional vehicles can take any path from source to destination. Usually conventional vehicle selects a path having minimum distance or minimum travelling time between source and destination. But for electrical vehicles path selected must have minimum energy consumption while travelling from source to destination. In this thesis a novel model has been proposed, To deal with problem of path selection for electric vehicle. Traditional algorithms used to determine shortest path have been analyzed and compared according to their features. In the proposed model energy consumption predicted, based upon many parameters such as Elevation changes, Regenerative breaking system, Distance from source to destination and speed limits. A road map in the form of graph presented and proposed algorithm implemented to determine shortest path for electric vehicle. It has been proved that path between source and destination having minimum travel time or minimum distance cannot be a shortest path for electric vehicle.

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In past few years, electric vehicles have attracted considerable attention due to growing concerns regarding the pollution caused by exhaust emissions of conventional Internal Combustion Engines. Enforcement of strict emission norms for conventional vehicles has not helped much because the ever-increasing demand for more vehicles has neutralized the effect. Another drawback of the Internal Combustion Engines is that their manufacturing process consumes more resources and causes more industrial pollution because their design is more complex as compared to electric vehicles. Anyway, conventional vehicles cannot go on forever in view of the depleting reserves of fossil fuels [1].

1.1 Rise in Surface Temperature of Earth.

The average earth surface temperature rises in the early 19th century around 1.62 degrees Fahrenheit (0.9 degrees Celsius), This increase in temperature is due to increase in emissions of greenhouse gases into the atmosphere [2].

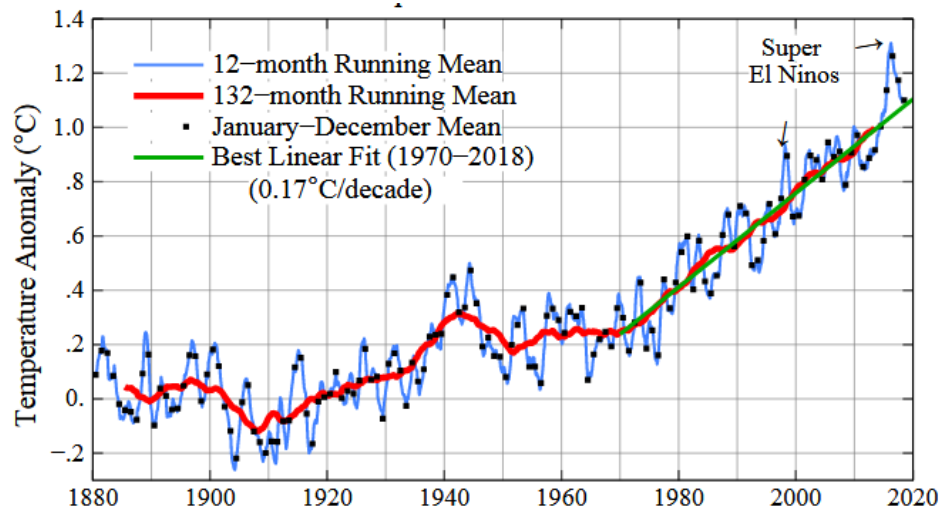


Figure 1.1 : Rise in surface temperature of earth [2].

Since Industry Revolution, atmospheric carbon dioxide concentration has risen by more than a third as a consequence of deforestation, land use modifications and fossil fuel burning. In 2013, for the first time in recorded history, CO₂ levels exceeded 400

ppm. It is essential to realize that 95% of the transportation energy of the planet comes from the combustion of fossil fuels, primarily diesel and petrol. Vehicles on road creates 50% emissions of the entire transport sector, which contributes 7% of the global CO₂ emissions [1].

The whole world is now facing the disastrous consequences of Global Warming. Everywhere in the globe, glaciers retreated. Ice is melting in the Arctic, Antarctic, Greenland, Himalayas and across other regions of the world [3], In reality, the study shows that in year 2006, only in the Arctic ocean 500,000 mi² of ice was melted, This huge amount of melting ice was much higher than any computer simulation performed by climate scientists. It was also predicted that Arctic zone will be free from ice by the year 2070.

Melting of ice results into increased levels of the oceans, with high possibility of flooding in low lying areas. Approximately 100 million individuals on the planet will live three feet above sea level, according to a forecast. Over the last century, global sea level grew by 8 inches and the rate of this rise is gradually accelerating along with rise in the temperature of seawater. The acidity of the surface ocean water also increased because the upper layers of the seas are absorbing huge amount of Carbon dioxide. Hurricanes have now become stronger and more intense. There are more draughts and heat waves. Cropping patterns have changed. Atmospheric pollution is also responsible for increase in diseases, especially respiratory and cardiovascular diseases.

To overcome damaging effects of global warming UN Kyoto Protocol was developed in 1997 [3]. All the participating countries have a mandatory reduction in coal fired power generation, increase nuclear power, replace conventional vehicles with electric vehicles, promote mass transportation and avoid energy wastage. Electric vehicle helps to decrease the dangerous air pollution caused by exhaust of vehicle. EV's are also less noisy than conventional vehicles, that mean less noise pollution.

1.2 What is Electric Vehicle (EV).

Electric Vehicle (EV) is propelled by a combination of electric motor and transmission system, Electric Vehicle withdraws power from pack of batteries or a fuel cell installed in the vehicle. Electric Vehicle is propelled by electric motor that make use of electricity as fuel, which is stored in pack of batteries. Electric Vehicle's are very different that conventional vehicles that consumes petrol and diesel as fuel, Electric Vehicle electric motor is less prone to failure than conventional engines because it has only few moving parts as compared to internal combustion engine. Electric Vehicle has no exhaust system or no tailpipe emission. EV's are more environment friendly.

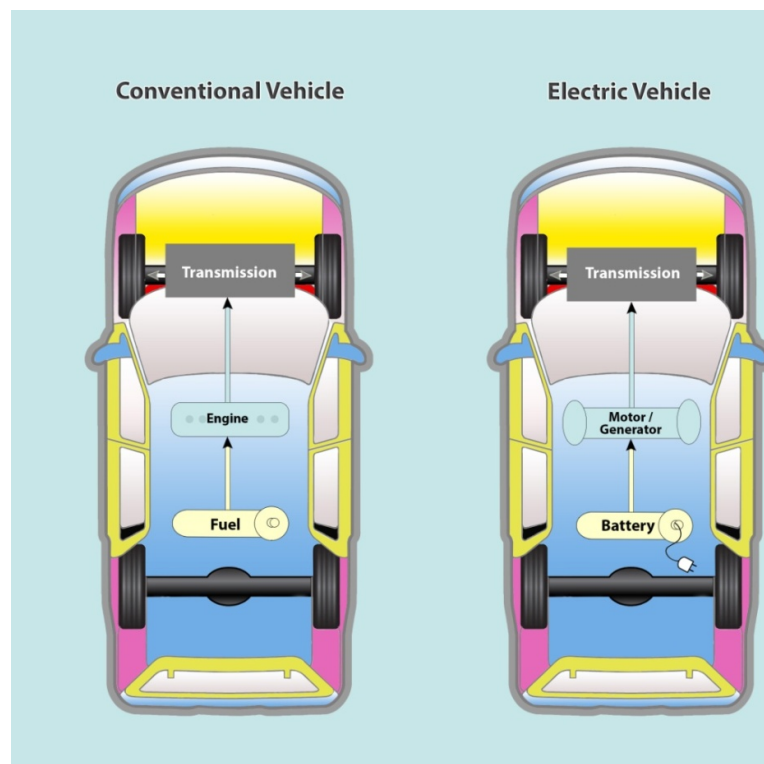


Figure 1.2 : Block diagram of conventional and electric vehicle.

Electric Vehicle's are faster than conventional vehicle. This is due to the ability of electric vehicles can generate high amount of torque from the starting of electric motor, but conventional vehicles reach that amount of torque after gaining speed. It gives Electric Vehicle an edge in starting speed and helps to reach 0 to 60 in small time. The lightweight feature of electric vehicle, due to the lack of kilos worth of metal under the hood, plays a important role.

1.3 Major Components of Electric Vehicles.

Following are the main electric vehicle elements.

1. Battery.

Batteries of an electric vehicle are used to store power in the form of electricity, this power is used by electric motor to propel the electric vehicle. Batteries used in EV are very different than used in consumer electronic devices like laptop and mobile phones. EV batteries are capable of storing high amount of power. In electric vehicles there are different types of batteries used.

- a) Lithium-ion(Li-ion).
- b) Lead Acid Batteries(LAB).
- c) Batteries for Nickel Metal Hydride(NiMH).

Table 1.1: List of automobile companies with vehicle model and battery type.

Company	Vehicle Model	Type of Battery
General Motors	Chevy-Volt	Li-Ion
Ford	Fusion	NiMH
Toyota	Prius	NiMH
BMW	Mini E	Li-ion
Nissan	Altima	NiMH
Tesla	Roadster	Li-Ion
ByD	E-6	Li-Ion
Think	ThinkEV	Li-Ion
Mitsubishi	iMiEV	Li-Ion
Honda	Civic	NiMH
Daimler-Benz	ML-450	NiMH
Chrysler	Chrysler-200C	Li-Ion

2. Electric Motor Controller.

Electric motor controller transfers energy from batteries to electric motors. It has a microprocessor chip, which is programmed to regulate the amount of power supplied from batteries to electric motor. Energy efficiency is controlled by motor controller. During the high acceleration it supplies more power to electric motor and during ideal stage only minimum required power is supplied. This will help to improve the energy efficiency of electric vehicle.

3. Electric Motor.

Electric motor is basically an engine of electric vehicle similar to conventional vehicles having internal combustion engine. Depending on setup of the car, electric motor may be AC or DC. AC motors are less in weight and less in price as compared to DC motors. Installation of DC motor is easy and less expensive, a major advantage of DC motor is that , it can deliver power more than it's capacity for small duration. This feature helps to provide quick pick up to electric vehicle, but at same time it produces very high amount of heat.

4. Regenerative Breaking System.

Regenerative breaking system helps to recharge the batteries whenever the breaks are applied to slow down the electric vehicle or vehicle moving down the hill. This system is capable for recharging up to 15-20 percent, but cannot fully recharge the vehicle.

5. Drive System.

Drive system essentially transfers electric motor power to electric vehicle wheels. Electric vehicle transmission system is very different than conventional vehicle. Mainly it is of two type.

- 1) **Single Motor** : This type of drive system has only one single electric motor that propels electric vehicle. Mostly it is used in front wheel drive vehicles.
- 2) **Multiple Motors** : This type of drive system has multiple motors, each motor has separate transmission system, basically each wheel has it's own electric motor.

1.4 History of Electric Vehicles.

Mr. William Morrison who lived in Des Moines, Iowa was the first person in America to produce a fairly road worthy electric powered vehicle in the year 1891. It had a 4 horsepower electric motor powered by a 24 cell battery. The weight of the battery was a massive 768 pounds that was more than 50% of the total weight of the automobile. It was able to cover a maximum distance of 14 miles in an hour, which was considered to be remarkable in those days [4].

In the year 1897 the Pope Manufacturing Company was the first company in America to manufacture and market the electric powered vehicles in considerable numbers. Pope manufacturing Company and one Mr. William C Whitney, who was already running an electric cab business, came together in the year 1899 to form Columbia Automobile Company with the main object of manufacturing and selling electric cars along with their cab business. [5].

The first functional starter for gasoline powered automobiles was invented by Charles Kettering in the year 1912. The battery operated starter replaced heavy hand operated crank starter. It made the gasoline powered automobiles more attractive and it ultimately led to the demise of electric powered vehicles, which seemed to be practical commercial product during the 1920s. Certain other factors like the desire for covering long distances, more powerful gasoline engines and easy availability of gasoline at cheap price also led to the demise of electric vehicles. Electric powered vehicles again attracted the attention of both customers and producers when the price of crude oil was raised and its output was restricted in the 1970s by the oil producing countries in the Middle East. Concern for the environment also had its impact. The renewed interest in electric cars resulted in introduction of world's first hybrid car produced on commercial scale "Prius" from Toyota Motors of Japan in the year 1997. This was followed by ultra-sporty Tesla Roadster from Tesla Motors of America in the year 2006. Nissan Motors of Japan was the next to produce an electric car named LEAF in the year 2008. It is able to cruise at 90 mph it can make a trip of 100 miles on a fully charged battery. The battery could be recharged up to eighty percent of its capacity in only half an hour.. Tata Motors is one of India's pioneers in this sector, winning the first public procurement tender on behalf of the Govt for Electric Vehicles in India floated by Energy Efficiency Services Limited (EESL). In 2017, from India.

1.5 Benefits of Electric Vehicles.

Major benefits are listed below.

