

Charging station location finding using Estimated Distance to Empty Prediction Algorithm



Yamini V., Ajayan S.

Abstract: Sometimes, Solar Electric Vehicles (SEV) drain out of power and stops in the middle of the journey. To overcome this problem, SEV is upgraded with on-board and off-board charging facilities. This paper proposes a prediction algorithm that considers solar power and battery power to find out the distance the vehicle can travel, thus helping the vehicle driver to stop at a charging station to charge the vehicle. The proposed algorithm is simulated for various driving cycles and results are presented and discussed.

Keywords- Electric Vehicles, Solar panels, Charging facilities, Range estimation, Prediction algorithm.

I. INTRODUCTION

In recent years, Electric vehicles are becoming more popular and have an advantage over fuel cost, reduced pollution, etc., Charging facilities of electric vehicles are more important when compared with fuel vehicles [1]. In order to reduce CO₂ emissions and pollution that is caused by fuel vehicles, car manufacturers developed an Electric vehicle as an alternative solution to fuel vehicle [2]. The performance of an Electric vehicle is based on its battery capacity and motor drive as in Fig. 1. Hence CO₂ emissions will be less thereby replacing the petrol engines [3]. SEV suffers from disadvantages such as low range, the inability of regenerative braking and low power output of vehicle-mounted panels. This paper proposes to charge an SEV by using both on-board solar panel charging and off-board charging station. During onboard charging, the vehicle absorbs energy from the sun and stores in battery which is used to run the vehicle. In the case of off-board charging, the vehicle battery is charged using solar charging stations[4]. Due to limited energy storage, the driving range of electric vehicles should be predicted to find a charging station to charge the Electric vehicle [5]. The range estimation or determination of range calculation gives distance that can be traveled with a particular state of charge (SOC) and indicating a charging station when the electric vehicle runs out of charge [6].

The driving cycle to charge an electric vehicle was designed based on two cases. In the first case, the vehicle will stop at each charging station and calculate the remaining amount of charge left in SOC to analyze whether the vehicle can able to run for the next charging station. In the second case, it is designed that the vehicle will stop directly at a particular location when the SOC of the battery becomes fully discharged.

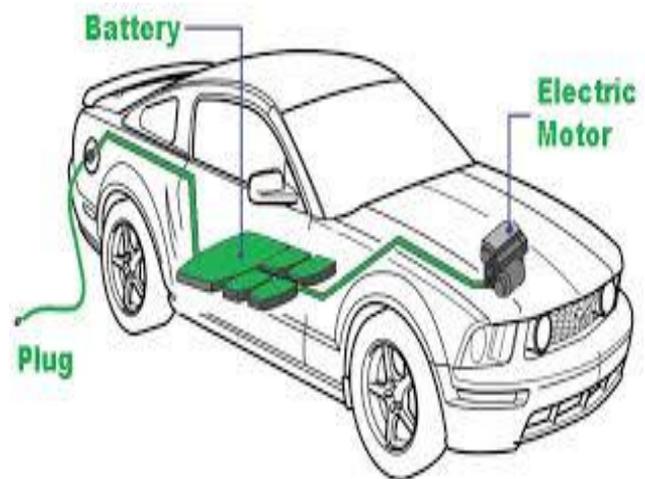


Fig. 1 Electric Vehicle [7]

II. METHODOLOGY

With the development of on-board solar EV, the solar radiation from sun varies from place to place and some climatic condition such as rainy seasons, panel does not get sufficient amount of reaction to charge a vehicle to run. To simplify this problem in this study we opted for both on-board and off-board charging.

The objective of this study is:

- To determine the power demand of the vehicle for a driving cycle and manage the power flow from solar panels and batteries to meet the power requirement.
- To determine/predict the distance that can be traveled by the vehicle by checking the state of charge of the battery and solar power.

To find a solution for the objectives, an estimated distance to empty prediction (EDEP) algorithm is developed.

III. VEHICLE CHARACTERISTICS

A. General description

A range-extended solar electric vehicle consists of solar panels, batteries, electric motors, and suitable power electronic converters and controllers to propel the vehicle. The block diagram is as shown in Fig. 2. The battery used in this paper is the lithium-ion battery (Li-ion) as it is lightweight.

