Sustainable and Optimal Rolling of Electric Vehicle on Roadways with Better Implementation

Sarita Samal, Chitralekha Jena, Roshan Kumar Soni, Rahul Verma, Sumeet Sahaya, and Prasanta Kumar Barik

1 Introduction

The ceaseless use of fossil fuels is eroding the earth's ability to provide a suitable environment for life. Its takeover of daily life has become so familiar that it is now critical to come up with an idea that is far more convincing than what ancient leaders stated [1, 2]. Electric vehicles are becoming increasingly popular among those who support the transition to a cleaner system of automobiles and avionics. As a result, the development of an electric vehicle plays an important role in avoiding the effects of pollution, climate change, unlikely price hikes and so on, while also putting an end to the use of fossil fuels to power vehicles. The regular spread of carbon dioxide would also be reduced in comparison with what we currently face [3]. Electric vehicles have already taken up slots in the share market with 28.8% in Norway, 6.4% in the Netherlands and China with 1.4%. While Tesla has already recorded a sale of almost 500,000 electric cars with Volkswagen in the second position in the year 2020. It's getting higher with various countries focusing to increase the number of EV

S. Samal (✉) · C. Jena · R. K. Soni
SoEE, KIIT DU, Bhubaneswar, Odisha, India
e-mail: ssamalfel@kiit.ac.in

C. Jena
e-mail: chitralekha.jenafel@kiit.ac.in

R. K. Soni
e-mail: 1803044@kiit.ac.in

R. Verma
ABES Engineering College, Ghaziabad, India

S. Sahaya
Department of EE, IIT (ISM), Dhanbad, Jharkhand, India

P. K. Barik
Department of MEE, CAET, OUAT, Bhubaneswar, Odisha, India

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occupancies. If 2020 had been an equally productive year, then a whooping amount of 40 million EVs would have crossed globally. They are powered by renewable energy instead of fossil fuel power plants that are capable of harming the environment. For that, huge number of electric vehicle and charging stations need to be built for a continuous supply of power. And in position, for a vehicle to reach by the time, they run out of charge. It's important to discuss the impact of electric vehicles on the distribution system. It is recorded to leap up with a peak load of 17.9% for 10% access and 35.8% when the access is increased to 20%. Power losses and voltage deviations are generated because of the higher peak load of an electric vehicle. This can also lead to the violation of the thermal limit of transformers and transmission lines. To reduce the distribution system, losses coordinated charging system is brought up. A coordinated charging system also ensures an even voltage range and keeps the distribution system from becoming overloaded. This works in conjunction with a coordinated charging process that generates lower peak loads or stays within limits. A coordinated charging system necessitates customer coordination for serial vehicle charging, which is frequently lacking in practice. As a result, in the majority of cases, refreshing the total area for a non-restricted process has yet to be established. For a rapid increase in the number of electric vehicles, an infrastructure that can provide well-planned facilities must be built [4, 5]. Of which, chargers are categorized into three levels. Level 1 charger or a residential charging option is of low power used for lesser charge consuming vehicles. The level 2 charger is a bit advanced than the previous one and requires protection when inside a residence. Lastly, commercial purposes come with a level 3 charger that is capable of fully charging a vehicle within an hour. It's in huge demand as it's very less time-consuming. But in return, it's costlier and without an appropriate plan, the electric power system can be overloaded. The ability of electric vehicles to provide a power reserve while the batteries are being charged stabilizes the electrical system. Primary supports to the EV system can lead to the control of primary and secondary frequencies and regulation of voltage. In an electrical power system, primary and secondary control reduces the frequency deviation and helps in a balanced supply, respectively. Electric vehicle charger is the major equipment for voltage regulation. Distribution systems follow one-way and outward energy flow while developing voltage safety and regulation plans. For handling daily load consumption, electric vehicles need to go through a regular plan. An unregulated charging process of electric vehicles leads to transmission line crowding that increases transmission line loss and decreases the quality of electric supply. Due to this, both electric vehicle batteries and grid systems are hampered. So, a well-scheduled and managed charging process is necessary to keep smart grids intact. Electric vehicles have a greater scope of making transportation easier and well affecting the electrical power system with the regular and properly planned charging process. They could replace the conventional method to help support the ecosystem.