- Electric Vehicles can help to decrease CO2 emissions, urban air pollution, global climate change, global warming effects and helps to implement new emission regulations[8].
- Electric Vehicles are 100% environment friendly because they are running on electric motors. Electric motor does not release any toxic gases in the environment [7].
- Electric Vehicle batteries are charged from electricity, produced from domestic source, which eliminates the dependency on foreign oil import.
- Electric Vehicle's goes through same robustness testing procedures as conventional vehicles. Electric vehicle has same safety features like airbags, breaking system as conventional vehicles have. This can save driver and other commuters in the vehicle from injuries, if an accident occurs [7].
- As per latest developments in electric vehicles, both purchase cost and maintenance cost is going down. Governments have started developing charging infrastructure and policy framework for electric vehicles for personal and commercial use. Large scale manufacturing of batteries and tax exclusion have attracted many manufactures to produce low prices electric vehicles [7].
- Electric Vehicles runs on electric motors, so it does not require any lubrication oils to the motor. it helps to reduce the maintenance cost [7].
- Electric Vehicles also reduces noise pollution as they are much silent. Conventional vehicles generates more sound due to internal combustion engine. But electric vehicle has electric motor that generates very less noise pollution and provides smooth driving experience, with maximum acceleration over long distances [7].
- Most of the electric vehicle parts are made from recyclable material, which is a step towards eco friendly vehicles. Interiors of EV are made from recycled plastic bottles and bags.
- Drive system of electric vehicle has very unique features, A single motor with high capacity can be installed or multiple motors can be installed in electric vehicle, in case of multiple motors, each wheel has a separate motor that propels the vehicle. Multiple motor system is very useful in case of off riding.

1.6 Reoccurring and Non-Financial Benefits of Electric Vehicles.

Apart from financial benefits for electric vehicle customers, Some recurring and non-financial advantages are provided to Electric Vehicle clients worldwide as listed below. Reoccurring and non-financial benefits are for electric vehicle customers after the purchase of the automobile and continues all the way from the time of purchasing it.

- Electric Vehicles in California can cruise through HOV (high-occupancy vehicle lane) and BUS lanes with a single occupant [8].
- Electric Vehicle owners have to pay discounted parking fees at public parking garages in California [8].
- In London boroughs, Electric Vehicles pay very less discounted parking fee [8].
- No need to pay for toll charges for roads, tunnels or bridges for Electric Vehicle owners in Norway [8].
- In Shanghai Electric Vehicles owners are exempted from license plate auction[8].
- In Norway Electric Vehicles owner pay a reduced annual tax[8].

1.7 Types of Electric vehicle.

It is possible to categorize electric vehicles into three groups.

1. **B.E.V.(Battery Electric Vehicle).**
2. **P.H.E.V.(Plug-in Hybrid Electric Vehicle)**
3. **H.E.V.(Hybrid Electric Vehicle)**

1.7.1 B.E.V. (Battery Electric Vehicle).

The car is propelled by an electric motor, Electric motor is powered by rechargeable batteries. BEV has a battery pack consisting of multiple small size batteries. It does not have any internal combustion engine like conventional vehicles, Batteries are charged from external source of electricity. However batteries are also charged at running time using regenerative braking system. Major benefits are low operating cost, no emission, smooth acceleration and can be charged at home. Some of the disadvantages are short driving range and more costly than conventional vehicle [9]. BEV has fixed amount of energy depending upon the size of batteries, so it may require recharging during the journey.

Example : Tesla Model S, Nissan Leaf, BMW i3, Smart EV, Ford Focus EV.

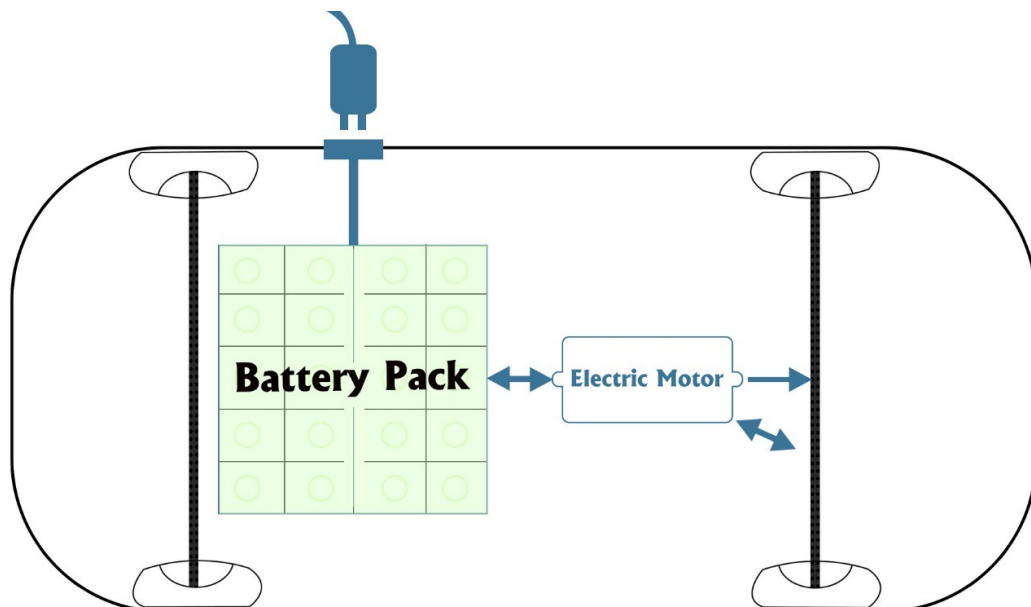


Figure 1.3 : Basic block diagram of Battery Electric Vehicle.

1.7.2 P.H.E.V. (Plug-in Hybrid Electric Vehicle)

Together with ICE(internal combustion engine) , PHEV has a BEV-like electric motor and batteries. ICE make use of fuel available in the fuel tank, where as electric motor is powered from pack of batteries. ICE is used to charge the batteries. ICE also propels vehicle when batteries are low.

PHEV has very low emission than conventional vehicle. Batteries can also charged from external electricity source. PHEV can be recharged at home garage or any public charging station. Major advantage is that it has more driving range than BEV, less fuel consumption and less emission than conventional vehicles. Some of the disadvantages are it needs fuel (Petrol/Diesel), maintenance of ICE such as oil change and operational cost is more than BEV [9].

Example : BMW i8, Cadillac ELR, GM Chevy Bolt, , Toyota Prius, Cadillac ELR, GM Chevy Volt, Porsche Panamera SE .

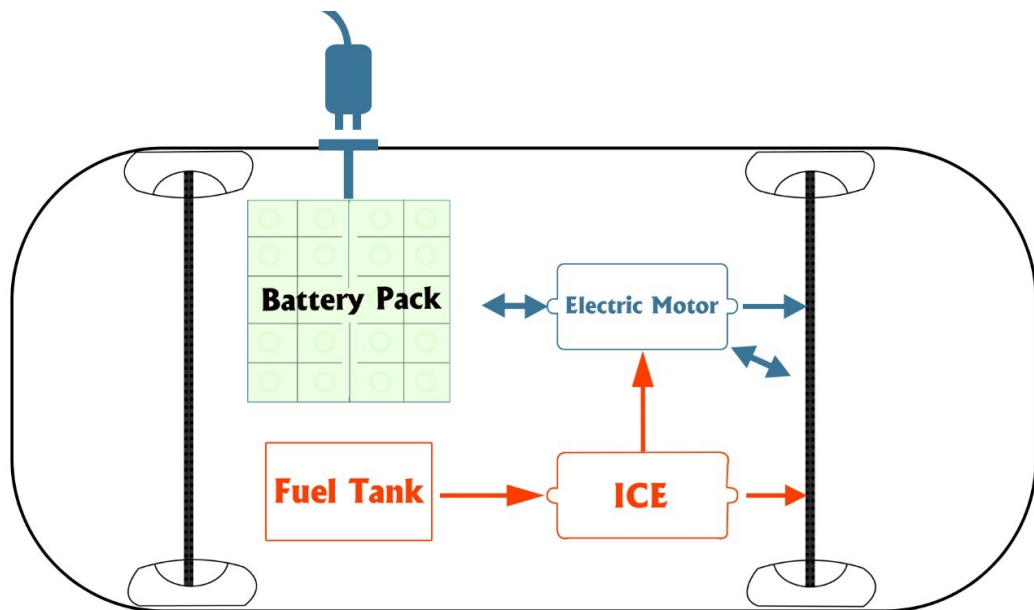


Figure 1.4 : Basic block diagram of Plug-in Hybrid Electric Vehicle.

1.7.3 H.E.V. (Hybrid Electric Vehicle).

Together with internal combustion engine, HEV uses electric motor. Electric vehicle motor is powered from pack of batteries and ICE-internal combustion engine make use of fuel tank. The transmission system can use both the electric motor and the ICE to simultaneously propel the car. Electric motor helps the car to be propelled by ICE. Designing hybrid electric cars is very complex.

Battery pack size of HEV is very small, However batteries cannot be charge by external electricity source. Batteries can only charge by internal combustion engine or regenerative braking system. Major advantage of these vehicle have high driving range and high fuel consumption efficiency.

But due to increased complexity of design the cost of vehicle is very high and maintenance cost is also very high than BEV [9].

Example : Civic Hybrid , Audi Q5 Hybrid, Acura ILX Hybrid, Cadillac Escalade Hybrid.

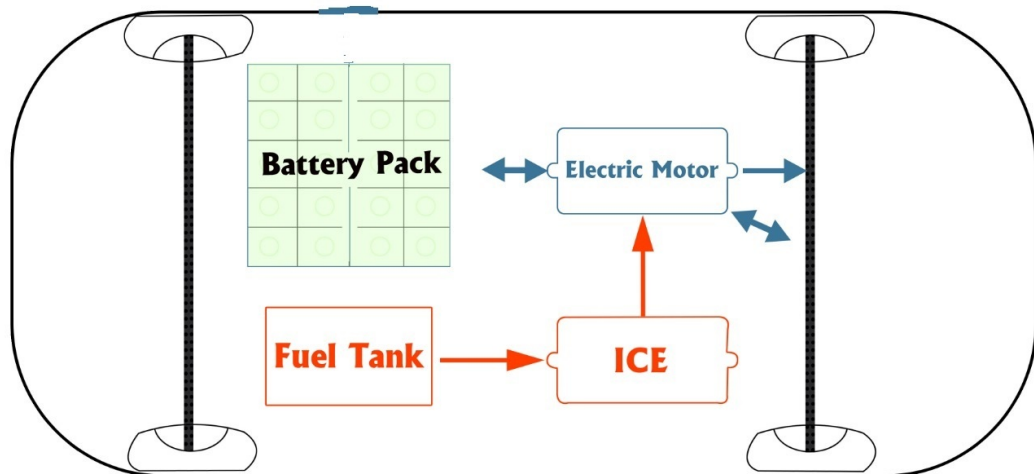


Figure 1.5 : Basic block diagram of Hybrid Electric Vehicle.

1.8 Charging of Electric Vehicle.

Electric vehicle charging is different from fueling conventional vehicles. Electric Vehicles are recharged at home garage, office parking or public charging stations. Owner of electric vehicle can charge the vehicle at home using on board charging. On board charging is slow as it charges at low power level.

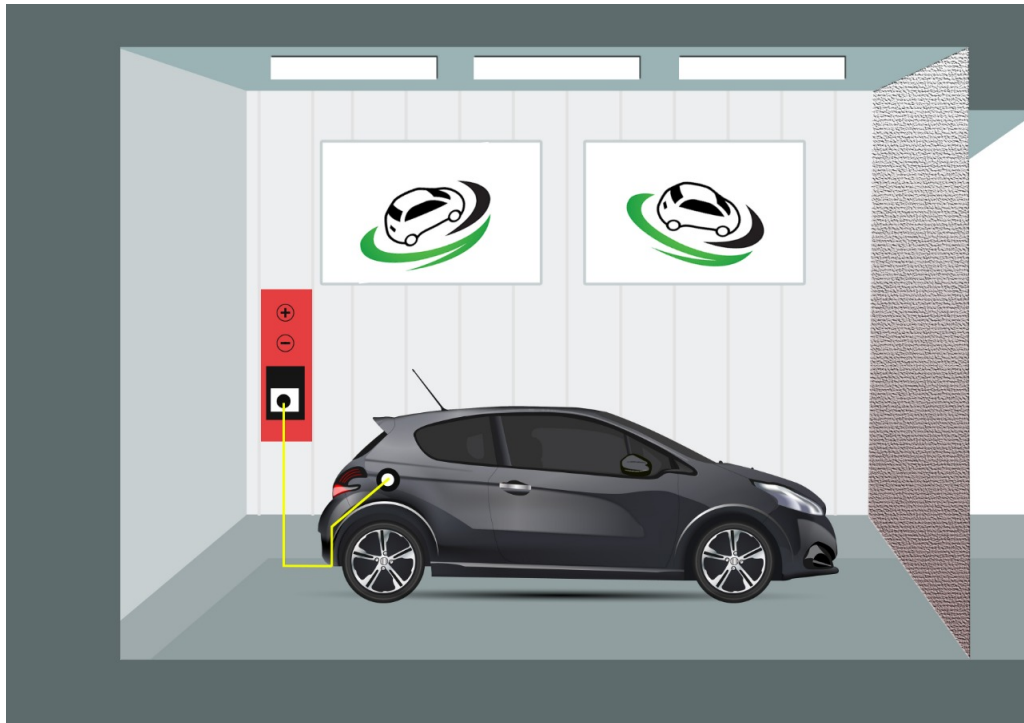


Figure 1.6 : Electric Vehicle charging at home garage.