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* Correspondence Author

Yamini V., Department of Electrical and Electronics Engineering Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India. Email: yaminivasanth13@gmail.com

Ajayan S., Department of Electrical and Electronics Engineering Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu, India. Email: ajayan85@gmail.com

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The power demand of the vehicle is dependent on the vehicle dynamics and on the driving cycle. As an SEV is having solar power and battery power, a controller is used for regulating the power from the two sources to the wheels.

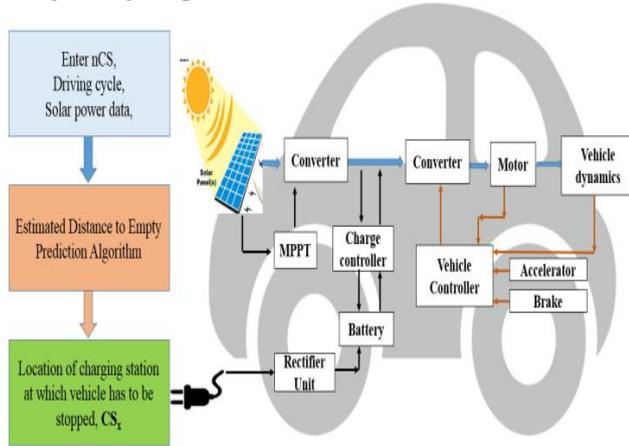


Fig. 2 Block diagram of SEV

This paper uses Maruti Alto K10's vehicle specification and features for vehicle modeling. The technical specifications of the vehicle are given in Table 1

Table 1 Specification of Maruti AltoK10

Description	Values
Width	1515mm
Height	1475mm
Length	3545mm
Ground clearance	160mm
wheelbase	2360mm
Tyres	155/65/R13
Kerb weight	769kg
Gross vehicle weight	1210kg

B. Mathematical Modeling

In this study, the proposed prediction algorithm is designed to drive the Maruti Alto K10 model vehicle. The vehicle model is expressed as a combination of various mechanical forces acting on the vehicle. They include drag force (F_{drag}), rolling force ($F_{rolling}$), acceleration force (F_{acc}) and climbing force (F_{climb}) which are calculated using the following equations.

$$F_{tot} = F_{drag} + F_{rolling} + F_{acc} + F_{climb} \quad (1)$$

$$F_{drag} = \frac{1}{2} c_d \rho A_f v^2 \quad (2)$$

$$F_{rolling} = \mu_R w \cos \theta \quad (3)$$

$$F_{acc} = ma \quad (4)$$

$$F_{climb} = mgsin\theta \quad (5)$$

Where c_d is the drag coefficient ($c_d = 0.32$), ρ is the air density ($\rho = 1.2kgm^{-3}$), A_f is the frontal area of the vehicle, v is vehicle speed in ms^{-1} , μ_R is the coefficient of rolling resistance ($\mu_R = 0.010$) and w is the weight of the car ($w = mg$) in kg and θ is the gradient of the road in degree.

For the vehicle under consideration which starts from rest ($u=0$) and reached a speed of 40 km/hr (11.1m/s) within 90sec, the values for various forces are calculated as follows.

$$\text{Frontal Area, } A_f = \text{height} \times \text{width} \times 0.85 = 1.899m^2$$

$$F_{drag} = \frac{1}{2} \times 0.32 \times 1.2 \times 1.899 \times 11.1^2 = 44.92N$$

For a horizontal road, gradient $\theta=0$.

$$F_{rolling} = 0.01 \times 1210 \times \cos 0 = 12.1N$$

$$F_{acc} = \frac{w(v-u)}{t} = \frac{1210}{9.8} \times 0.123 = 15.19N$$

$$F_{climb} = 1210 \times \sin 0 = 0$$

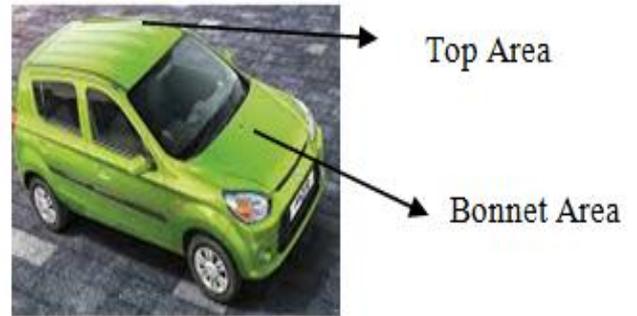
Therefore, the total tractive force is given by,

$$F_{tot} = 44.92 + 12.1 + 15.19 + 0 = 72.21N$$

C. Solar panel design calculations

The vehicle under study is mounted with a solar panel on the top and bonnet area. The total power output of the solar panel depends on the panel area, solar irradiance and efficiency of panel used.