The following are the primary objectives of this study:

We need to understand the aims and their corresponding objectives when conducting research and presenting a paper on the implementation of an electric vehicle. The aim is simply the abbreviation for targets and objectives, which are the actions we must take in order to achieve our goals.

- Implementation of an electric vehicle as a mode of transportation.
- Reducing the use of traditional fossil fuels.
- Reducing the impact of pollution, particularly, carbon emissions.
- Sustainable development in renewable energy is being implemented.
- The successful implementation of an electrical distribution system for smooth operation.
- Reduced global warming.
- Economic development and technological advancement in society.

If we need to achieve all these aims successfully, then the below objectives should be taken into consideration for a long time because it will not have a short time efficiency.

- People must learn about social responsibilities in order to understand the current situation and gain enthusiasm for using electric vehicles.
- We need to think together to reduce pollutant gases and atmospheric temperature there, so that the overall consumption of fossil fuel through our IC engine-based vehicle can be greatly reduced.
- The entire world is looking for long-term development, particularly in the energy generation sectors. As a result, we must also think about it and contribute to achieving zero-carbon emissions through energy generation from renewable sources. Even for charging our electric vehicles, using renewable energy sources can be a great idea, and this can help a lot in the context of EV implementation.
- If there are so many electric vehicles on the road and there aren't enough charging stations and charging facilities, it won't be a successful strategy. As a result, the installation of a regular charging station within a certain distance must be done correctly.
- As we can see, the process of fossil fuels (Petrol/Diesel) is at its peak, so reducing fossil fuel usage and switching to electric vehicles will also help a lot in avoiding high daily communication costs.

This is how all these possible aims can be achieved after the successful placement of electric vehicles in the distribution system. Later on, in the further parts of the report, we will be discussing methodology and mathematical expressions for better understanding.

2 Problem Statement and Formulation

With the help of lots of researches from different published research papers, it is clear to us that the overall implementation or placement is not that much easier. From the literature review, it is very clear that the distribution system and their placement completely depend on the implementation of charging stations and it is one of the most effective problems for increasing the number of electric vehicles in roadways. The limitation in the implementation of EVs is nothing but its limited range. For conventional fuel-based vehicles, there is not a limited range due to the presence of fuel pumps and refueling time is very less. But for an electric vehicle since the charging time is long and it is not sufficient in the country, therefore, the problem begins with the implementation of electric vehicles and the distribution network of charging stations throughout the roadways. Following these problem statements, we have to move forward in this paper so that EVs and their charging stations can be implemented [4]. For better understanding, the problem statements are written below in bullet points so that we can proceed with those points step by step.

1. Implementation of an electric vehicle instead of a conventional IC engine-based vehicle.
2. Implementation of charging station on a regular interval in the roadways.
3. Getting advanced technologies for fast charging so that the recharging time can be reduced.
4. Increasing better efficiency for the usage of battery power in terms of better range for a fully charged battery as well as the battery life cycle for economic feasibility within customers.

3 Methodology

For an in-depth understanding of the overall technology few points related to EV are discussed in this part of the paper. The discussion-based on a technological factor will help us to visualize the engineering terminologies and their implementation in the real world. Electric vehicle load modeling, photovoltaic generation modeling and modeling of test systems in open DDS are the basic thing covered here.

Electric vehicle load modeling

The load modeling of an electric vehicle is nothing but the demand of charging in a particular charging station which depends on the overall distribution system. The distribution system has four main factors, and these are arrival time, departure time, number of arrivals and departure and finally traveling distance. Different data based on these parameters will help a lot for its proper implementation/placement. The arrival time of a vehicle is taken as the starting point for a vehicle and the departure time of the vehicle to another charging station is taken as the time of a run. The gap between these times is the time of a run. In between this run time, the traveled distance is the range of the vehicle from a fully charged battery [1]. According to these data, a probability function is prepared for getting their distribution. Estimation of these parameters will help a lot for the charging stations to fulfill the desired demands for a smooth operation. The initial state of charge in an electric vehicle depends on the traveled distance.