Parking lots can be utilized for charging of Electric Vehicles, because vehicles remain parked in parking lots for several hours daily. Customers can leave their vehicle at parking lot without any need to care about the charging process.

Different types of electric vehicles having different type of batteries and requires different amount of voltage and current to charge the batteries. Basically charging systems can be categorized into two major types based upon power levels[10].

- 1. On Board Charging.**
- 2. Off Board Charging.**

On-Board charging is done using a charger placed within the vehicle, It transforms AC power to DC power for charging the batteries. Owner of electric vehicle can charge the vehicle at home using on board charging. On board charging is slow as it charges at low power level. On the other hand, off-board charging also know as DC charging is very fast as direct DC power is sent to batteries for charging. It requires less time for the electric car to charge.. Due to high power levels battery heating can be problem in off board charging [10].

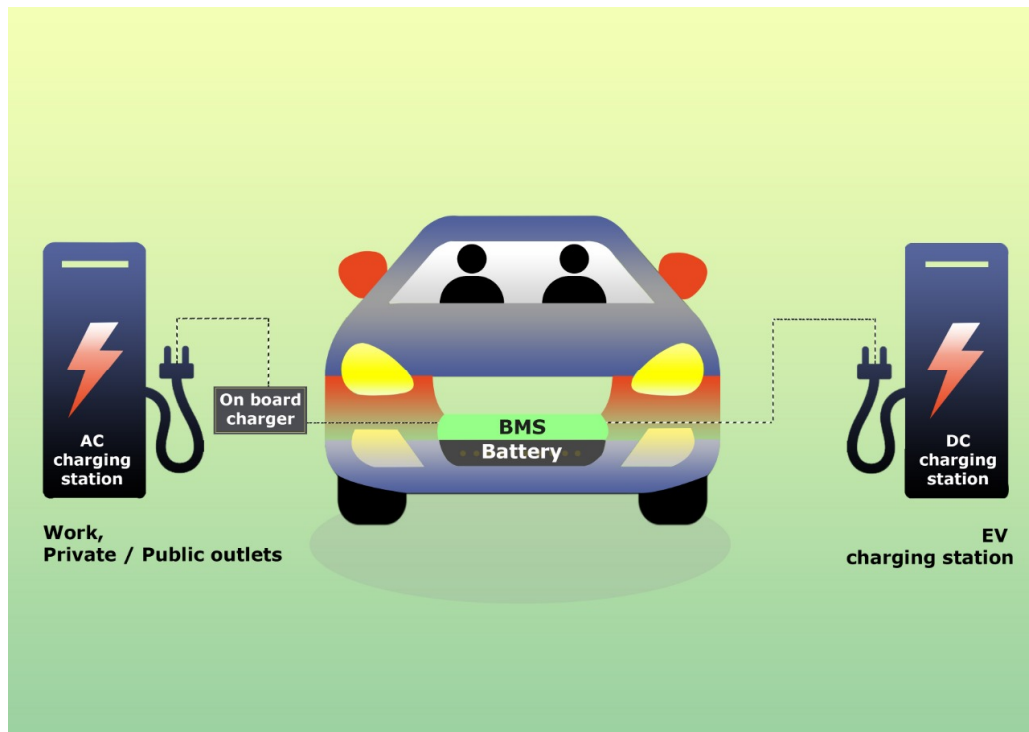


Figure 1.7 : On-Board and Off-Board Charging system.

Most of the moment electric vehicle charging occurs overnight in a garage at home owners. It is possible to plug electric vehicles into a power socket in the garage. This type of charging comes under Level-1 which may take many hours for full charging. Level-2 charging is a very quick technique of charging. Standard J1772-2009 connector is used for level-1 charging is, Diameter of the connector is 43mm and it has five pins. it ensures safety of vehicle and drive during charging in wet conditions. It is also shock proof. It has also proximity sensor that detects the movement of vehicle during charging.

Installation of Level one and Level two charging systems in both personal (home) and public services, It needs an outlet of 240 Volts. Different levels of charging energy are sum up in Table 1.2 [10].

Table 1.2 : Summary of power levels for charging of Electric Vehicles [10].

Charging Level	On/Off Board	Location Type	Power	Time
Level-1 120Volt AC 230 Volt AC	On Board	Home	1.4kW 1.9kW	4 to11 Hours 11 to36 Hours
Level-2 240Volt AC 400Volt AC	On Board	Home & Public	4kW 8kW 19.2kW	1 to 4 Hours 2 to 6 Hours 2 to 3 Hours
Level-3 208-600Volt DC	Off-Board	Commercial Charging Stations	50kW 100kW	0.4 to 1 Hour 0.2 to 0.5 Hour

Battery chargers play a crucial role in the electric vehicle development process. Time taken to charge battery and battery lifetime are connected to each other, Properties of the battery charger are also directly connected with batter life and charging time. A reliable and efficient charger is required along with low weight, low cost, high power density and small volume [10].

Among all charging levels, Level-1 charging method is very slow charging method. Level one is a typical single phase grounded power socket 120 Volt/15 Ampere, such as NEMA 5-15R. The standard connection make use of J1772 interface with electric vehicle Alternating Current port. Level-2 charging technique for permanent personal (home) and public charging equipment is the fundamental technique. To prevent duplicating power electronics, Level-2 charging infrastructure mounted on board. Level-2 infrastructure provides 208 Volt or 240 Volt charging (up to 19.2 kW at 80 Ampere). It may use a permanent device and a private or public link setup.

Level-3 is fully commercial and fastest charging method. It offers very high speed charging in very less time almost 1 hour. Similar to current petrol pumps, it can be set up on freeways, rest regions and town charging points. It works at or above 480 Volts. To provide controlled AC to DC converter, it needs a three-phase circuit along with an off-board charger. The car link can be direct DC [10].

1.9 Global Stock of Electric Vehicles.

In 2017, the total inventory of electric vehicles crossed a mark of 3 million, after crossing the 1 million mark in the year 2015 and the 2 million mark in 2016 [6]. There were 3,70,000 electric powered buses and 250 million electric powered two-wheelers in aggregate in the world in the year 2017. China has played a major role in the development of these modes of transport as it has 99% of the total stocks of such buses and two-wheelers that exist in the world. The number of such vehicles is also on the rise in Europe and India [6].

United States used to have the largest stock of electric powered vehicles amongst all the countries till 2015. But United States lost its top position in the field in the year 2016. China has emerged as the global leader and continues to maintain its position till date. There are 200 million two wheelers powered by electricity, 3 to 4 million low-speed electric vehicles and about 3,00,000 electric busses in China. China has become global leader in the various modes of electric powered transport [6].

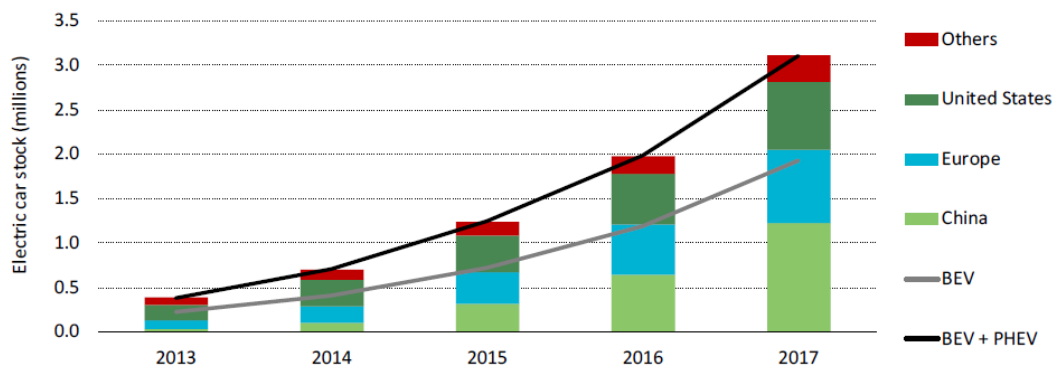


Figure 1.8 : Global stock of electric vehicles.

1.10 Major Challenges for Electric Vehicles.

Electric vehicles are almost a century old now, But still only few models are available for customers as only few companies are manufacturing electric vehicles. Despite of the fact that electric engines occupies less space, highly compact, and highly efficient than conventional vehicles, while the batteries are getting better and better. Still electric vehicles are facing many issues and challenges as given below.

- Biggest challenge for Electric Vehicles is their small driving range and frequent charging requirement as driving range is typically limited only to 100–200 kilometers. EV's cruising range is very less than the normal automobile. So driving range must be close to conventional vehicles [1].
- As the number of electric vehicles are increasing, Charging infrastructure must grow in the same way as conventional vehicle fueling infrastructure is available today [1].
- The cost of batteries directly affects the price of electric vehicle, at present the cost of batteries is very high, it must be kept low, this will help to decrease the cost of Electric Vehicle as compared to conventional vehicle and more customer will be attracted towards electric vehicles [1].
- Government policy makers must provide financial (tax exemption, loans at very less rate of interest, toll plaza fee exemption, no vehicle registration fees) and non-financial benefits (drive EV in High Occupancy Vehicle Lane) to encourage the customers for the purchase of electric vehicles[8].

1.11 Organization of Thesis.

The following chapters are structured in this thesis.

- Chapter-2:** This chapter gives information about state of art of electric vehicle routing and charging techniques
- Chapter-3:** This chapter gives information about gap analysis and objectives of this thesis.
- Chapter-4:** This chapter gives information about design and implementation of the work presented in thesis.
- Chapter-5:** This chapter presents the outcomes of the data experiment conducted in this dissertation.
- Chapter-6:** This section provides data on the conclusion of this thesis and future work.

Electric vehicles are propelled by electric motor that use electricity as a fuel which is stored in batteries. EV's are very different from conventional vehicles that consumes petrol and diesel as fuel. Conventional vehicles can have many different routes from source to destination. Conventional vehicle selects a route having minimum distance or minimum travelling time between source and destination. But for electrical vehicles selected route must have minimum energy consumption while travelling from source to destination [11]. An energy consumption model for electric vehicle was proposed [12]. This energy consumption model is based upon many parameters such as Elevation changes, Regenerative breaking system, Distance from source to destination, Speed limits, Temperature, Auxiliary loads and Traffic information [12]. As Electric Vehicle generates power during breaking and moving down hill and store this power into batteries for later use. Other parameters such as elevation change, friction, speed limits, auxiliary loads, traffic, driving style has great impact on the performance of Electric Vehicle.

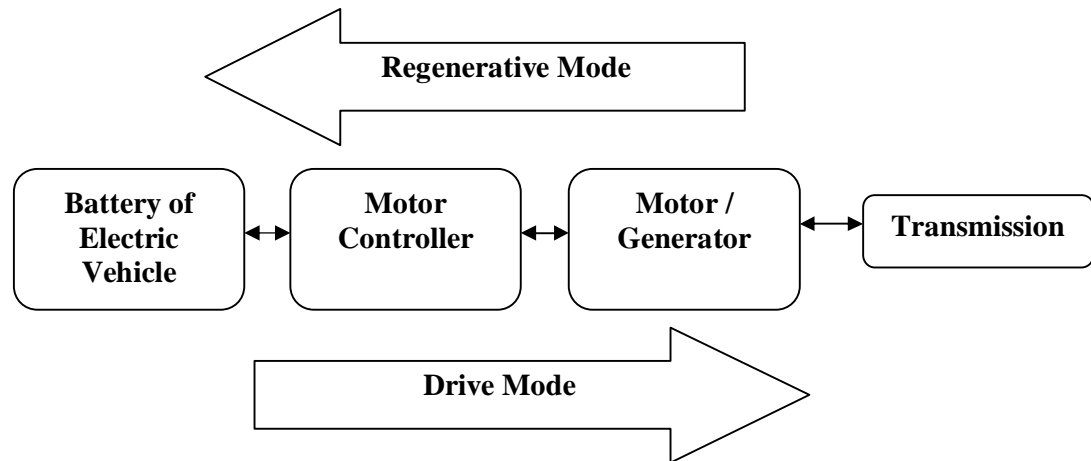


Figure 2.1 : Regenerative braking system of electric vehicle.

Electric Vehicle route planning is very challenging task as traditional algorithms like Dijkstra are not designed for Electric Vehicles, Traditional algorithms measure shortest distance or minimum travelling time between source and destination [11]. These algorithms works fine for conventional vehicles. But for Electric Vehicle it

does not work as many other parameters are taken into consideration for finding the minimum energy consumption path between source and destination.

The proposed model of energy consumption can be used to calculate an electric vehicle's energy consumption [12]. This paper demonstrates that route having shortest distance and less travel time are not energy efficient routes. They proposed and Bellman Ford based model to find energy efficient route [11]. Proposed model is not suitable for large and complex maps. It does not provide any information about charging stations on the selected route[11].