$$\text{Total panel power} = (\text{Average solar power} \times \text{Panel area} \times \text{Panel efficiency}) \quad (6)$$



$$\text{Top Area} = 98 \times 153 \text{ cm}^2 = 1.4994 \text{ m}^2$$

$$\text{Bonnet Area} = 99 \times 123 \text{ cm}^2 = 1.2177 \text{ m}^2$$

Therefore, the total panel area calculated is given by, $A=2.7171m^2$.

Solar radiation varies over a day and also is seasonal. Hence for this study, annual average solar irradiance is taken from [8]. Annual average solar irradiance for some places under study is as given in Table 2

Table 2 Annual solar irradiance of various places

Places	Annual average solar irradiance (kWh/m ² /day)
Chennai	5.08
Coimbatore	5.35
Mumbai	5.35
Kerala	5.68
Kolkata	4.12

The place considered for this study is Coimbatore which has got an annual average solar irradiance of 5.35kWh/m²/day. Various solar panels have got different power conversion capabilities, thin-film panels having the highest. Since it is flexible, it could be easily mounted on the surface of the car. The conversion efficiency of the thin-film solar panel is 28.8% [9].

Considering the average annual solar irradiance, the average solar radiation falling on the panel can be calculated as

$$\frac{5.35 \text{ kWh/m}^2}{24h} = 222.91 \text{ W/m}^2$$

Hence, the total power generated by the panel mounted on the car is calculated as:

Total panel power
= (Average solar power × Panel area
× Panel efficiency)
= 222.92 × 2.7171 × 0.288 = 174.44 W.

D. Power demand equation

The instantaneous power demand ($P_{demand}(t)$) can be estimated by knowing the total tractive force and velocity (obtained from the driving cycle)

$$P_{demand}(t) = \frac{F_{tot}(t) \times v(t)}{\eta_{trans}} \tag{7}$$

All vehicles require some amount of power for auxiliary supporting systems. Hence, the total power demand ($P_{total\ demand}$) is given by

$$P_{total\ demand} = P_{demand}(t) + P_{aux} \tag{8}$$

where, η_{trans} is the transmission efficiency (80%), P_{aux} is the auxiliary power (1000W) used for vehicle support systems, lights, air conditioning etc.

The total power demand of the vehicle is met by the battery and solar panels. It is evident from section C that the battery supplies most of the traction power required by the vehicle.

Therefore battery power is given by,

$$P_{batt}(t) = P_{total\ demand}(t) - P_{solar}(t) \tag{9}$$

E. SOC Equation

The battery life is affected if it is allowed to discharge below 30% of the state of charge (SOC). Hence, SOC plays an important role in the range as well as the life of the battery. It is found using the equation:

$$SoC(t) = SoC(t-\Delta t) - \eta_{batt} \frac{P_{batt}}{Q_{batt}} \Delta t \tag{10}$$

where, η_{batt} is the efficiency of the battery. If P_{batt} is positive, the battery is discharging and if negative, it is charging. The charging and discharging efficiency of the Li-ion battery is 98% and 90% respectively [10]

Existing Electric vehicles, Nissan leaf Electric vehicle uses the li-ion battery of 24kWh, and electric vehicle of li-polymer battery uses 30kWh. A battery rating of 180Ah, 12V is taken into consideration for study in this paper. Therefore, the battery rating is 2.160kWh, which is comparatively less than other available electric vehicles. Solar panels act as an on-board charger and range extender, supplementing the power demand.

IV. DRIVING CYCLE

In this paper, the driving cycle is designed for two cases for the study of the prediction algorithm.

Driving cycle-1 - In this driving cycle, the vehicle will stop at each charging location and calculate how much amount of SOC has been left to cover the remaining distance. The remaining range is based on the distance from the vehicle's current location and estimated charging location.

Driving cycle-2 - In this driving cycle, the vehicle will directly calculate the estimated location where the vehicle needs to stop for charging and does not stop at each location for charging. The vehicle will stop at a particular location whenever the SOC goes down and the battery needs to be charged.

