A Hybrid Intelligent Controller for Extended-Range Electric Vehicles

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ABSTRACT

A smart battery electric vehicle control framework is proposed in this paper. The specific controller empowers ceaseless observation and management of the battery's state with the scope of extending the vehicle's driving range under varying temperature and driving pattern conditions. The proposed method utilizes an incorporated scheme for dealing with a crossover energy stockpiling framework to expand a battery's lifespan while further ensuring its smooth activity.

Keywords-electric vehicle; battery; energy storage system; hybrid electric vehicle controller; automation

I. INTRODUCTION

The exhaust emissions of gasoline-powered automobiles are primary contributors to air pollution. It is vital to convert cars that run on fossil fuels into vehicles that run on green energy to accomplish the low-carbon objectives of green cities. Electric Vehicles (EVs) do not produce emissions or pollutants, so they play a significant part in this transition [1]. On the other hand, the marketing of electric cars is greatly hindered by technological restrictions, such as low battery power and limited driving range. Not only do Extended-Range Electric Vehicles (EREVs) possess the qualities of low emissions, but they also can expand the mileage that cars can tolerate for an extended period. In traditional Hybrid Electric Vehicles (HEVs), the battery functions as an energy buffer [2]. Over the course of the journey, there is a little fluctuation in the State Of Charge (SOC) of the battery. EREVs, on the other hand, are plug-in HEVs equipped with a large battery that can store electric power provided by a charging station. During its charging cycle, the EREV leaves a charging station with its battery energy at its maximum capacity until it arrives at another charging station [3]. If the EREV completes its journey and reaches the next charging station with a low amount of battery charge, it will be able to store more clean energy from the grid, thus decreasing the quantity of gasoline used. In the past, two different control procedures have been used to accomplish the control objectives indicated above [4]: The Charging Deplete/Charging Sustain (CD/CS) approach and the mixed control technique. The first part of the former approach is referred to as the CD stage, and it is achieved by cars operating in a mode that is inside the All-Electric Range (AER). In addition to the AER, the extender is activated as the primary energy source in order to meet the typical power requirements of the Traction Motor (TM) [5]. When there is a higher demand for power, such as when there is a rapid acceleration or when there is an upslope, the battery works in conjunction with the extender to ensure that the SOC of the battery is maintained in a narrow range over the lower bound. This stage is referred to as the CS stage [6]. An EV's only energy source is a battery. This can cause issues in case the latter is not joined with a regulator. During the EV design phase, the primary obstructions are: Inadequate charging framework, reliance on imported batteries, reliance on imported segments and parts, range anxiety, high EV cost, limited choices of superior EVs, inadequate power supply in some parts of India, lack of value support, and possible car industry slump.

II. ENERGY STORAGE REQUIREMENTS

The energy stockpiling mechanism of an EV should be lightweight, with high energy density, easy to control, must convey the initial current, and must have a long life cycle, transient security, and low activity cost. The distance an EV can travel is restricted by numerous elements. Authors in [3] deem SOC and the wellbeing of a lithium-ion battery cell significant quality measures for EVs. With regard to driving patterns, one of the factors negatively influencing a battery's operation is the frequent beginning and halting due to traffic and street conditions. Therefore, a battery encounters pressure, bringing down its charging time and its lifespan. Outside temperature variances also affect the battery's performance [4]. To guarantee a legitimate energy stockpiling framework plan, misfortunes and working conditions should be considered. Additionally, an auxiliary fuel source should be utilized [5].

III. DRIVING PATTERNS

Lithium-ion battery efficiency is affected by driving patterns, which may alter the battery usage. Battery current fluctuates with driving standards. The main driving patterns are: city traffic (light and heavy), suburban, state highway, national highway, express highway, local/country loads, small towns, hilly/high range areas (Figure 1). The actual habits of a driver may diminish the battery's performance or life expectancy [6, 7].

Energy stockpiling is fundamental for EVs on the grounds of energy density and weight. Energy density is mostly subject to the vehicle's design, construction, and mileage. Authors in [8] offer an energy stockpiling methodology for EVs that is subject to driving examples. Authors in [9] investigated load difference and its importance for EVs.