As the map size increases complexity also increase and finding energy efficient route becomes a time consuming process. To overcome the high processing time and large complexity, A parallel implementation model was proposed based upon Bellman ford algorithm[13]. An embedded GPU (Graphics Processing Unit) is used for real time implementation and It is more useful and improves performance to 9.9x compared to CPU serial execution [13].

Initially electric vehicle are used as private vehicle only and no commercial use, but with advancement in technologies of electric vehicle many cab service provides are now introducing plug-in electric cars in their fleet. These cab rides are shared by different customers having different destinations. Our existing route planners are designed for conventional vehicles, so these route planners cannot be used for EV's as they did not consider battery properties while route planning. Electric vehicle may visit same charging station for charging, but at different time of the day. An evolutionary genetic algorithm is proposed for electric vehicle that finds route between source and destination by considering battery capacity and number of charging stations along the route in order to decrease the energy usage, travel time and distance [14]. Genetic algorithms explore more solution space and reduces the computational burden for solving non polynomial problems. It generates solution in a very good amount of time with minimum load on cpu. Algorithm proposed helps to reduce the number of recharging stations during the journey.

Intelligent Transport System (ITS) provides solution to various problems such as traffic congestion, air and noise pollutions along with routing services. A routing

algorithm was proposed for EV which finds minimum travelling time or minimum energy consumption route for EV using historical speed profiles[15]. it has also proposed an idea that apart from energy efficient route energy efficient driving is also very important while driving an EV. Energy efficiency driving means adjusting speed according to road traffic, vehicle characteristics and environmental conditions. It also concludes that driving style has significant impact on the energy consumption of vehicle [15].

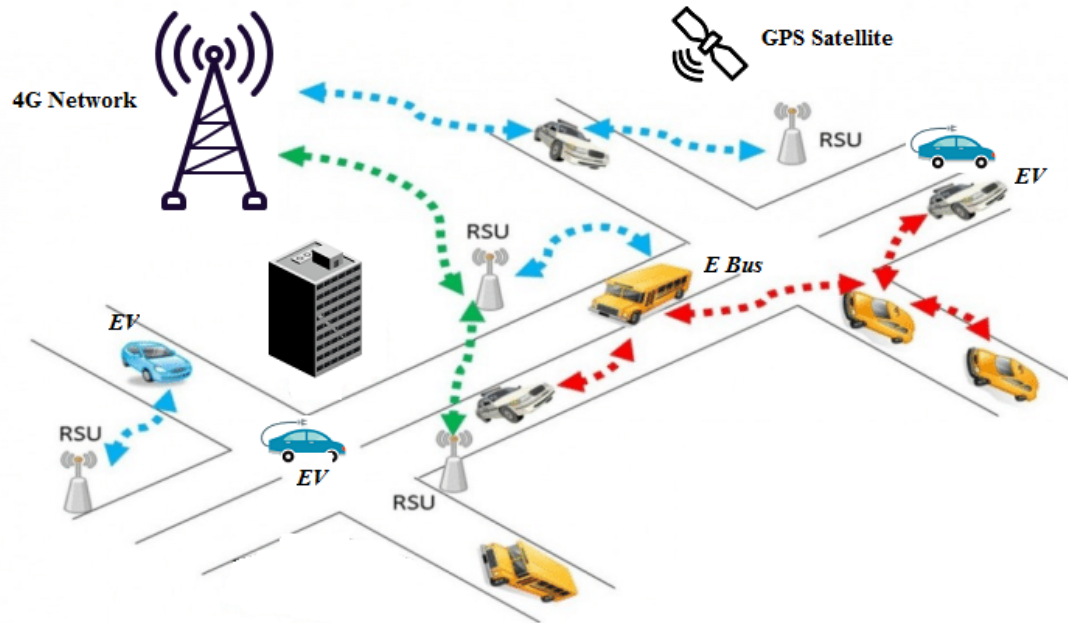


Figure 2.2 : Intelligent Transport System diagram.

Innovative transport system and smart grid technologies helps to quick adaptation of electric vehicles in urban area as it offers a variety of options for ride sharing[16]. Modern urban transport system like Uber offers sharing ride with multiple passengers. This will affect the route selection depending upon the individual destination of each passenger. A multi objective model was proposed to find an energy efficient route along with charging price that helps the service provide for making pre trip decisions [16].

As number of electric vehicles increases, there may be long waiting queues for charging at charging stations, An intention aware routing system is proposed that predicts the congestion at charging station and helps to select the route that has minimum driving time and minimum waiting time at charging station [17].

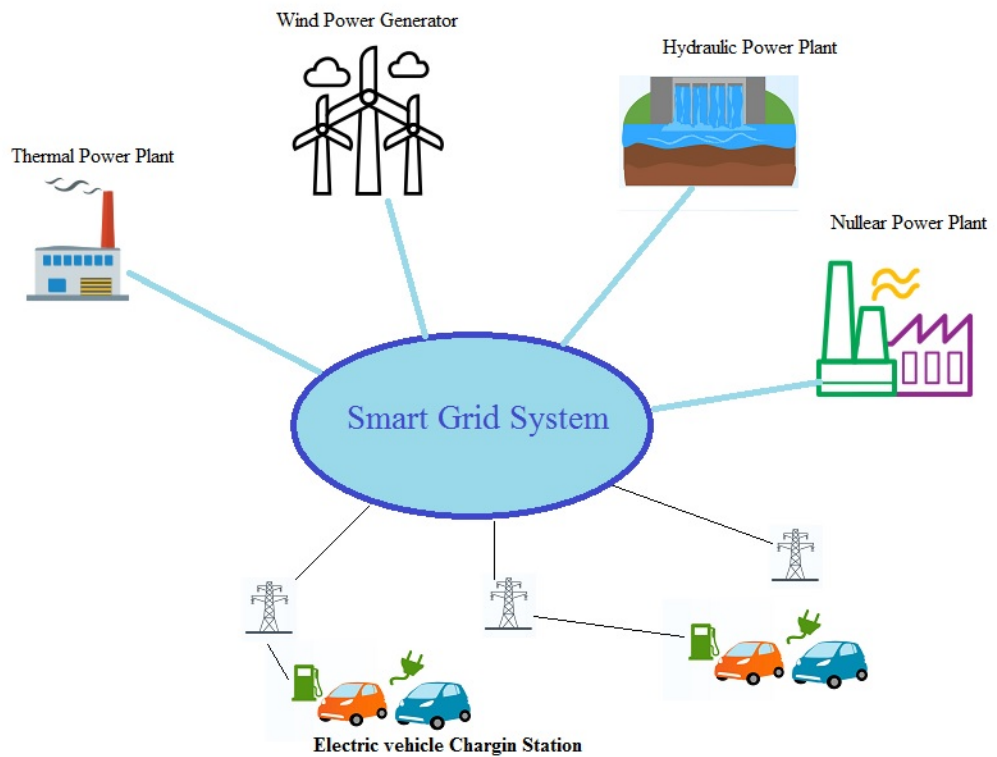


Figure 2.3 : Electric vehicle charging using smart grid system .

Apart from electric motor, HVAC (Heating Ventilation & Air Conditioning) also consumes power from batteries. So HVAC system can affect the route selection process. A joint optimization method is proposed that optimizes the electric motor power consumption along with HVAC power consumption [18], This optimization helps to improve driving range and battery life.

A very important parameter that can impact the EV route selection process is the amount of traffic present on the selected route [19]. Route selected based upon the historical data does not reflect the real time traffic information, due to which EV may consume more power than estimated for selected route which results into increased travelling cost. Based upon real time traffic information, EV route selection model as proposed that helps to avoid traffic jams and reduces the travelling cost and distance[19].

A multi objective ant colony based optimization method was proposed to generate route plan for EV[20]. The route plans is based upon the velocity, charging mode and air conditioner of the EV. Proposed solution ensures multiple objectives along with driver specific constraints [20].

An EV might have to visit multiple locations within a city and each location has some priority assigned. All the locations must be visited as per assigned priority. During the visit EV may require charging and charging prices are charging dynamically throughout the day, based upon the load of the grid. An optimized route planner is proposed that minimizes the charging cost and also visits all the locations of as per the assigned priority [21].

As the number of electric vehicle increasing continuously, demand of public charging facilities are also increasing. So electric vehicle charging management system is required at parking lots to avoid long waiting time at parking lot and change in charging requirements, poor quality of service and ensure minimum price to the PEV customer. Parking lots can be utilized for charging of PEV because vehicles remain parked in parking lots for several hours daily. Customers can leave their vehicle in parking lot and no need to care about the charging process.

Many Researcher's has proposed different scheduling algorithm like FIFS (First in First Server), EDF (Earliest Deadline First), HPBA (heuristics & proportion-based assignment) to minimize parking lot's power expenditure by allocating best power amount to the parking time slots along with variation in power cost .

Major objective of scheduling algorithm and control system is to reduce parking lot's power cost by allocating best power amount to the different parking slot timings along with variation in power cost. Methods used to create the initial population is particle swarm optimization (PSO) , proportion-based assignment (HPBA) & heuristics algorithms used to resolve the minimization problem. Results show that the objective of minimizing the energy price and meeting the energy requirements with limitations was accomplished by the algorithms. Algorithm performs much better than first-in-first-serve random search (FIFSF) [25].

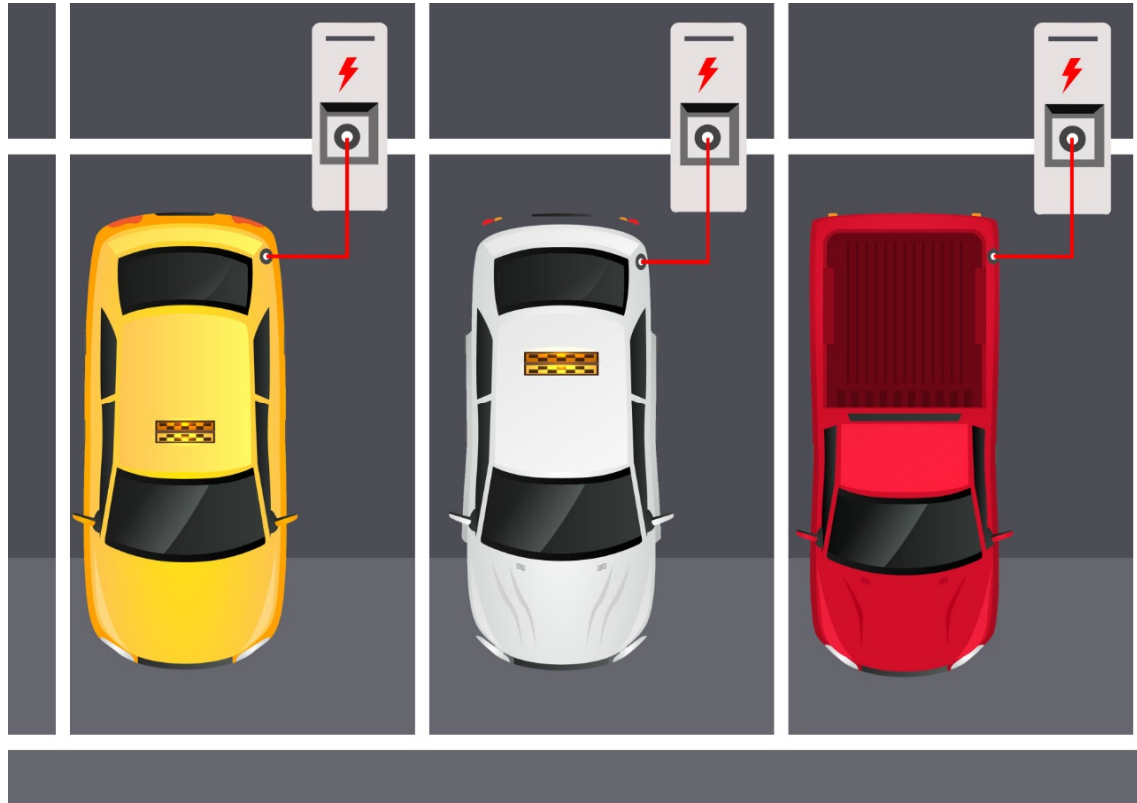


Figure 2.4 : Electric vehicle charging at parking lot.

Electric vehicle charging in centralized parking lot is managed using different charging scheduling algorithms by assuming that movement information is available at the start of day. Algorithm gets most out of the complete number of fully charged electric vehicles for the precise amount of charging stations. The latest algorithm release optimizes the complete energy stored in the batteries of the electric vehicle. Some inactive time slots were discovered to be accessible [26].

Under distributed environment and uncoordinated electric vehicle charging requirements results in increased demand of more energy with higher cost. An optimized charging method proposed for electric vehicle recharging spots in distributed system that can minimize power price, while fulfilling the customer demands. Fuzzy-rule-based algorithm used to dispatch power to the electric vehicles for each charging station. The algorithm ensures that the results are optimal in every perspective globally and result in minimal computational burden [27].