This can be expressed as, in (1)

$$\mathrm{SOC}_{\mathrm{initial}} = 1 - \left(\frac{\text{Distance travelled}}{\text{Maximum distance covered}}\right) \forall e \in E \tag{1}$$

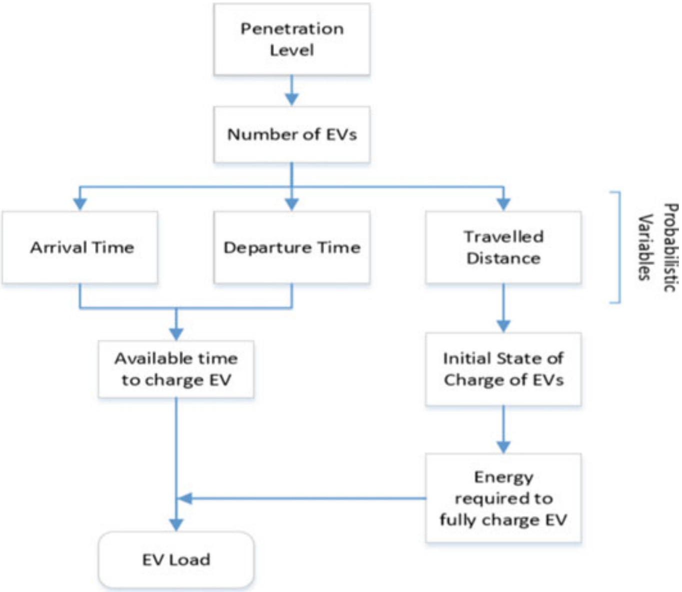

Fig. 1 EV load estimation flowchart

The maximum distance signifies the total distance that can be covered by the vehicle when it is in full charge condition (Fig. 1).

Though the report is based on a review of the electric vehicle placement and its successful rolling in the roadways for upcoming days, but a secondary data is gathered from different research papers which are shown below. The reason behind it is to get a general overview regarding their literature review and data collection [1].

Photovoltaic generation modeling

To enhance the usage of renewable sources of energy along with the implementation in the overall electrical distribution system, the solar/photovoltaic cell implementation is one of the most effective solutions. It can be used just like a solar power grid for the generation of electricity and the generated power can be utilized for charging stations by converting the source current from DC to AC through inverter circuits. There might be some problems during its implementation because of rapid weather changing but as a whole, for a long time, it will have a significant figure in terms of environmental effects (Zero emission) and cost-effectiveness [1]. This type of generation unit can also be implemented in rooftop solutions for small commercial goods carrying vehicles. In some cases, rooftop solar panels proved very efficient for charging electric vehicles within personal property instead of using services from on-road charging stations. In technical point of view for the desired load estimation, the generation from a PV module can be expressed as below (Table 1).

$$P_{PV} = 0.995 \times \eta \times A \times I \times (T_m - T_{ref})$$

where

η	Pannel efficiency
A	Pannel area
I	Irradiance
T_m	Measured temperature in °C
T_{ref}	Reference temperature 25 °C.

Table 1 Vehicle user and charging station data with probability distribution function researched data [1]

Data	Distribution categories	Different parameters in distribution
Residential feeders (EV)		
Evening arrivals	Extreme value	$\xi = 0.0613$ $\sigma = 0.5129$ $\mu = 18.7393$
Morning departure	Extreme value	$\xi = -0.252$ $\sigma = 1.180$ $\mu = 7.09$
Commercial feeders		
Morning arrivals	Extreme value	$\xi = 0.0629$ $\sigma = 0.546$ $\mu = 8.905$
Evening arrivals	Weibull distribution	$\lambda = 16.038$ $k = 18.022$
Evening departure	Extreme value	$\xi = -0.282$ $\sigma = 1.116$ $\mu = 16.407$
Night departure	Extreme value	$\xi = -0.277$ $\sigma = 0.536$ $\mu = 20.549$
Commercial and residential feeders (EV)		
Traveled distance	Extreme value	$\xi = 0.0474$ $\sigma = 7.901$ $\mu = 12.882$

Modeling of test system in open Data Distribution System (DDS)