IV. RANGE ANXIETY

Regarding the increment of the vehicle range, vehicle charging and an EV energy stockpiling framework are both required. To meet the vehicle's energy needs, an energy stockpiling framework that is fit to provide the required energy should be utilized. Diminishing release time is caused by expansions in battery strain. This suggests that in order to guarantee that optimum current is drawn from the battery, the current scheme should contain an approach to augment the current [10].

Reach anxiety is the concern drivers get when they are worried about the quantity of kilometers that their EV can cover before it is re-energized. The target of this paper is to reduce range anxiety utilizing improved battery controls. Authors in [12] examined the compromises of proficiency, energy utilization, and engine heat dispersal while creating and surveying a battery-EV power train. Controlling battery frameworks is essential. The effects of battery release control on vehicle range were researched in [13], with the aim of ensuring longer battery use times to upgrade the mileage per charge.

(a)

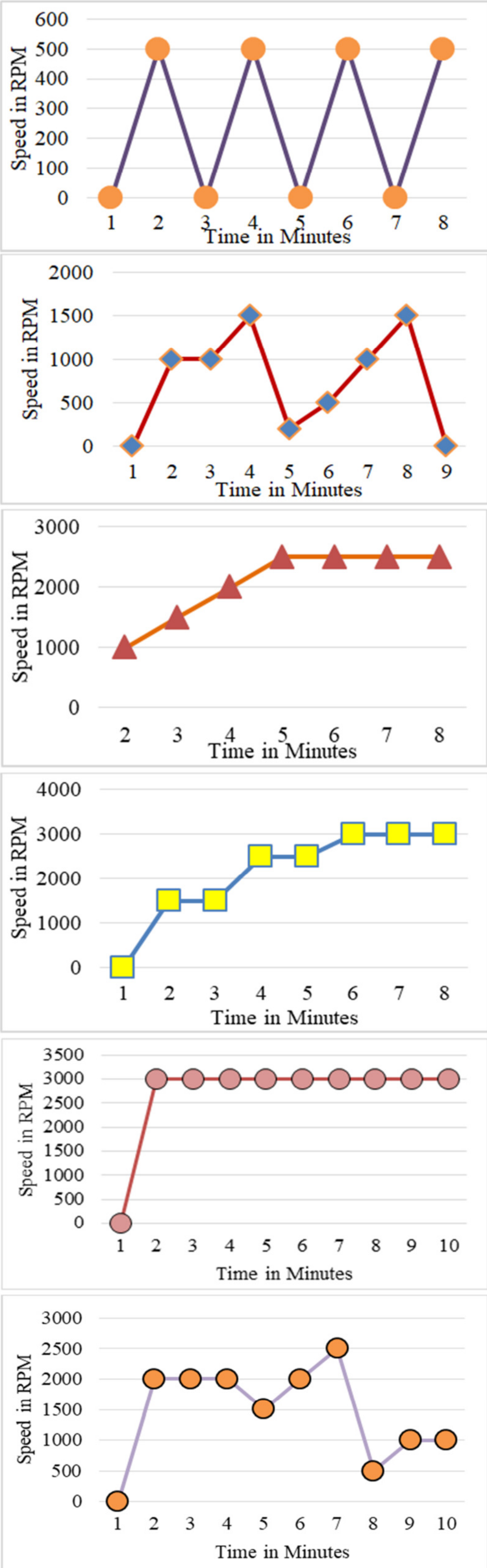
(b)

(c)

(d)

(e)

(f)



(g)

(h)