The driving cycle for the above two cases is as shown in Fig. 3

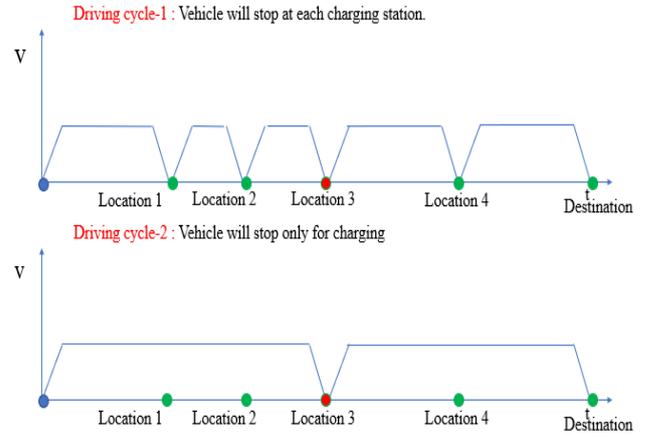


Fig. 3 Driving cycle 1 and 2

V. PREDICTED LOCATION FINDING FOR SOLAR EV CHARGING

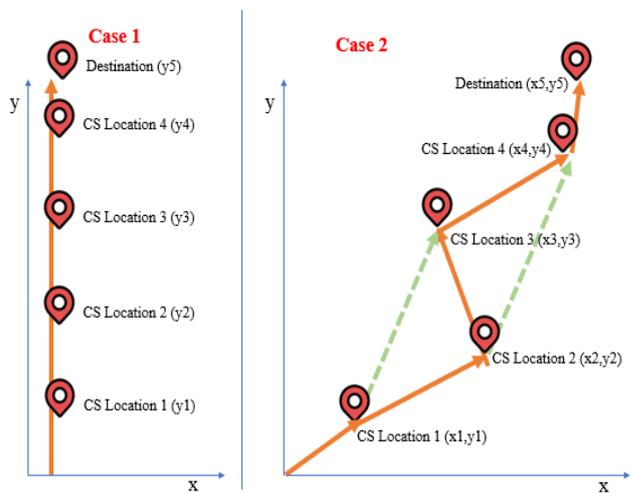


Fig. 4 Two kinds of pathways (a) Linear pathway (LP) and 2D pathway (2DP)

As shown in Fig. (4a), (4b) location for charging has opted for two kinds of pathways (a) Linear pathway (LP) and 2D pathway (2DP).

In the first case, the charging stations are assumed to be located along a straight road and distance between the adjacent stations is known. Hence, for a vehicle starting from the origin, the proposed algorithm has to find out the distance the vehicle can travel and determine the charging station at which the vehicle has to stop for charging.

In the second case, charging station locations are scattered over a 2-D area whose coordinates are known and the vehicle can move to any of the charging stations from the origin based on the available charge that is left for the vehicle to travel [11]. When the exact coordinates are given, the distance between two charging stations is given by the formula,

$$S(t) = \sqrt{(CS_{x2} - CS_{x1})^2 + (CS_{y2} - CS_{y1})^2}$$

Where $(CS_{x2} - CS_{x1})$ and $(CS_{y2} - CS_{y1})$ are the location co-ordinates of stations 1 and 2 respectively.

VI. ALGORITHM

Estimated Distance to Empty Prediction (EDEP) Algorithm

In this project, the proposed Estimated Distance to Empty Prediction Algorithm gives an appropriate charging station at which the vehicle can stop to charge its batteries. Once the driving cycle, the number of charging stations, solar irradiance and locations of charging stations are known, the EDEP algorithm first calculates the instantaneous power demand and hence the total power requirement for the vehicle to finish the journey. Secondly, based on the instantaneous solar irradiance and state of charge of the battery, the algorithm predicts the estimated distance the vehicle can travel (SOC_{travel}) with the energy stored in battery and energy obtained from solar panels. Thirdly, the EDEP algorithm checks whether the vehicle can travel up to the next charging station, one by one. If the vehicle cannot reach the next charging station, then the algorithm gives an output command to stop the vehicle for charging at the current station itself.

The flowchart representation for the EDEP algorithm is given in Fig. 5 to measure the distance between charging stations and to predict the distance that can be traveled by the vehicle. The EDEP algorithm is simulated and the results are discussed in section VI.