In terms of modeling in the test system within the distribution network is not an easy thing to do, but for their testing conventional techniques like Newton Raphson, Gauss Seidal methods will not be appropriate for this particular case study. For these limitations we have seen in different research papers authors are trying to solve them with the help of general theories of Kirchhoff's law maybe it if KCL and KVL [1]. In this case with the help of MATLAB and an open DDS interface, the optimization can be found out if one can successfully implement the below-given flowchart in the interface. All elements are represented by their nodal admittance matrix. In this particular process for optimization, the system builds an admittance matrix and initiates the entire process by selecting any random voltage vector V_o so that the system interface can calculate the current from each of the circuit elements. The new value V_{n+1} is calculated by the below-given equation in the system interface [1]. This particular iterative technique takes place till the convergence criterion takes place in the optimization iteration.

$$V_{n+1} = [Y_{\text{system}}]/I_{\text{PC}} V_n \tag{2}$$

The results in the Open DDS should be imported into MATLAB interface for studying the optimization technique. For getting rid of this complex situation, PSO comes into the role. PSO allows the optimization iteration for its running multiple times. This kind of analysis will help a lot to get estimation about the future scenario and will also help to provide the sizing of charging stations for the optimal placement of the electric vehicle [3].

4 Mathematical Evaluation

The implementation of electric vehicles within the optimal distribution network needs some feasibility for its charging stations. Now one question will be there, that is the main factors to be introduced in the mathematical evaluation for optimal placement of EV in the distribution system. Since there is nothing more technical because the overall feasibility depending on the usage of electricity and their loss makeup. So, the mathematical evaluation focuses on the losses associated with the loss in different sections of the distribution network.

Decision vector

The decision vector is the thing, which represents the actual locations of charging stations within the distribution network. The decision matrix is represented as CSP [5].

$$\text{CSP} = \begin{cases} 1, \text{ if CS is required} \\ 0, \text{ otherwise} \end{cases} \quad i = 1, 2, 3, \ldots, n \tag{3}$$

Multi-objective functions

It is a problem-solving phenomenon in which problems related to QCS can be solved. The multi-objective functions consist of two different sub-objectives those are,

1. Transportation energy loss cost
2. Substation energy loss cost.

Transportation energy loss cost

In this process, we can see an EV needs to go a certain distance to reach the nearest charging station. In this process, there might have a loss which is known as transportation energy loss and the cost associated with this is known as TEL cost [5]. Let us consider the EV moves from its *j*th position to the *i*th position and in this trajectory, the transportation energy loss will be obtained by a mathematical expression.

$$I_{ij} = \text{diag(CSP)} \times \left|\text{loc}_{\text{EV}}^{j} - \text{loc}_{\text{CS}}^{i}\right|, \quad i = 1, 2, 3, \ldots, N_{\text{CS}}$$

where

N_{CS} Number of charging stations
$\text{loc}_{\text{EV}}^{j}$ Location of EV
$\text{loc}_{\text{CS}}^{i}$ Location of charging station.

$$\text{TEL}_j = P_{\text{E}} \times S_{\text{EC}} \times L_{j\,\text{min}}$$

where

P_{E} Electricity price rs/Kwh
S_{EC} Energy consumption per km
$L_{j\,\text{min}}$ Minimum length L_{ij}.

Now the normalized cost associated with TEL can be expressed as,

$$\text{TEL}_{\text{norm}} = \frac{\sum_{j=1}^{N_{\text{EV}}} \text{TEL}_{j\,\text{min}}}{\text{TEL}_{\text{max}}}, \quad j = 1, 2, 3, \ldots, N_{\text{EV}}$$

Substation energy loss cost

Instead of transportation energy losses due to the distribution parameters, there might have some losses too. The EV load within the charging station can be expressed as,

$$L_{\text{EV}}^{i} = N_{\text{char}}^{i} \times N_{\text{EV}}^{\text{CS}i} \times P_r$$

where

$N_{\mathrm{EV}}^{\mathrm{CS}i}$ Number of EVs utilizing charging station
N_{char}^{i} Number of chargers within the charging station
P_r Required per EV.

There will also be some additional losses in the charging station, those are expressed below.

$$\mathrm{APL}_{\mathrm{EV}} = \mathrm{TPL}_{\mathrm{EV}} - \mathrm{TPL}_{\mathrm{original}}$$

where

$\mathrm{TPL}_{\mathrm{EV}}$ Total power loss when CS is connected to the grid with actual load
$\mathrm{TPL}_{\mathrm{original}}$ Total power loss when CS is not connected to the grid.