Web portal is designed to collect the data like starting and likely state of charge (SoC) and incoming and outgoing time from electric vehicle owner in advance. It helps to eliminate gap between power grid and users. A unique web portal proposed for registration system to collect the actual future energy demands from electric vehicle owners well in advance. It helps to reduce the slit between the power grid and end electric vehicle owner, which results into highly reliable information about starting and likely state of charge (SoC) along with incoming and outgoing time. Data is processed by social benefit maximization Algorithm evaluating the price response timetable for EVs and estimating the marginal price distribution (DLMP) signal. [28].

Electric vehicle charging scheduling at parking lot along with battery degradation cost. A cost model for battery deprivation is created to store the battery efficiency deprivation characteristics while recharging. A realistic charging method is suggested for combining the battery degradation impacts into electric vehicle charging scheduling system. The results presents better Performance of the suggested technique for both batteries deprivation price and reduction in system peak power load, that gives benefits to charging station and electric vehicle owner [29].

As number of electric vehicles increases, more uncoordinated recharging scheduling may increase the power load on grid side. Smart charging process becomes very critical. Most clients want to pay the as quickly as the price goes down, this leads to a big power surge that raises the grid's load and reduces power grid efficiency, along with operating cost. A charging cost model was constructed to solve this issue, taking into account the electricity rates, the movement of EV and the setup of the charger for EV batteries. The simulation findings show that the energy surge is decreased from 320% to 120% for unidirectional structures in the event of hundred percent dispersion [30].

Parking entrance control and scheduling system that consider the income of recharging stations and the customer obligations. A calculus based scheduling algorithm proposed, it increases the revenue of the recharging station. An overloading

scenario is used to prove that it is NP-complete. A heuristic algorithm developed to greedily reject all the requests of demands till the remaining demands can be fulfilled properly. [31].

The effect of aggregating electric vehicles on the planning and pricing of power grid systems. A middle entity, the electric vehicle aggregator, is participating in the market on behalf of the owners of electric vehicles through optimal self-planning as part of the price-taking policy. The findings start to show a non-regular output as the size of the electric vehicle fleet rises to a limit so that it has a major effect on the unit's commitment timetable [32].

During working hours charging for electric vehicles at parking lot near to commercial towers , where electric vehicle parked for most of the time. To develop the best charging strategy, a two-stage algorithm with dynamic programming is created, Use of the anticipated short-term future information together with long-term assessment of historical data.. Before leaving, all electric cars must be completely charged. [33].

An online intelligent system for electric vehicles in distributed system, that can manage the energy requirements of critical electric vehicle, which having short parking time and large charging time. Scores are assigned too electric vehicle through a fuzzy expert system. [34].

A parking lot that can manage both EV and internal combustion engine vehicles by applying parking policy that can handle EV customer requirements for recharging and profit maximization for parking provides. Three different policies are proposed in this paper depending upon the number of vehicles and charging demand at particular time period. it suggests to install 49% charging points in parking spots [35].

A real-time electric vehicle charging method is suggested for charging, that can accommodate charging demands response algorithm for the parking area. The charging schedule is designed as a binary optimization issue such as the on - off policy affects the speed of electric vehicles charging faster. Real-time optimal scheduling policy for the parking lot operator is created to accommodate most electric

vehicles in the parking lot, At particular moment, the reduced dynamic electricity price meets the charging demands of the owners of electric vehicles [36].

The V-Charge system proposes new combination of independent parking system with automatic recharging with highest level of comfort to electric vehicle owners along with optimal mixture of public and private transportation. It also discusses problems related to large-scale electric vehicle deployment. Real time parking data is used to asses five different schedulers. Results showed the highest matching scheduler for each case, mainly the scanning strategy, resulting in elevated uses while decreasing the burden of changing the charging station [37].

A two stage method proposed for a micro grid electric vehicle parking deck. First stage make use of stochastic process to decrease the uncertainty of the solar power output. Output of first stage gives the electric vehicle parking deck operators with the expected power selling cost for next day's operations. Second stage determines the selling price and parking charges according to the expected power price from the first stage along with maximizing the total revenue. Results shows that proposed system can successfully increases the income [38].

Table 2.1 : Summary of state-of-art methodologies.

SN	Author	Year	Algorithm	Parameters									
				Vehicle Configuration	Regenerative Breaking	HVAC	Battery Properties	Charging Stops	Charging Price	Driving Profile	Weather Information	Priority Destination	Traffic Information
1	Francesco Alesiani	2014	Genetic Algorithm	Yes	Yes	---	---	Yes	---	---	---	---	---
2	Rami Abousleiman	2015	Bellmanford	Yes	Yes	---	---	---	---	---	---	---	---
3	Mathijs M.	2015	Markov decision process	---	---	---	---	Yes	---	---	---	---	---
4	Tao Chen	2016	Mathematical Model	Yes	Yes	Yes	---	Yes	Yes	---	---	---	---
5	Shuwei Zhang	2016	Ant Colony Optimization	Yes	---	Yes	---	---	---	---	---	---	Yes
6	Amir Masoud Bozorgi	2017	K-Shortest	Yes	Yes	---	---	---	---	Yes	Yes	---	Yes
7	Korosh Vatanparvar	2017	Joint Optimization	Yes	Yes	Yes	Yes				Yes	---	---
8	Hongming Yang	2017	Mathematical Model	---	---	---	---	---	Yes	---	---	---	Yes
9	S Raagapriya	2017	Heuristic Aproach, Breadth First Search	---	---	---	---	Yes	Yes	---	---	Yes	---
10	Adam Chambers	2018	Bellmanford Parallel Implementation	Yes	Yes	---	---	---	---	---	---	---	---

This chapter describes the thesis ' motivation, analysis of gaps, and goal.

3.1 Motivation

In today's time, entire world is struggling with the disastrous consequences of Global Warming. For instance, fast melting of glaciers resulting in a percentage increase in sea level every year, unexpectedly changing cropping cycles. Atmospheric pollution is also responsible for increase in diseases, especially respiratory and cardiovascular diseases. Electric Vehicles is prominent key problem solutions that can help reduce CO₂ emissions. This has led to our research focus in contributing towards the implementation of electric vehicles technologies in transportation sector.

3.2 Gap Analysis

- Traditional algorithms like Dijkstra, which are used to find shortest path for conventional vehicles are unable to solve shortest path problem for electric vehicle.
- Depending on the size of the battery pack, electric vehicles have a maximum fixed amount of energy available which may not be sufficient to travel from source to destination, so it is also important to determine the charging stations required for electric vehicles to be charged during the journey.
- Energy consumed by electric vehicle for traveling from source to destination is influenced by various factors such as road conditions, road grade, driving style, weather conditions and other vehicle properties. All these factors must be considered for finding the minimum energy consumption route.
- Electric vehicle may use HVAC (heating ventilation and air conditioning) system depending upon weather conditions, which also withdraw power from batteries, Electric vehicle may contain auxiliary loads. So a joint optimization method is required, which will consider all these parameters while determining the route for electric vehicle.
- Traffic congestion on the route has great impact on the performance of electric vehicle, So dynamic routing method is required that can navigate electric vehicle through congestion free route along with minimum energy consumption.

- Electric vehicle Battery has characteristics such as maximum capacity of battery, time required to recharge the batteries and charging level. As batteries are getting older their charging time increases and output decreases, so charging profile must be taken into consideration while determining the route for electric vehicle.

3.3 Objectives of Thesis.

1. To study the traditional algorithms for selection of an efficient path from source to destination.
2. To identify the significance of traditional algorithms for electric vehicles .
3. To design an algorithm for energy efficient path prediction for electric vehicles.

3.4 Methodology.

Traditional algorithms used to find the efficient path from source to destination will be analyzed based upon the complexity of algorithm and approach used by them to find an efficient path. Algorithms that can be used for electric vehicle to determine efficient path will be evaluated. As electric vehicle uses as electricity as fuel, so a model will be used to calculate the energy consumption for electric vehicle, and proposed algorithm will be used to determine energy efficient path for electric vehicle.

DESIGN & IMPLEMENTATION

This chapter discusses the design and execution of the work proposed to achieve the goals of the thesis.

4.1 Traditional algorithms for selection of an efficient path.

There are many algorithms available to determine efficient path from source to destination. For conventional vehicles, these algorithms are designed. Conventional vehicles can go from source to destination with many candidate paths. Conventional vehicle selects a path having minimum distance or minimum travelling time between source and destination. Following are the traditional algorithms used to determine efficient path from source to destination.

1. Dijkstra Algorithm.
2. Suurballe Algorithm.
3. Bellman Ford Algorithm.
4. Fredman Algorithm.
5. Johnson algorithm.
6. Viterbi algorithm.
7. Floyd Warshall Algorithm.

1. Dijkstra Algorithm.

Dijkstra algorithm developed by Edsger W. Dijkstra in the year 1956. Original version of this algorithm used to determine shortest path between two nodes. But this algorithm's modified version determines the shortest path from the source node to all other nodes in the graph. Properties of algorithm are given below.

- 1) All paths of graph must be directed.
- 2) Each edge has some weight, weight may be distance, time or cost.
- 3) Negative weights are not allowed.
- 4) Greedy approach is used.

2. Suurballe Algorithm.

This algorithm developed by John W. Suurballe and published in the year 1974. This algorithm determines two disjoint paths from directed graph having positive edge weights. These two paths joins the similar pair of vertices having lowest total length. some of the properties of algorithm are given below.

- 1) Determine shortest path having disjoint paths.
- 2) Works for directed graphs only.
- 3) Negative weights are not supported.
- 4) Greedy approach is used.

3. Bellman Ford Algorithm.

Richard Bellman and Lester Ford, Jr. developed this algorithm. It determines the shortest path to all other vertex in the graph from source to destination.

- 1) Works for directed graph.
- 2) It supports negative weights.
- 3) Greedy approach is used.
- 4) It can detect the negative cycles in graph.
- 5) Slower than Dijkstra algorithm.

4. Fredman Algorithm.

This algorithm was developed by M. L. Fredman and D. E. Willard. It is used to determine the shortest distance between all the graph node pairs. It make use of fibonacci heap data structure.

- 1) Determines shortest path among all the nodes.
- 2) It does not support negative weights.
- 3) Greedy approach is used

5. Johnson algorithm.

Donald B. Johnson created this algorithm in 1977. This algorithm uses two algorithms Dijkstra and bellman ford algorithms. It determines shortest path among all the modes of the graph.

- 1) It supports positive and negative weights.
- 2) Combination of Dijkstra and Bellman ford is used.
- 3) works for directed and weighted graph only.

6. Viterbi algorithm.

This algorithm was developed by Andrew Viterbi in the year 1967. It determines shortest path between source and destination for directed and weighted graph. It utilizes markov process to determine shortest path. Each node in graph represents state and edges represents the transitions. A shortest path is determined by process by traversing from state to state.

- 1) Markov Process is used to find shortest path.
- 2) Graph must be weighted and directed.
- 3) No support for negative weighted edges.
- 4) Dynamic programming approach is used.

7. Floyd Warshall Algorithm.

This algorithm was developed by Robert Floyd and Stephen Warshall in the year 1962. It determines shortest path among all the nodes of a weighted and directed graph. some properties of the algorithm are given below.

- 1) It works with both positive and negative weights.
- 2) Dynamic programming approach is used.
- 3) Easy to implement.
- 4) Suitable for dense graphs.

4.2 Comparison of traditional algorithms.

Comparison of traditional algorithms available to determine efficient path from source to destination for conventional vehicles in table 4.1.

Table 4.1 : Comparison of traditional algorithms for shortest path problem.

Algorithm	Complexity V= Vertices , E=Edges	Approach	Negative weight Edge Support
Dijkstra	$O(v^2)$	Greedy	✘
Suurballe	$O(E + V \log V)$	Greedy	✘
Bellman Ford	$O(v^3)$	Dynamic	✓
Fredman	$O(E + V \log V)$	Greedy	✘
Johnson	$O(V^2 \log V + VE)$	Dynamic	✓
Viterbi	$O(v^2)$	Dynamic	✘
Floyd Warshall	$O(v^3)$	Dynamic	✓

From table 4.1, we can conclude that all the traditional algorithms does not support negative weighted edges. Only Bellman ford, Johnson and Floyd Warshall algorithm supports negative weighted edges. To determine efficient path from source to destination for electric vehicle negative weighted edges plays a vital role, As electric vehicles have regenerative breaking properly, Regenerative breaking system helps to recharge the batteries whenever the breaks are applied to slow down the electric vehicle or vehicle moving down the hill. Due to this regenerative breaking, some time power consumed by electric vehicle to travel between two point is less than the power regenerated by regenerative breaking system. The total cost of travelling between two points becomes negative. This negative cost is assigned to the edge of graph. So more than one edges may have negative cost from source to destination. So algorithms that supports negative edge weights can be used to determine shortest path from source to destination for electric vehicle.

4.3 Proposed Algorithm

Steps of proposed algorithm are given below.

Step-1 : Input electric vehicle configuration.