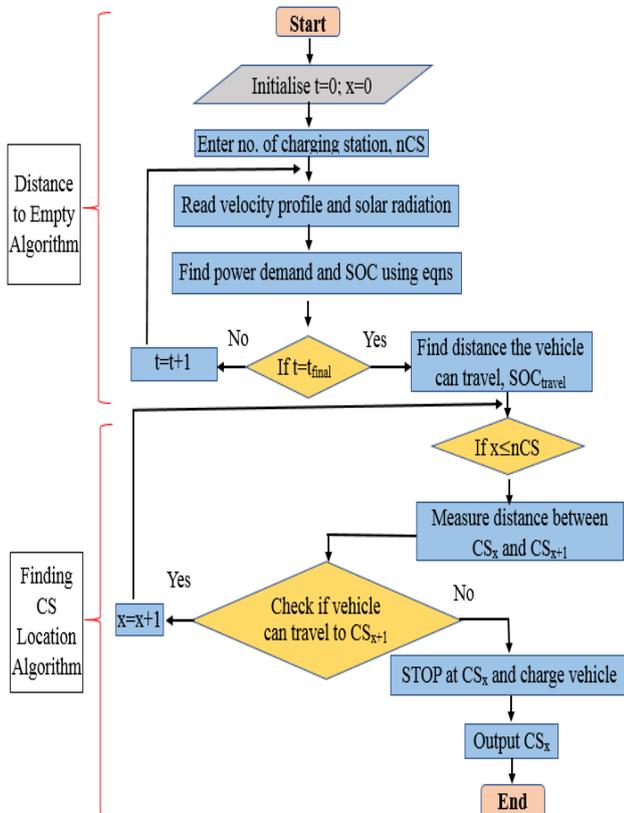


Fig. 5 Flowchart of EDEP Algorithm.

VII. RESULTS AND DISCUSSION

For the simulation of the EDEP algorithm, six number of charging stations are considered and various cases are analyzed. The driving cycle considered is as shown in Fig. 6 and Fig. 7

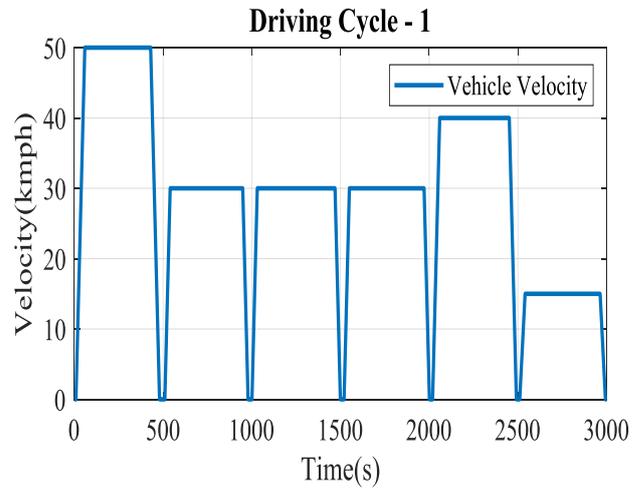


Fig. 6 Driving cycle-1

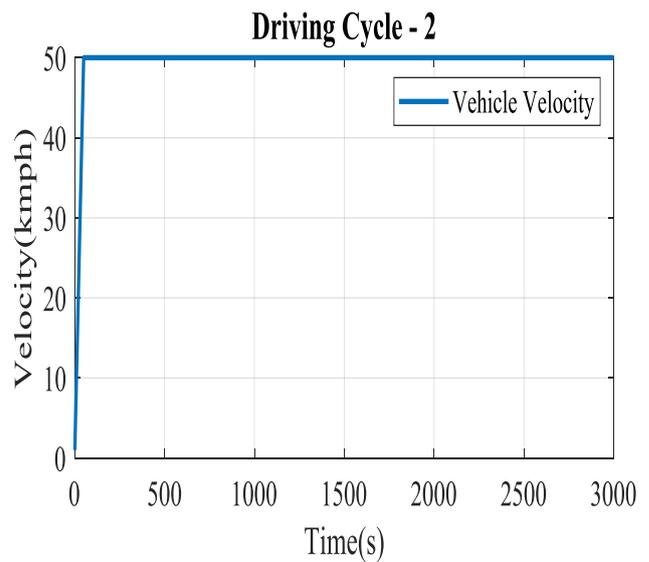


Fig. 7 Driving cycle-2

With driving cycle 1, the vehicle moves at a maximum velocity of 50km/hr and stops at each six charging stations. It spans for a duration of 3000 seconds. When the vehicle is at the origin, the EDEP algorithm predicts the distance the vehicle can travel and intimates the driver at which charging station he should stop for charging. The simulations are carried out with an assumption that the battery is having an initial charge of 80% and that the car travels on a sunny day.