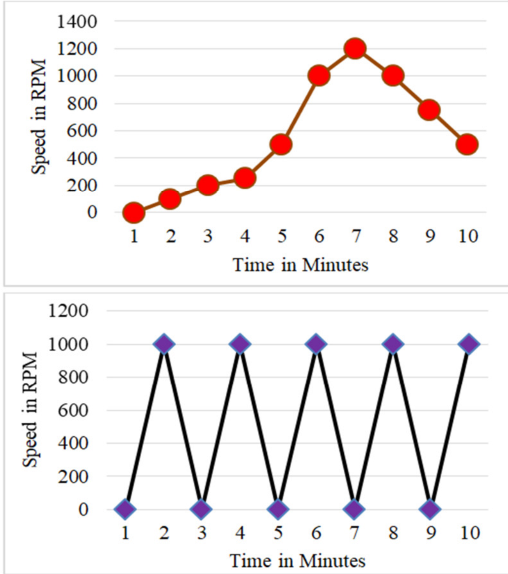


Fig. 1. Driving patterns: (a) city, (b) suburban, (c) state highway, (d) national highway, (e) express highway, (f) local/country roads, (g) small town, (h) hilly areas.

V. ELECTRIC VEHICLE RANGE EXTENSION

A complex energy regulator may assist with range anxiety in EVs. A range expansion procedure for EVs is proposed in [14]. To keep the cycle working, a shrewd regulator should screen information and input boundaries. Authors in [15] fostered a mixture energy stockpiling framework that utilizes fuel to extend the range of EVs. With this technique, the capacity devices are: (a) a super capacitor, (b) a main battery, (c) a backup battery, and (d) a charging source (photovoltaic cell). In the design, modeling, and hardware implementation of a next generation EREV, street conditions and vehicle load are considered [16], while a smart regulator uses boundaries for the battery and directs energy flow. The settings of the regulator administer the activity of the energy stockpiling mechanisms. The vehicle is halted when the speed is zero or when the supercapacitor is activated to move it. When the vehicle gets going, the capacitor that backs it off is deactivated and the main battery pack is turned on, whereas the secondary battery pack is charged through a sun-powered cell. If the main battery pack is depleted, the secondary battery will be turned on. By putting the battery on a sturdier establishment, the tension on the battery is limited. This has the effect of broadening the lifespan of the battery and improving its effectiveness. Authors in [17] examined the execution of a low-voltage-to-cell battery adjusting circuit. A productivity strategy for a DC-DC converter in a half breed energy stockpiling framework for EVs is presented in [18]. EV designers should be informed about a few issues, including the heaviness of the framework, the type of the EV, the need for energy stockpiling, driving patterns, and the scope of the vehicle. Each framework should uphold and be viable when combined with every other framework. The EV's amassing capacity, energy, framework plan, and boundary configuration should all be viable to assemble the vehicle.

VI. DESIGN OF THE RANGE EXTENDED ELECTRIC ENERGY STORAGE SYSTEM CONTROL ALGORITHM

Since it includes several different energy sources, this hybrid energy storage system has less dependency on a single energy source, offering the former better overall performance [19]. An unscented Kalman filter-based battery SOC estimation and the peak power prediction approach for the power distribution of hybrid electric automobiles for on-road applications is proposed. Changes in needs, switching, and charging will be handled by the controller, as shown in Figure 2.

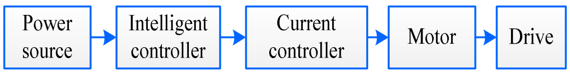


Fig. 2. Connections of the functional parts.

A. *Functions of Each Part*

- Power sources (lithium-ion batteries and super capacitor). They form the energy storage system which powers the micro controller and the EV.
- Intelligent controller: It controls and monitors all the parameters of the energy storage system and the EV in order to optimize the current from the battery/power source.
- Power electronic current controller/converter: It limits the maximum current given to the motor.
- The motor: It drives the vehicle.
- Battery management system: It records the parameters of the battery and the super capacitor.
- Speed sensor/driving pattern recognizer: It gives feedback parameters to the controller.