Step-2 : Create a graph to represent road map .

Step-3 : Calculate energy consumption for each edge of graph using electric vehicle configuration and road map parameters.

Step-4 : Apply shortest path techniques that supports negative edge weight.

Step-5 : Display energy efficient path on map.

4.4 Determine minimum energy consumption path .

Electric vehicles are very different from conventional vehicles that consumes petrol and diesel as fuel and their energy consumption is calculated in kilometers per liter or miles per gallon. Conventional vehicles can have many different paths from origin to destination. Conventional vehicle selects a path having minimum distance or minimum travelling time between source and destination. But for electrical vehicles selected path must have minimum energy consumption while travelling from origin to destination [11]. An electric vehicle energy consumption model was suggested [12]. An electric vehicle's energy usage is the amount of power at the battery terminal. As per principles of vehicle dynamics for any vehicle, the sum of forces acting on moving vehicle are given by (i).

$$F_{total} = F_{roll_resistance} + F_{rode_grade} + F_{air_resistance} + F_{acceleration} \quad (1)$$

$F_{roll_resistance}$ **Rolling Resistance** is the force against the vehicle's movement. It is the strength between electric vehicle and road tires.

$$F_{roll_resistance} = M \times g \times f_r \quad (2)$$

F_{road_grade} **Road Grade** is a measure of slope. it indicates how much road inclined from horizontal. It might be negative as vehicle moving downhill.

$$F_{road_grade} = M \times g \times i \quad (3)$$

$F_{air_resistance}$ **Resistance** of electric vehicle against air.

$$F_{air_resistance} = 0.5 \times P_a \times C_d \times A_f \quad (4)$$

$F_{acceleration}$ **Acceleration** force acting on electric vehicle

$$F_{acceleration} = M \times \delta \times a \quad (5)$$

M	Mass of electric vehicle in Kg.	A_f	Front area of electric vehicle.
g	Gravitational acceleration.	δ	Rotational inertia factor.
f_r	Rolling resistance.	V	Velocity in m/s
P_a	Air mass density.	a	acceleration in m/s ²
C_d	Aerodynamic drag coefficient.	i	Road grade.

The total energy needed to move the electric vehicle at ' V ' speed is provided by (6).

$$Power_{out} = F_{total} \times V \quad (6)$$

Electric vehicles have regenerative breaking system that generates power when vehicle is moving down the hill or while pressing the breaks. This energy is used to charge the electric vehicle's batteries.

$$Power_{regenerative} = \alpha \times Power_{out} \quad (7)$$

α indicates the percentage regenerative energy that regenerated by motor of electric vehicle. Value of α ($0 < \alpha < 1$).

Total power acting on electric vehicle is given by (viii).

$$Power_{total} = Power_{out} + Power_{regenerative} \quad (8)$$

So total power is some power used to move the electric vehicle and power generated by regenerative system to recharge the batteries of electric vehicle. A road map is created (Figure 4.1) in the form of directed graph $G = (V,E)$ is used to determine efficient path for electric vehicle. $|V|$ is set of vertices and $|E|$ is set of edges.

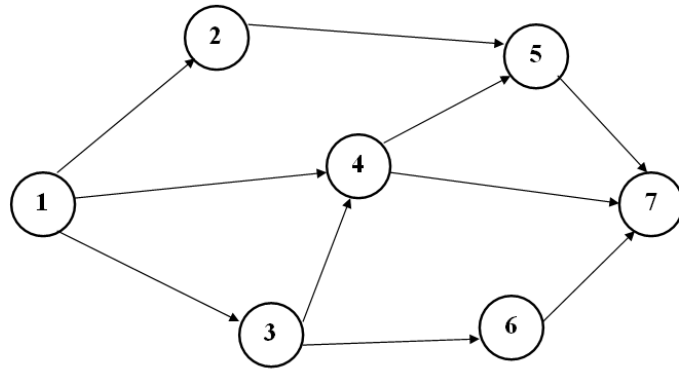


Figure 4.1 : Road map in the form of graph.

To implement shortest path algorithm on the graph given in figure 4.1, we have to assign cost to all the edges of the graph, The edge cost can be the distance between two nodes, the time to travel between two nodes or the power needed to move the electric car between two nodes. The table 4.2 shows different types of edge costs.

Table 4.2 : Edge wise distance, speed and energy consumption.

Edge	Distance (meters)	Speed (meters/second)	Energy Consumption
(1,2)	400	13.88	9
(1,4)	1800	33.33	80
(1,3)	700	13.88	-1
(3,6)	600	13.88	14
(6,7)	350	11.11	2
(3,4)	90	2.7	3
(4,7)	920	27.7	2
(4,5)	450	13.88	7
(5,7)	1200	33.33	15
(2,5)	640	20.83	11

A typical electric vehicle configuration parameters are given in table 4.3. These parameters are used to calculate power required to move electric vehicle between two nodes.

Table 4.3 : Typical electric vehicle configuration.

M	Mass of electric vehicle in Kg.	1500 kg
g	Gravitational acceleration.	9.8 m/s²
<i>f_r</i>	Rolling resistance.	0.005
<i>P_a</i>	Air mass density.	1.275 kg/m³
<i>C_d</i>	Aerodynamic drag coefficient.	0.25
<i>A_f</i>	Front area of electric vehicle.	2.25 m²
δ	Rotational inertia factor.	1
α	Regenerative breaking factor	0.4 to 0.6

Bellman ford strategy is being used to determine the shortest route between source and destination for an electric car. we have to find shortest paths based upon distance, speed and energy consumption.

1. Distance wise shortest path : All the edge costs of graph given in figure 4.1 are replaced with distance between node of graph given in table 4.2 and updated graph is given in figure 4.2.

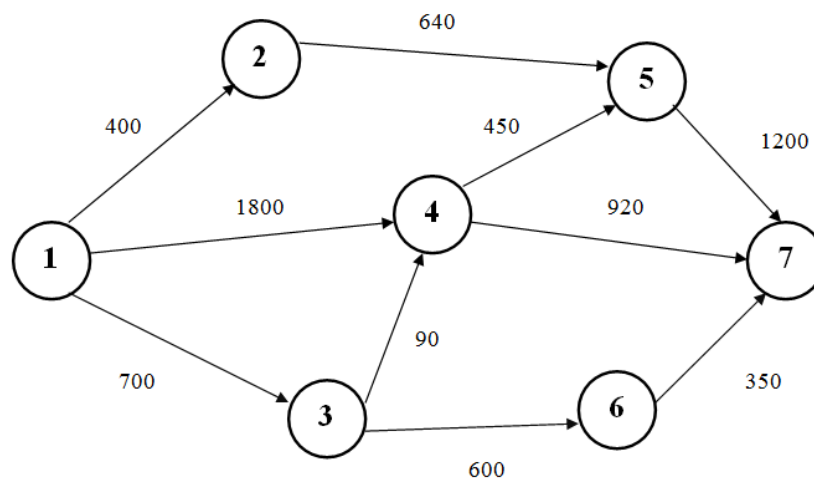


Figure 4.2 : Road map in the form of graph with distance as edge cost.

Shortest path demined between source=1 and destination=7 , based upon distance between nodes is **1 to 3 to 6 to 7** shown in figure 4.3.

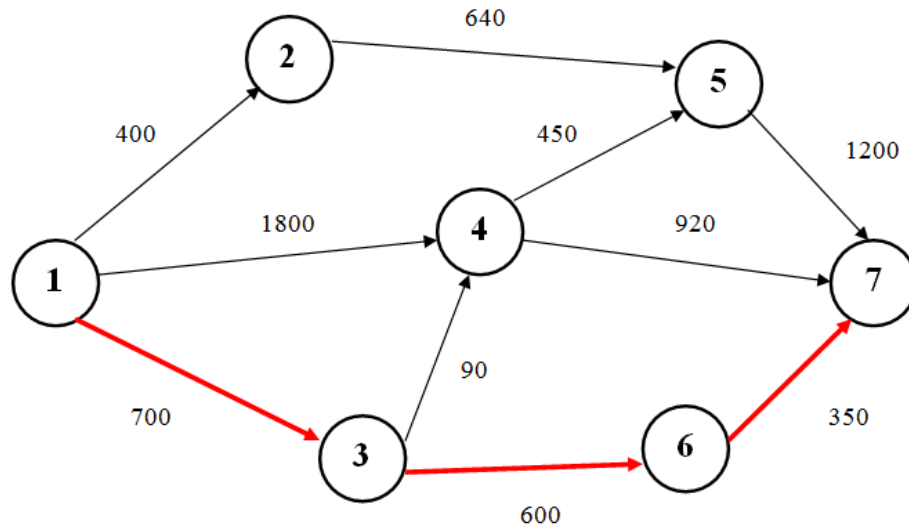


Figure 4.3 : Shortest path based upon distance.

2. Energy consumption wise shortest path.

All the edge costs of graph given in figure 4.1 are replaced with energy consumption required (given in table 4.2) to move electric vehicle between nodes of the graph and updated graph is given in figure 4.4.

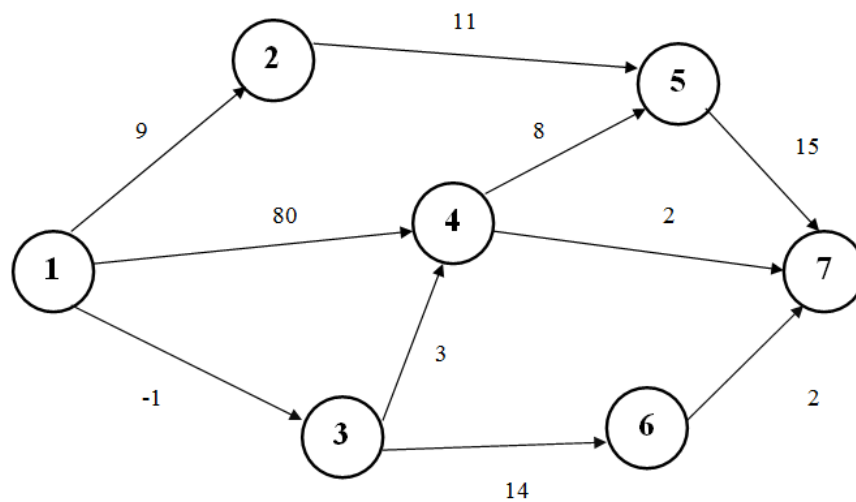


Figure 4.4 : Road map graph with energy consumption as edge cost.

Shortest path demined between source=1 and destination=7 , based upon energy consumption between nodes is **1 to 3 to 4 to 7** shown in figure 4.5.

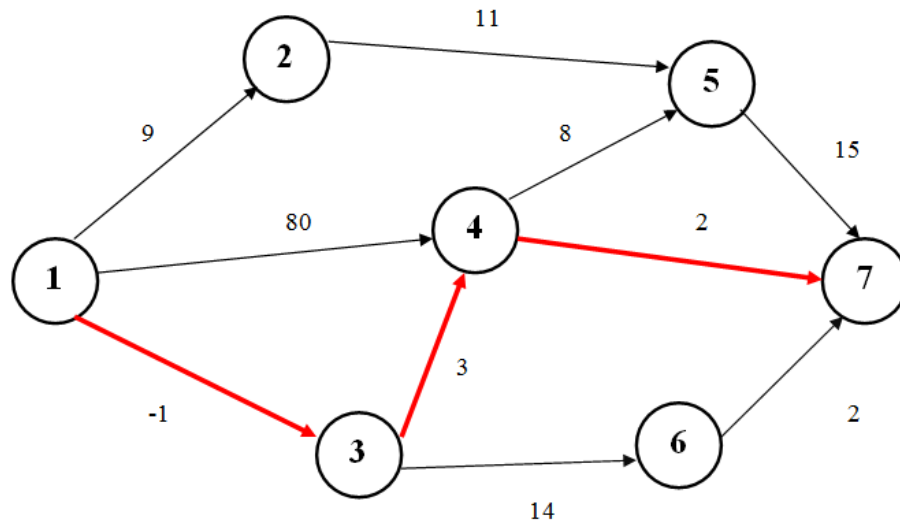


Figure 4.5 : Shortest path based upon energy consumption.

Shortest paths are determined based upon distance and energy consumption by electric vehicle. Both the paths are different. So a path having minimum travelling distance cannot be a shortest path for electric vehicle.

Conventional vehicles can have many different routes from source to destination. Conventional vehicle selects a route having minimum distance or minimum travelling time between source and destination. But for electrical vehicles selected route must have minimum energy consumption while travelling from source to destination

So electric vehicle route planning is very challenging task as traditional algorithms like Dijkstra are not designed for Electric Vehicles, Traditional algorithms measure shortest distance or minimum travelling time between source and destination.