Finally,

$$\mathrm{SEL}_m = \mathrm{APL}_{\mathrm{EV}} \times t_{\mathrm{ef}}(m) \times P_{\mathrm{E}}$$

where

$t_{\mathrm{ef}}(m)$ Effective operating hour when CS connected to grid bus(m).

Now the normalized cost due to substation energy loss is,

$$\mathrm{SEL}_{\mathrm{norm}} = \frac{\sum_{m=1}^{N_{\mathrm{bus}}} \mathrm{SEL}_m}{\mathrm{SEL}_{\mathrm{max}}}, \quad m = 1, 2, 3, \ldots, N_{\mathrm{bus}}$$

where

N_{bus} Number of busses in the distribution network
$\mathrm{SEL}_{\mathrm{max}}$ Maximum SEL cost.

This is how the entire energy loss calculation can be achieved with some simple expression. Though there are so many types of detail mathematical evaluation, which is needed for actual representation, but for optimal placement, since we are using the term optimal; therefore, the losses and their costing are to be optimized in the initial phase. Therefore, it will be sufficient for understanding and for more detailed calculation there, we will need the exact power train solution for individual EVs [5].

5 Result Analysis

According to the mathematical evaluations that have been done in this paper, the entire thing related to the losses is very few for their incorporation. The factors consisting of TEL and SEL costs will not affect the overall distribution system because the charging stations and their charging points will be connected with vehicles all the time. It is because of the large charging time of EVs. The combination of TEL and SEL represents the optimal solution for the implementation of EV and its distribution system [5]. For reducing the SEL cost, the transmission system of the charging station is to be designed with proper parameters and that can give the best possible optimization.

5.1 Current Scenario and Progress

The entire process for implementation of electric vehicles in the distribution system not only converged to the topic of its charging station sizing and placement. It has so many things to consider when there is a long-time approach to a particular technology. From Asian to European countries, everyone is most capable to achieve their target. 2025 is the target to achieve where most of the countries working so hard to replace 15% of IC engine-based vehicles with electric vehicles. Also, for electric vehicles along with their price, government tax, insurance costing, road tax, and electricity tariff prices are reduced. For these reasons, the electric vehicle selling and their usages for commercial and domestic usages are increasing in nature [6]. As this paper is focused on the optimal placement of electric vehicles, therefore, the charging station and their technology development is also an important thing to be addressed. Now if we can check some secondary Internet source data about the sales of EVs in different countries, then it will be clear to us about the leading country for successful implementation of EV (Fig. 2).

It is very good to see such improvement in the sales of electric vehicles throughout the world which depicts actual sustainable development in terms of getting clean and green energy. Among different countries and subcontinents, China, USA and Europe are leading in its marketing and all other countries are also putting their efforts in its implementation [9]. For a developing country, India is also in the development process in which various small companies are getting the promotion by the government for their EV manufacturing on Make in India context. Also, to increase the level of technology in most of the universities are also applying soft skill development on such type of topics so that students can achieve vast knowledge for the development of