- Case (i)- LP-Driving cycle-1 and SOC lower limit set to 20%

In this case, the SOC lower limit set is 20%. Hence, the algorithm will allow discharge of up to 20% and predicts how far the vehicle will travel (SOC_{travel}). The algorithm then compares SOC_{travel} with the charging station locations and gives the charging station number as output. In Fig. 6, Fig. 7, the green dots indicate the charging station locations and red color dot denotes the output of the EDEP algorithm.

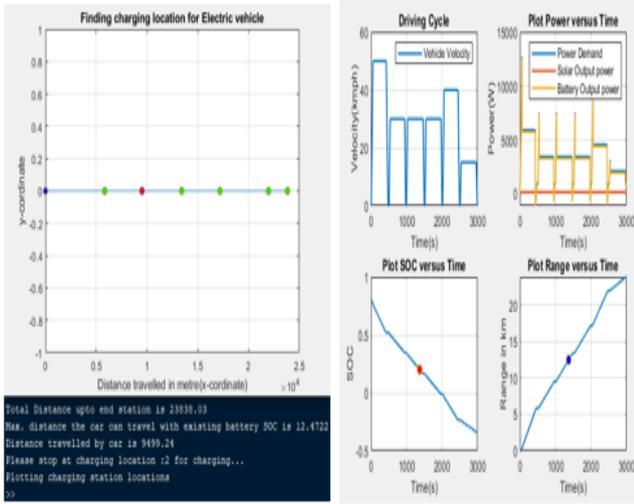


Fig. 6 Case (i): Driving cycle-1 and SoC limit 20%

Here in Fig. 6, the output states that the total distance that can be traveled to the end station is 23,838m. The EDEP algorithm calculates the maximum distance that the vehicle can travel with the existing SOC is 12,472m. The algorithm then searches for a charging station which is within 12,472m. At 9000m there is a charging station and the next charging location is beyond 12,472m. Hence, the EDEP algorithm gives out an output “stop at charging location-2 for charging”.

➤ Case (ii): LP-Driving cycle-1 and SOC lower limit set to 50%

In this case, the vehicle moves with driving cycle-1 velocity profile, but with a SOC limit of 50%. It means that the vehicle can discharge its battery up to a 50% level.

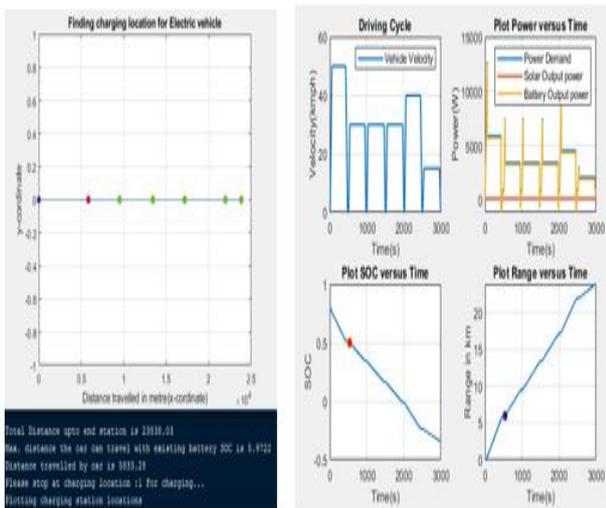


Fig. 7 Case (ii): Driving cycle-1 and SoC limit 50%

As shown in Fig. 7, the EDEP algorithm predicts the SOC_{travel} as 5,972m, beyond which the vehicle will drain out of charge before reaching the next charging station. Hence, the EDEP algorithm gives an output “charging location-1”.