B. *Block Diagram of the Proposed Controller*

Figure 3 displays the block diagram of the novel intelligent integrated hybrid energy storage system controller that includes a primary battery, an auxiliary battery, a super capacitor, solar charging, driving patterns, traffic circumstances, and vehicle load. The use of current, input, and feedback parameters to optimize current are the primary roles of the intelligent controller. Data derived from the evaluation process (speed, driving patterns, gradient angle, load current) are considered when controlling the main battery bank, the auxiliary battery, the super capacitor, and the solar panel. The controller regulates the current drawn by the electronic converter and sent to the motor. Lithium-ion batteries and super capacitor power the EV. Display operations, including the controller, are powered by an extra battery. A solar panel is utilized to charge the auxiliary battery and the super capacitor. Even if the primary battery is completely depleted, it will be possible to utilize control and display features. The super capacitor will provide power when movement is initiated or ascending or at surges, whilst the main battery would power the vehicle at constant speeds. An optimum driving pattern is exhibited on the HMI when the power/torque need is recognized from the driving pattern, extracted from the user control block established by the user. This research suggests a controller that will allow EVs to cover greater ranges. Authors in [20-23] describe how the acceleration and deceleration patterns of drivers affect the velocity control of EVs. Traffic and road conditions are given to the driver in order to be able to regulate the use of the accelerator and brake pedal [24-30].

C. *Intelligent Algorithm based on the Fuzzy Logic Controller*

The algorithm controls the priority sets (super capacitor, main battery) and acts according to a priority hierarchy based on the availability of sources for charging the battery and powering the motor. The constraints are: driving patterns, driver behavior, road conditions, and traffic conditions. The control system functions are depicted in Tables I and II. Equation (1) is used to represent the amount of power used and (2) demonstrates the distance covered based on the driving pattern.

If $f(x)$ is the power requirement, then:

$$f(x) = ax + b \tag{1}$$

where x is the power requirement from the super capacitor, a is the driving pattern factor, and b is the positive power.

The distance covered by the driving pattern is expressed by:

$$dj = \sqrt{x1 - cj1} \dots \tag{2}$$

where d is the distance, x is the sampling point, c represents the cluster, and j = 1,2,3.

An integrated control algorithm for hybrid and electric cars called the Novel Hybrid Integrated Intelligent Control (HHIIC) was utilized to lower the strain on the battery and to optimize the current flow to prolong range. The Energy Storage System (ESS) showcases better performance due to the battery discharge time extension regulated by the intelligent controller.

TABLE I. RULE-BASED FUZZY LOGIC MEMBERSHIP FUNCTIONS

Operating condition	**Switch condition**	**Power allocation**
Driving: Battery and super capacitor	$P_{min} < P_{demand}$ *and* $SOC_{UCmin} < SOC_{UC}$	$P_{uc} = aP_{demand} + bP_{bat}$ $t = -u$
Driving: Battery	$P_{min} < P_{demand}$ *and* $SOC_{UCmin} < SOC_{UC}$	$p_{bat} = p_{demand}$ $P_{uc} = 0$
Driving: Battery	$0 \leq Pdem \leq Pmin$ $0 < P_{demand} < P_{min}$	$p_{bat} = p_{demand}$ $P_{uc} = 0$
Solar: Super capacitor	$P_{demand} < 0$ $SOC_{UCmax} < SOC_{UC}$	$p_{bat} = p_{demand}$ $P_{uc} = 0$
Braking: Neither	$P_{dem} < 0\&$ $SOC_{UCmax} < SOC_{UC}$	$P_{bat} = 0$ $P_{uc} = 0$

TABLE II. RULE-BASED FUZZY LOGIC MEMBERSHIP FUNCTION

Input and output	**Actual domain**	**Fuzzy domain**	**Membership function**	**Fuzzy subset levels**
P_{demand}	0-90	[0 to 1]	Gauss type/Bilateral Gauss	3
V_{trend}	[-3 to 3]	[-3 to 3]	Rectangle	7
G_{road}	[-10 to 10]	[-1 to 1]	Rectangle	7
a_{uc_corr}	[-0.2 to 0.2]	[-0.2 to 0.2]	Gauss type/Bilateral Gauss	7

D. Performance Analysis of the Proposed Controller

To consider the impact of varying conditions on EVs, tests were conducted with a novel hybrid crossover energy stockpiling control framework. Energy utilization allows EVs to cover longer distances [24-27]. The tests involved driving on various courses at different rates, with changing climate conditions, and speed patterns. The EV was running on super capacitor for movement initiation, and on the principle battery when moving with constant speed.