4.5 Comparison of different algorithms used for electric vehicle.

	Dijkstra Algorithm	Bellman-Ford Algorithm	Johnson Algorithm
1	Dijkstra algorithm used to fix the shortest path problem with a single source.	Using the Bellman-Ford algorithm, the shortest path from source vertex to any other vertex can be found.	Johnson algorithm is used to solve all pair shortest path problem. it uses both Dijkstra and Bellman-ford algorithms.
2	It does not support negative weight edge.	It supports negative weights	It supports negative weights
3	Cannot be used to find minimum energy consumption path for electric vehicle as it cannot handle negative weight edges.	It can be used to find minimum consumption path for electric vehicle as it can handle negative weight edges. However performance decreases as number of nodes increases beyond 100.	It can be used to find minimum consumption path for electric vehicle as it can handle negative weight edges. performance is stable as number of nodes increases.
4	In Dijkstra each node has information about the cost of all other links in the graph	It has only information about neighbor link cost.	Johnson algorithm uses 'reweighing' technique to find shortest path.
5	Time Complexity - $O(V^2)$	$O(V^3)$	$O(V^2 \log V + VE)$
6	Each edge relaxed only once.	Each edge may relax multiple times	Each edge may relax multiple times

4.6 Determine charging station stops.

After determining the minimum energy consumption route next step is to identify charging stations along the route depending on the **SoC** of electric vehicle. Let C_{max} is maximum capacity of battery and SoC_{ev} represents state of charge at any point of time of an EV. It was assumed that all the nodes have charging stations. All the charging stations may have different prices (per unit) depending upon their source. A charging station can have power from multiple sources such as power from thermal plant, solar power, wind mill power or nuclear power. So price for charging may be different at different charging stations.

Table 4.4 : List of charging stations with price.

Nodes	1	2	3	4	5	6	7
Charging Station	CS1	CS2	CS3	CS4	CS5	CS6	CS7
Price (per unit)	5	4	5	2	6	3	2

Depending upon the status of Soc charging stations will be selected, Let consider a route determined between origin and destination (1 to 7) is 1->3->4->7.

Case - 1 : Let $C_{max} = SoC_{ev} = 6$.

Order of recommended Charging station stops : CS4

Case - 2 : Let $C_{max} = 6$ and $SoC_{ev} = 0$.

Order of recommended Charging station stops : CS1 -> CS4

This chapter discusses about the experiment results.

5.1 Traditional Algorithms for Electric Vehicle.

Traditional algorithms used to determine energy efficient path for electric vehicle have one major difference that they can support negative weighted edges. Algorithms like Dijkstra, Viterbi can determine shortest path for conventional vehicles, because conventional vehicle selects shortest path having minimum distance or minimum travelling time between source and destination. Only Bellman ford, Johnson and Floyd Warshall algorithm supports negative weighted edges and can be used in case of electric vehicles.

Table 5.1 : Algorithms used to find energy efficient path for EV.

Algorithm	Complexity V= Vertices , E=Edges	Approach	Negative weight Edge Support
Bellman Ford	$O(v^3)$	Dynamic	✓
Johnson	$O(V^2 \log V + VE)$	Dynamic	✓
Floyd Warshall	$O(v^3)$	Dynamic	✓

An electric car power usage model was suggested. Energy usage of an electric vehicle is sum of powers at battery terminal. The amount of forces acting on moving vehicles is based on the principles of vehicle dynamics for any car. A road map is created in the form of directed graph $G = (V,E)$ is used to determine efficient path for electric vehicle.

Practical implement shortest path algorithm was done in 'R' language, Multiple graphs are created, each graph contains different type of edge cost, The edge cost can be the distance between two nodes, the time to travel between two nodes, or the energy needed to move between two nodes of the electric vehicle.

A map in the form of graph is created (Figure 5.1). Each edge of the graph represents distance in meters between two nodes. Node '1' is selected as source node and node '7' is selected as destination node. Bellman ford approach is applied to determine shortest path between '1' and '7'. Shortest path determined is 1 to 3 to 6 to 7 (Figure 5.2).

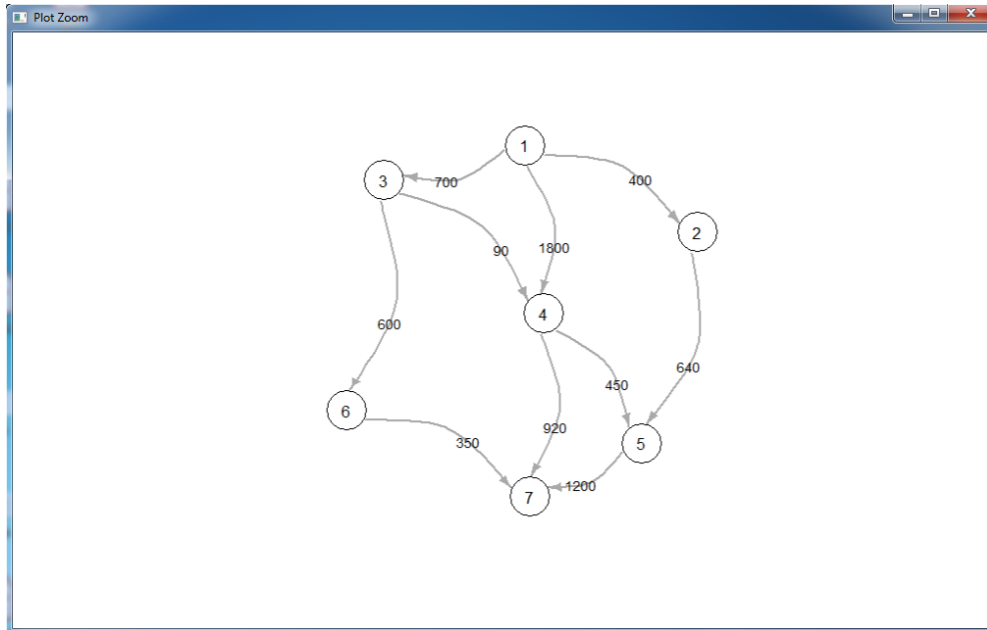


Figure 5.1 : Road map in the form of graph with distance as edge cost.

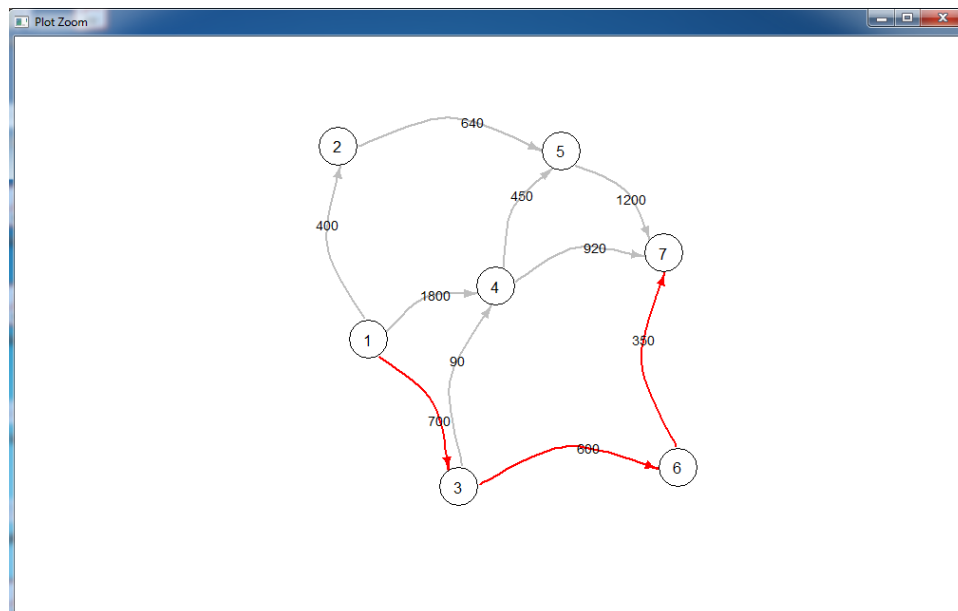


Figure 5.2 : Shortest path based upon distance.

Another map is created (Figure 5.3), Each edge of the graph represents amount of essential energy for electric vehicle to travel between two nodes. Node '1' is selected as source node and node '7' is selected as destination node. Bellman ford approach is applied to determine shortest path between '1' and '7'. Shortest path determined is 1 to 3 to 4 to 7 (Figure 5.4).

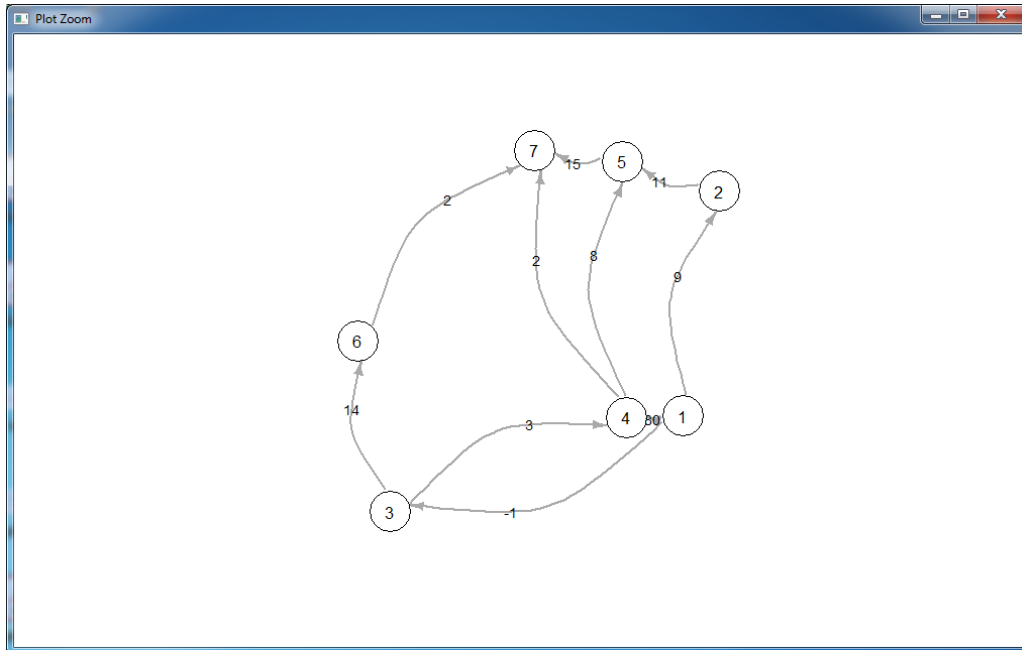


Figure 5.3 : Road map graph with energy consumption as edge cost.

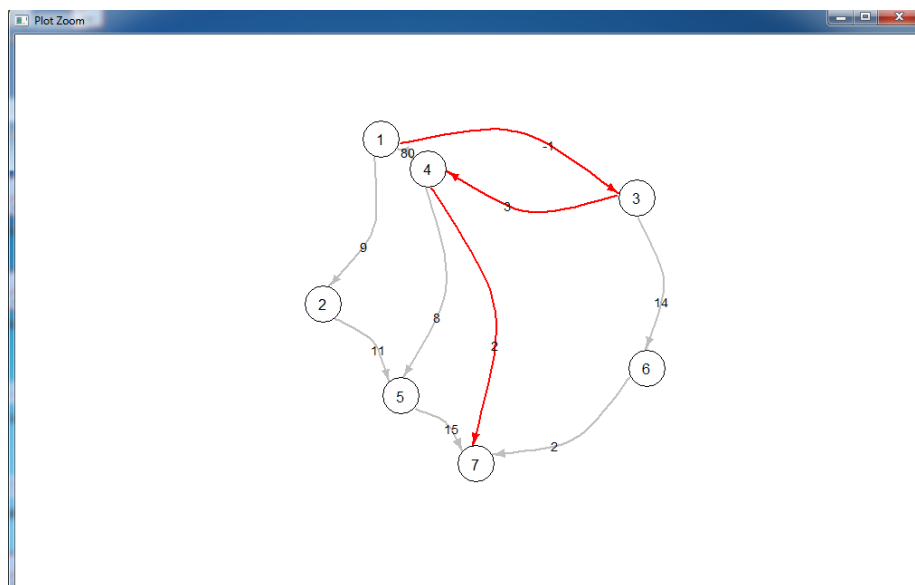


Figure 5.4 : Shortest path based upon energy consumption.

As shown in figure 5.4, shortest path for electric vehicle based upon energy consumption is very different than shortest path determined based upon distance, So a shortest path having minimum distance or minimum traveling time cannot be a shortest path for electric vehicle. comparison of results based upon time, distance and energy consumption is given below.

5.2 Results for path having shortest travel time.

Path with minimum travelling time is **1 to 2 to 5 to 7**.

Table 5.2 : Results for Path with minimum travel time.