➤ Case (iii): LP-Driving cycle-2 and SOC lower limit set to 20%

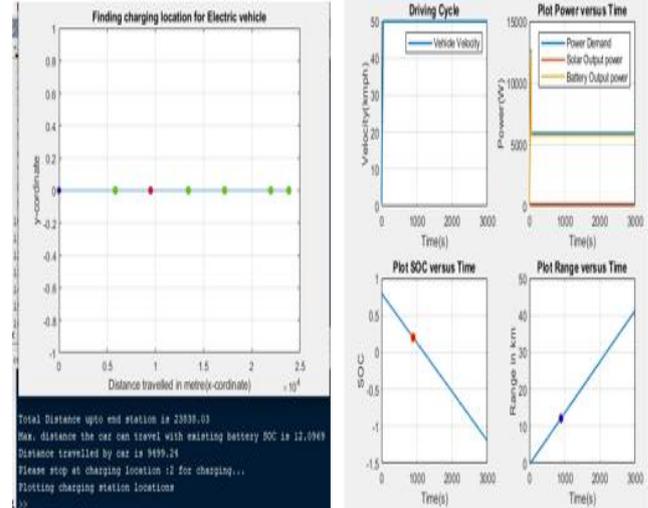


Fig. 8 Case (iii): Driving cycle-2 and SoC limit 20%

In case (iii), the vehicle moves with driving cycle-2 velocity profile and is a kind of dynamic distance to travel prediction. As per the EDEP algorithm, the SOC_{travel} is 12.0963m. Hence, the vehicle has to stop at charging location-2 for charging.

➤ Case (iv):LP- Driving cycle-2 and SOC lower limit set to 50%

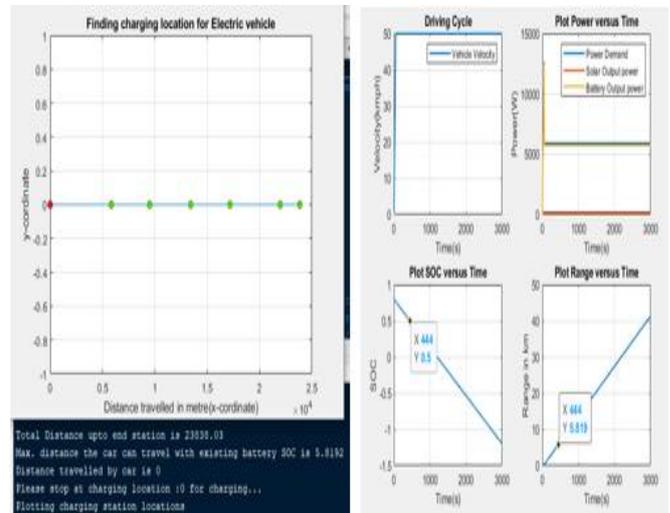


Fig. 9 Case (iv): Driving cycle-2 and SoC limit 50%

The case (iv) is similar to case (iii), except that the SOC limit is 50%. As per EDEP algorithm, the SOC_{travel} is 5,019m. Hence, if the vehicle starts journey, it cannot even reach the first charging location. So the vehicle battery has to be charged or else the vehicle has to be parked at the origin for some more time so that battery can be charged from solar panels.

➤ Case (v):2DP- Driving cycle-2 and SOC lower limit set to 20%

In case (v), the data input to the EDEP algorithm are the x-y coordinates of the charging locations. This is similar to the GPS coordinates of the charging station with latitude and longitude data.

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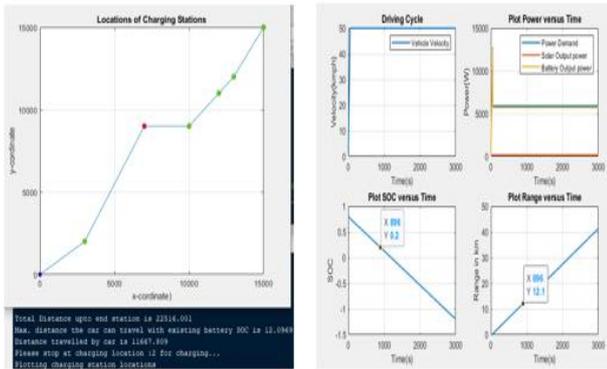


Fig. 10 Case (v): 2DP-Driving cycle-2 and SoC limit 20%

The EDEP algorithm finds out the distance between the charging station locations. Here for the simulation, random location coordinates are given as shown in **Fig. 10**. The vehicle follows a driving cycle-2 velocity profile with a SOC limit of 20%. EDEP algorithm finds out the SOC travel as 12,096.9m and hence gives an output “stop at charging location-2 for charging”.

➤ *Case (vi): 2DP- Driving cycle-2 and SOC lower limit set to 50%*

This is similar to case (v), but with a SOC limit of 50%. The EDEP algorithm predicts that the vehicle can travel up to 7,916.4m with the existing SOC. Hence, the vehicle has to be stopped at charging station-1 for charging the battery as shown in **Fig. 11**.