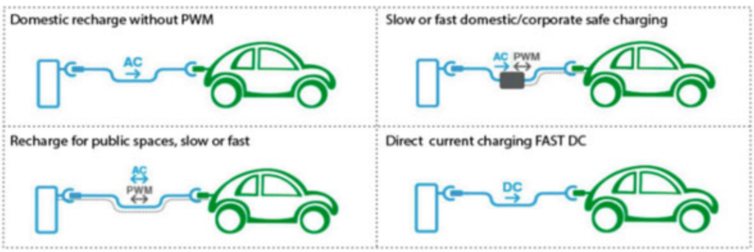

Fig. 2 Different types of charging methods for EVs

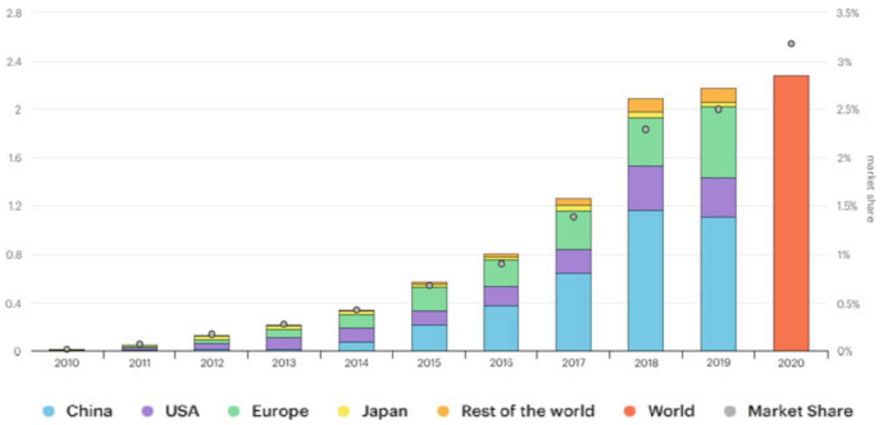

Fig. 3 Global electric vehicles sales from 2010 to 2020 year and country wise data

EV for sustainable development. Society of automotive engineers (SAE) also doing different events in regular years for in-house EV development racing from different college teams. Such kinds of initiatives are giving a hugely positive result and based on it is expected that by 2030 more than 50% of vehicles IC engine-based vehicles will be replaced by electric vehicles [7] (Fig. 3).

5.2 *Implementation and Target*

Though different countries are achieving their target in EV implementation but some other countries are lagging behind their target. India, Pakistan and Africa continents are not able to match their target. China, US and some European countries are replaced most of their public transport vehicles (Buses and Taxi) with an electric vehicle. In those countries, this is possible just because of adequate charging stations. The countries lagging in the implementation of EV is just because of their branches for charging, their infrastructure is placed only in few metro cities. As per the government announcement, 30% of the vehicles in India will be replaced by EVs within 2030 [8, 9]. Tata, Mahindra, Maruti Suzuki, Nissan and various car manufacturing companies are doing their R&D for a successful implementation, but in a country like India with a very high population, it is not that feasible. So, instead of making a huge change in the public transport medium if we can get some benefit from the implementation of EV in private transport medium will become more feasible. For that reason, companies like Hero Electric, Okinawa and Yo-bikes are getting more exposure from the customer point of view because they are focusing on daily commuting bikes that are not expensive and can be charged in domestic lines also for personal usage. Tesla is one of the leading companies in EV manufacturing field doing great in this field. They are making a greater number of EV charging stations compared to their vehicle production so that the movement will become flexible. For developing countries to initiate their production plant, they are also working hard on it [10, 11]. Tesla also going to build their production plant in India very soon, which will be a revolutionary decision for Indian EV placement.

5.3 Drawbacks in the Development

Though there are so many good things are available in the optimal placement of electric vehicles in the entire distribution system. But in the actual scenario, there are so many drawbacks. If those limitations or drawbacks cannot be overcome by the meantime, there will not be optimal placement. Therefore, during all these conversations, such type of evaluation is necessary. If there are so many drawbacks, then how it is incorporated in various countries successfully is the main question [12, 13]. So, considering other countries' success factors, we will need to focus on them so that the implementation will achieve sustainability.

All the possible drawbacks are listed below in bullet points,

- Since we are saying about the less usage of fossil fuel by using more numbers of electric vehicles. But the interesting thing is the law of conservation of energy, according to that during charging, we are consuming electricity and for the generation of electrical energy power plants are using fossil fuels like coal [14]. Therefore, how the difference can be achieved is the main problem for a country like India, Pakistan, etc., because these countries are mainly dependent on fossil fuel-based power plants. This type of scenario cannot be changed until or unless the power plants will become renewable.
- Another problem is the placement of charging stations in the whole distribution unit. In this case, we have lots of difficulties. First of all, in conventional petrol pumps, the timing of refueling is very less so the movement of the vehicle is faster and for that reason, there we do not need a large space for vehicle parking [15]. But when it will be a charging station it will take almost 4–5 h for full charging therefore the number of vehicles in the charging station and their movement will become slow. In this situation, the charging station will need a huge space for a parking facility. Also, for a long-time charging, the arrival time will hamper so many urgent activities. Also, in this case, all companies should maintain the same type of design specification for their hardware systems so that all EV brands can use the same charging station just like a fuel pump [16].
- Finally, the last problem can be the non-user-friendly nature of the operation. Basically, electric vehicles are not conventional and their maintenance and operational activities are not conventional. Therefore, the optimal implementation will be achieved only after a long time of usage.