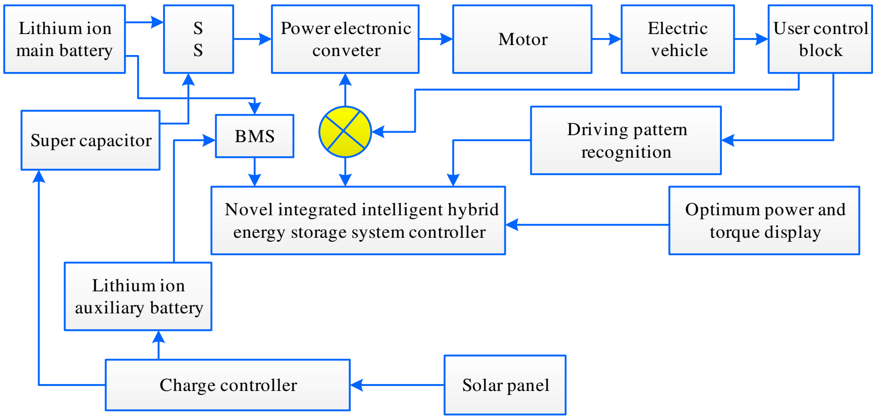


Fig. 3. Connections of the functional parts.

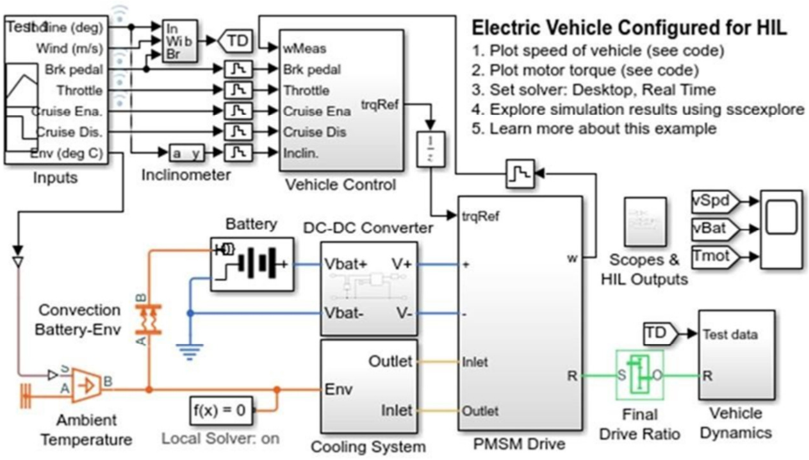


Fig. 4. Simulation hardware model of a generic EV.

VII. RESULTS AND DISCUSSION

The Matlab/Simulink tests on how progressing conditions change the mathematical limits and how those segments convert into setup features of the vehicle where conducted with the aid of an expanded vehicle model. The EV model's schematic outline is displayed in Figure 4. The vehicle's speed is constrained by the reenactment model that is related with the PC through an interface. Li-ion batteries and a super capacitor power the electric vehicle. Other devices, including the controller, are powered by a secondary battery. The points of interest of the EV model are indicated in Table III. When solar power is available, the secondary battery and the super capacitor are charged. Whether or not the main battery is completely depleted, utilizing control and showing features will be possible. Current spike occurrences are the occasions when the super capacitor controls the vehicle. The main battery controls the vehicle at constant speeds, while the solar charging device powers the super capacitor and the secondary battery. The optimal driving model is shown on the HMI and the driving model is setup by the customer. Cloud data or the customer control block choose the traffic and road conditions. Using a super capacitor makes it easier to use a lithium battery, making it possible to initiate and accelerate simultaneously. Tables IV-VII portray the range extension at various conditions and Figures 5-7 visualize the results. The Matlab code copies the distinctive driving conditions that occur during the driving example of an EV, helping to select how the energy utilization changes under various conditions [22].

Regulator calculations that can upgrade and control the energy flow will permit EVs to cover longer distances. It was observed that the proposed control approach may accomplish greater vehicle range expansion than the elective control techniques. Figure 5 delineates the rate extension of the release time for various driving patterns. Table V shows the release time expansion under various temperature conditions, as depicted in Figure 6. When the SOC drops, the temperature of the lithium-ion battery also drops.