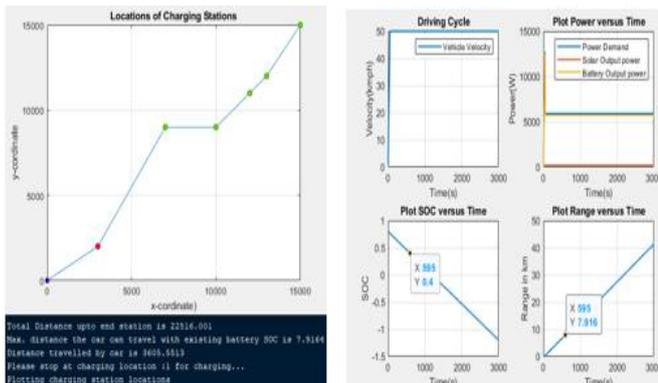


Fig. 11 Case (vi): 2DP-Driving cycle-2 and SoC limit 50%

A. Summarized outputs for driving cycles with different limits

Table 3 Driving cycle-1 EDEPA outputs

SOC lower limit	Max distance that can be traveled SOC (km)	Actual distance traveled to the nearest charging station (km)	Predicted charging station
0.1	14.5722	13.4159	CS-3
0.2	12.4722	9.49924	CS-2
0.3	10.2722	9.49924	CS-2
0.4	8.1722	5.83328	CS-1
0.5	5.9722	5.83328	CS-1

Table 4 Driving cycle-2 EDEPA outputs

SOC lower limit	Max distance that can be traveled SOC	Actual distance traveled to the nearest charging station	Predicted charging station
0.1	14.1803	13.4159	CS-3
0.2	12.0969	9.49924	CS-2
0.3	9.9997	9.49924	CS-2
0.4	7.9167	5.83328	CS-1
0.5	5.8192	0	CS-0

	(km)	station (km)	
0.1	14.1803	13.4159	CS-3
0.2	12.0969	9.49924	CS-2
0.3	9.9997	9.49924	CS-2
0.4	7.9167	5.83328	CS-1
0.5	5.8192	0	CS-0

Table 3 and Table 4 shows the summary of EDEP algorithm outputs for different limits of SOC given. The table shows the maximum distance that can be travelled on the second column and the actual distance travelled by the vehicle on reaching the predicted charging station. It can be seen that the vehicle is able to travel more distance if the battery is allowed to discharge more. That is, the distance that can be travelled with a 10% SOC limit is more than with a 50% SOC limit. The output of 20% and 50% SOC limits for driving cycle-1 are as shown in Fig. 6 and Fig. 7 respectively. Similarly, the output of 20% and 50% SOC limits for driving cycle-2 are as shown in Fig. 8 and Fig. 9 respectively.

VIII. CONCLUSION

The solar electric vehicle is an amazing advancement in future car technology as it offers a cheap and eco-friendly way to solve the current energy crisis and greenhouse gas problems. In this paper, a solar electric vehicle modeling is done which can calculate the instantaneous power demand of a vehicle for a given driving cycle. An estimated distance to empty prediction algorithm is proposed to predict the distance the vehicle can travel with the current battery SOC and solar power available. The proposed algorithm is verified with the help of an Indian car Maruti Alto K10. The EDEP algorithm can help the vehicle drivers to appropriately charge their SEVs and would never drain out of battery in the middle. It is hoped that solar electric vehicle manufacturers can implement this algorithm in cars. As future work, this algorithm could be modified with actual GPS locations of charging stations and a driver alerting system by using a cloud model and Web app can be developed.

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AUTHORS PROFILE



Yamini V., is currently doing her final year M.tech in Renewable Energy Technology at Karunya Institute of Technology and Sciences, Tamil Nadu India. Her project areas include Electric Vehicle and IoT. She is currently working on her project in Solar Electric Vehicle.



Ajayan S is currently working as Assistant professor in Department of Electrical and Electronics Engineering, Karunya Institute of Technology and Sciences, Tamilnadu, India. He is pursuing his Ph.D at Karunya Institute of Technology and Sciences. His area of research includes fuel cell, electric vehicles, power electronics and drives. He is a member of AMIE, IETE, ISTE, IAENG and SAEINDIA.