	Edges		
	1 to 2	2 to 5	5 to 7
Distance	400 meter	640 meter	1200 meter
Speed	13.88 m/s ²	20.83 m/s ²	33.33 m/s ²
Travel Time	28.81 seconds	30.72 seconds	36.00 seconds

From table 5.2, we can derive information given below

Total distance traveled : 2240 meters.
Average speed : 22.68 m/s²
Time taken : 95.53 seconds

2. Results for path having shortest distance between source and destination.

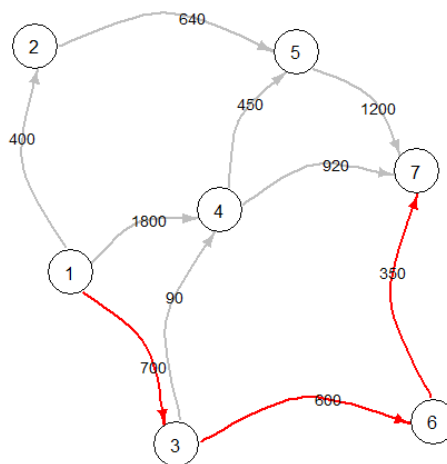


Figure 5.5 : Shortest path based upon distance.

From figure 5.4, Shortest path with minimum distance is **1 to 3 to 6 to 7**.

Table 5.3 : Results for Path with minimum distance.

	Edges		
	1 to 3	3 to 6	6 to 7
Distance	700 meter	600 meter	350 meter
Speed	13.88 m/s ²	13.88 m/s ²	11.11 m/s ²
Travel Time	50.43 seconds	43.22 seconds	31.50 seconds

From table 5.3, we can derive information given below

Total distance traveled : 1650 meters.
Average speed : 12.9 m/s²
Time taken : 125.15 seconds

5.3 Results for path having minimum energy consumption.

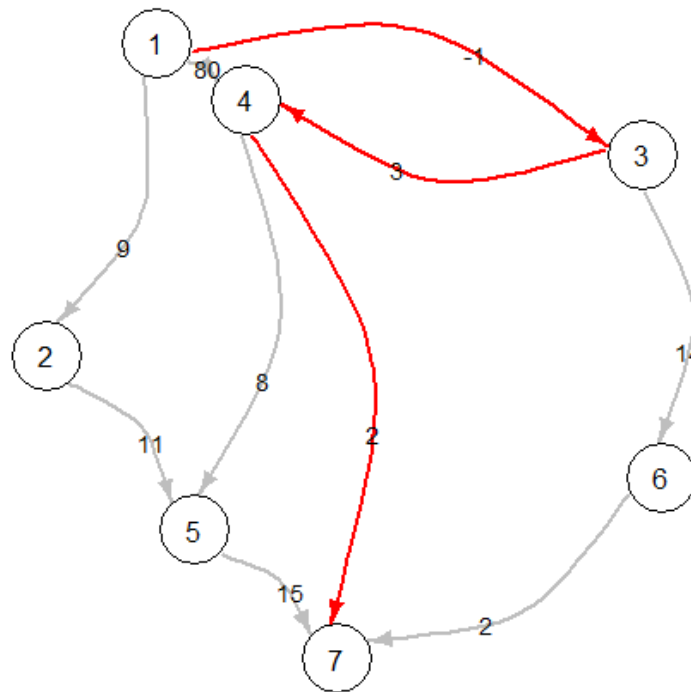


Figure 5.6 : Shortest path based upon energy consumption.

From figure 5.5, Shortest path with minimum energy consumption is **1 to 3 to 4 to 7**.

Table 5.4 : Results for Path with minimum energy consumption.

	Edges		
	1 to 3	3 to 4	4 to 7
Distance	700 meter	90 meter	920 meter
Speed	13.88 m/s ²	2.7 m/s ²	27.7 m/s ²
Travel Time	50.43 seconds	33.33 seconds	33.21 seconds

From table 5.4, we can derive information given below

Total distance traveled : 1710 meters.
Average speed : 14.76 m/s²
Time taken : 116.94 seconds

From experiment results, it is observed that minimum travel time path takes 95.53 seconds, but energy efficient path takes 116.94 seconds, So path having minimum travel time cannot be shortest path for electric vehicle.

It is also observed that path having minimum travel distance is 1650 meters, but energy efficient path travel distance is 1710 meters, So path having minimum travelling distance cannot be a shortest path for electric vehicle.

CONCLUSION & FUTURE WORK

This chapter discusses about conclusion and future direction of the work presented in this thesis.

6.1 Conclusions.

- Traditional algorithms used to determine shortest path have been analyzed and compared according to their features.
- A road map in the form of graph presented and proposed algorithm implemented to determine shortest path for electric vehicle.
- It has been proved that path between source and destination having minimum travel time cannot be a shortest path for electric vehicle.
- It has been proved that path between source and destination having minimum traveling distance cannot be a shortest path for electric vehicle.
- Energy efficient path was determined for electric vehicle.

6.1 Future Work.

- To determine energy efficient path on large size map, subject to minimum computation load and time. So a parallel implementation of algorithm can help to reduce the computational load and time.

REFERENCES

- [1] R. Hannappel, "The impact of global warming on the automotive industry," 2017.
- [2] J. Hansen, R. Ruedy, M. Sato, and K. Lo, "Global Surface Temperature Change," *Reviews of Geophysics*, vol. 48, no. 4, 2010
- [3] B. Bose, "Global Warming: Energy, Environmental Pollution, and the Impact of Power Electronics," *IEEE Industrial Electronics Magazine*, vol. 4, no. 1, pp. 6–17, 2010.
- [4] C. Sulzberger, "An early road warrior: electric vehicles in the early years of the automobile," *IEEE Power and Energy Magazine*, vol. 2, no. 3, pp. 66–71, 2004.
- [5] R. Cowan and S. Hultén, "Escaping lock-in: The case of the electric vehicle," *Technological Forecasting and Social Change*, vol. 53, no. 1, pp. 61–79, 1996.
- [6] "IEA - Shaping a secure and sustainable future for all," International Energy Agency. [Online]. Available: <https://www.iea.org/>. [Accessed: 26-Jun-2019].
- [7] "Advantages and Disadvantages of Electric Cars," *Conserve Energy Future*, 25-Dec-2016. [Online]. Available: <https://www.conserve-energy-future.com/advantages-and-disadvantages-of-electric-cars.php>. [Accessed: 26-Jun-2019].
- [8] S. Hardman, "Understanding the impact of reoccurring and non-financial incentives on plug-in electric vehicle adoption – A review," *Transportation Research Part A: Policy and Practice*, vol. 119, pp. 1–14, 2019.
- [9] C. C. Chan, "The State of the Art of Electric, Hybrid, and Fuel Cell Vehicles," *Proceedings of the IEEE*, vol. 95, no. 4, pp. 704–718, 2007.
- [10] M. Yilmaz and P. T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles," *IEEE Transactions on Power Electronics*, vol. 28, no. 5, pp. 2151–2169, 2013.
- [11] R. Abousleiman and O. Rawashdeh, "A Bellman-Ford approach to energy efficient routing of electric vehicles," 2015 IEEE Transportation Electrification Conference and Expo (ITEC), 2015.
- [12] R. Abousleiman and O. Rawashdeh, "Energy consumption model of an electric vehicle," 2015 IEEE Transportation Electrification Conference and Expo (ITEC), 2015.
- [13] A. Chambers, M. Eavis-Oquinn, V. Roberge, and M. Tarbouchi, "Route planning for electric vehicle efficiency using the Bellman-Ford algorithm on an embedded GPU," 2018 4th International Conference on Optimization and Applications (ICOA), 2018.
- [14] F. Alesiani and N. Maslekar, "Optimization of Charging Stops for Fleet of Electric Vehicles: A Genetic Approach," *IEEE Intelligent Transportation Systems Magazine*, vol. 6, no. 3, pp. 10–21, 2014.
- [15] A. M. Bozorgi, M. Farasat, and A. Mahmoud, "A Time and Energy Efficient Routing Algorithm for Electric Vehicles Based on Historical Driving Data," *IEEE Transactions on Intelligent Vehicles*, vol. 2, no. 4, pp. 308–320, 2017.

- [16] T. Chen, B. Zhang, H. Pourbabak, A. Kavousi-Fard, and W. Su, "Optimal Routing and Charging of an Electric Vehicle Fleet for High-Efficiency Dynamic Transit Systems," *IEEE Transactions on Smart Grid*, vol. 9, no. 4, pp. 3563–3572, 2018.
- [17] M. M. D. Weerdt, S. Stein, E. H. Gerding, V. Robu, and N. R. Jennings, "Intention-Aware Routing of Electric Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 17, no. 5, pp. 1472–1482, 2016.
- [18] K. Vatanparvar and M. A. A. Faruque, "Path to Eco-Driving: Electric Vehicle HVAC and Route Joint Optimization," *IEEE Design & Test*, vol. 35, no. 6, pp. 8–15, 2018.
- [19] H. Yang, Y. Deng, J. Qiu, M. Li, M. Lai, and Z. Y. Dong, "Electric Vehicle Route Selection and Charging Navigation Strategy Based on Crowd Sensing," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 5, pp. 2214–2226, 2017.
- [20] H. Yang, Y. Deng, J. Qiu, M. Li, M. Lai, and Z. Y. Dong, "Electric Vehicle Route Selection and Charging Navigation Strategy Based on Crowd Sensing," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 5, pp. 2214–2226, 2017.
- [21] S. Raagapriya, A. Ain, and P. Dasgupta, "Route optimization for an electric vehicle with priority destinations," 2017 International Conference On Smart Technologies For Smart Nation (SmartTechCon), 2017.
- [22] R. Schönfelder, M. Leucker, and S. Walther, "Efficient Profile Routing for Electric Vehicles," *Lecture Notes in Computer Science Internet of Vehicles – Technologies and Services*, pp. 21–30, 2014.
- [23] A. Artmeier, J. Haselmayr, M. Leucker, and M. Sachenbacher, "The Shortest Path Problem Revisited: Optimal Routing for Electric Vehicles," *KI 2010: Advances in Artificial Intelligence Lecture Notes in Computer Science*, pp. 309–316, 2010.
- [24] H. Wu, G. K. H. Pang, K. L. Choy, and H. Y. Lam, "A scheduling and control system for electric vehicle charging at parking lot," 2017 11th Asian Control Conference (ASCC), 2017.
- [25] R. Alvaro and J. Fraile-Ardanuy, "Charge scheduling strategies for managing an electric vehicle fleet parking," *IEEE EUROCON 2015 - International Conference on Computer as a Tool (EUROCON)*, 2015.
- [26] Y. Zheng, Y. Song, D. J. Hill, and K. Meng, "Online Distributed MPC-Based Optimal Scheduling for EV Charging Stations in Distribution Systems," *IEEE Transactions on Industrial Informatics*, vol. 15, no. 2, pp. 638–649, 2019.
- [27] R. Rana and S. Mishra, "Day-Ahead Scheduling of Electric Vehicles for Overloading Management in Active Distribution System via Web-Based Application," *IEEE Systems Journal*, pp. 1–11, 2018.
- [28] Z. Wei, Y. Li, and L. Cai, "Electric Vehicle Charging Scheme for a Park-and-Charge System Considering Battery Degradation Costs," *IEEE Transactions on Intelligent Vehicles*, vol. 3, no. 3, pp. 361–373, 2018.
- [29] W. Zhang, C. Dreise, R. Shao, and L. Chang, "An improved minimum-cost charging schedule for large-scale penetration of electric vehicles," 2018 IEEE Applied Power Electronics Conference and Exposition (APEC), 2018.

- [30] B. Wang and J. Yang, "Optimal electric vehicle charging scheduling with time-varying profits," 2018 52nd Annual Conference on Information Sciences and Systems (CISS), 2018.
- [31] S. I. Vagropoulos, G. A. Balaskas, and A. G. Bakirtzis, "An Investigation of Plug-In Electric Vehicle Charging Impact on Power Systems Scheduling and Energy Costs," *IEEE Transactions on Power Systems*, vol. 32, no. 3, pp. 1902–1912, 2017.
- [32] L. Zhang and Y. Li, "Optimal Management for Parking-Lot Electric Vehicle Charging by Two-Stage Approximate Dynamic Programming," *IEEE Transactions on Smart Grid*, vol. 8, no. 4, pp. 1722–1730, 2017.
- [33] E. Akhavan-Rezai, M. F. Shaaban, E. F. El-Saadany, and F. Karray, "Online Intelligent Demand Management of Plug-In Electric Vehicles in Future Smart Parking Lots," *IEEE Systems Journal*, vol. 10, no. 2, pp. 483–494, 2016.
- [34] J. Babic, A. Carvalho, W. Ketter, and V. Podobnik, "Evaluating Policies for Parking Lots Handling Electric Vehicles," *IEEE Access*, vol. 6, pp. 944–961, 2018.
- [35] L. Yao, W. H. Lim, and T. S. Tsai, "A Real-Time Charging Scheme for Demand Response in Electric Vehicle Parking Station," *IEEE Transactions on Smart Grid*, vol. 8, no. 1, pp. 52–62, 2017.
- [36] J. Timpner and L. Wolf, "Design and Evaluation of Charging Station Scheduling Strategies for Electric Vehicles," *IEEE Transactions on Intelligent Transportation Systems*, vol. 15, no. 2, pp. 579–588, 2014.
- [37] Y. Guo, J. Xiong, S. Xu, and W. Su, "Two-stage economic operation of microgrid-like electric vehicle parking deck," 2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), 2016.