5.4 Environmental Sustainability

The usage of electric vehicles and the optimal placement of charging stations will reduce the usage of fossil fuels like petrol and diesel for daily commutation in cars and bikes. Different pollutant gasses like CO_2, CO, SO_2 and unburned hydrocarbon will affect a lot in the environment [17]. The most effective pollution can be termed as temperature increment/global warming, lesser rain and acid rain. These will harm the healthy life of human beings and plants. For long-term usage of EV, the fossil fuel usage will be reduced and the generation of pollutant gasses will also be reduced. Therefore, the sustainability factors can be achieved in terms of environmental sustainability after long-term usage [12].

5.5 Economical Sustainability

In the context of economical sustainability, the expenditure should be lesser compared to the fossil fuel expenditure. Though there will not be a very high difference for long-term usage, it will have benefits. To describe this thing, a comparative study is explained below for ease of understanding. Here we can see how feasible is the electric vehicle for getting economical sustainability for long-term usage. The general expenditure can be reduced to a great extend for such type of implementation. Even if we can initiate the things like, only using EV for local daily commutation, then also the economical sustainability will become a great factor for our daily expenditure [18] (Table 2).

Table 2 Costing/expenditure analysis for economical sustainable study (as per practical scenario observed)

Conventional ICE vehicle	Electric vehicle
Cost of ICE vehicle: INR 100,000	Cost of electric vehicle: INR 80,000
Daily commute: 50 km	Daily commute: 50 km
Mileage: 50 km/lit of petrol	Mileage: 50 km/charge
Petrol price: INR 100 per lit	Electricity price: INR 30 per charge
Daily expenditure: INR100	Daily expenditure: INR 30
Yearly maintenance cost: INR 10,000 (engine oil change)	Yearly maintenance cost: INR 1000 (only few things to be done)
Total cost for fuel per annum: INR 36,500	Total cost for charging per annum: INR 10,950
Total expenditure per annum for ICEV: 100,000 + 10,000 + 36,500 = INR 146,500	Total expenditure per annum for EVs: 80,000 + 1000 + 10,950 = INR 91,950
Total saving per annum in electric vehicle: 146,500–91,950 = INR 54,550	
If we assume the battery life will be 3 years then also we are saving an amount: [(3 × 54,550) – Battery price] = [163650 – 50,000 (approx)] = INR 113,650	

Along with this, the charging cost associated with the electric vehicle can be reduced by the implementation of personal rooftop solar panels, which will give zero costing on charging. Hence if one can think properly and can make an initial investment, the overall economical sustainability can be enhanced to a great extend [19–22]. Therefore, in clear terminology, we can see the overall sustainability factors are good enough for the implementation of electric vehicle and their entire distribution unit with effective charging stations for long-distance traveling along with some fast-charging technologies [23].

6 Conclusion

This paper discusses the optimal placement of electric vehicles and their distribution system via charging stations. There are numerous advantages and disadvantages to optimal placement, but the main goal of this paper is to show how they can be successfully placed. As a result, from the beginning to the end of this paper, we covered every possible point, such as introduction, literature review, methodology, mathematical evaluation and many more. All of these points will assist us in obtaining the most accurate information about EV placement. Because the optimal placement of EVs in the distribution network is primarily concerned with the distribution of charging stations, the loss parameters for CS distribution are mathematically explained in the mathematical evaluation. Additionally, sizing is a challenge for optimal placement because during the holiday season, there will be a large number of vehicles on the roads, and charging stations must accommodate all of them, and the electrical parameter with their capacity must be adequate. Even through a comparative analysis, we have demonstrated the economic sustainability factor associated with EVs. Finally, in a nutshell, we can say that the implementation of EV in the distribution network is optimal in some countries, while in others, we must collaborate to make it optimal in all aspects.

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