TABLE III. SPECIFICATIONS OF THE EV MODEL

Quantity / Capacity	**Unit / Type**
Weight (vehicle)	830 kg
Dimensions	3280×1514×1560 (Turning Radius=3.90)
Tyre Size	Front: R16
	Rear: R16
Speed (max)	81 km/h
Voltage	48 V
Main battery capacity (Lithium – ion)	210 Ah
Running time in km (battery)	120 (full charge)
Super capacitor capacity	500 F / 1000 A / 5.55 Ah
Auxiliary battery capacity	21 Ah
Solar panel capacity	480 W / 48 V / 10 A
Current controller	600 A (peak)
Communication module	Bluetooth

TABLE IV. DISCHARGE TIME EXTENSION IN PERCENTAGE FOR DIFFERENT DRIVING PATTERNS

SOC	**Driving Patterns Constant (dv/dt)**								
	T(°C)	**City**	**Suburban**	**State highway**	**National highway**	**Express highway**	**High range/ hilly area**	**Small town**	**Average discharge time increase (%)**
	28	0.05	0.05	0.05	0.05	0.05	0.05	0.05	4.13
5	28	0.1	0.1	0.1	0.1	0.1	0.1	0.1	4.13
10	27.5	0.15	0.15	0.15	0.15	0.15	0.15	0.15	4.13
15	27	0.2	0.2	0.2	0.2	0.2	0.2	0.2	4.13
20	26.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	4.13
25	26	0.3	0.3	0.3	0.3	0.3	0.3	0.3	4.13
35	25.425	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.13
40	25.4	0.45	0.45	0.45	0.45	0.45	0.45	0.45	4.13
45	25.325	0.5	0.5	0.5	0.5	0.5	0.5	0.5	4.13
50	25.3	0.55	0.55	0.55	0.55	0.55	0.55	0.55	4.13
55	25.225	0.6	0.6	0.6	0.6	0.6	0.6	0.6	4.13
60	25.2	0.65	0.65	0.65	0.65	0.65	0.65	0.65	4.13
65	25.175	0.7	0.7	0.7	0.7	0.7	0.7	0.7	4.13
70	25.15	0.75	0.75	0.75	0.75	0.75	0.75	0.75	4.13
80	25.1	0.85	0.85	0.85	0.85	0.85	0.85	0.85	4.13
75	25.075	0.9	0.9	0.9	0.9	0.9	0.9	0.9	4.13
90	25.05	0.95	0.95	0.95	0.95	0.95	0.95	0.95	4.13
95	25.025	1	1	1	1	1	1	1	4.13
100	25	1.5	1.5	1.5	1.5	1	1.5	1.5	4.13

TABLE V. DISCHARGE TIME EXTENSION (%) FOR DIFFERENT BATTERY SOC VALUES

Rules	**Main battery SOC (%)**	**Super capacitor SOC (%)**	**Temperature (°C)**	**Battery discharge time with/without controller (hr)**	**Range extension (%)**
VERY LOW	0	0	28		
VERY LOW	5	5	28		
VERY LOW	10	10	27.5		
VERY LOW	15	15	27		
VERY LOW	20	20	26.5		
LOW	25	25	26		
LOW	30	30	25.5		
LOW	35	35	25.425		
LOW	40	40	25.4		
LOW	45	45	25.325		
MEDIUM	50	50	25.3	1.48/1.54	4.13
MEDIUM	55	55	25.225		
MEDIUM	60	60	25.2		
MEDIUM	65	65	25.175		
MEDIUM	70	70	25.15		
HIGH	75	75	25.125		
HIGH	80	80	25.1		
HIGH	75	85	25.075		
HIGH	90	90	25.05		
HIGH	95	95	25.025		
HIGH	100	100	25		

Figure 7 illustrates the acquired range extension for different driving patterns. The release period of the battery is affected by the measure of tension on the battery, which expands the measure of the smart regulator's impact on the battery and also expands the EV range.

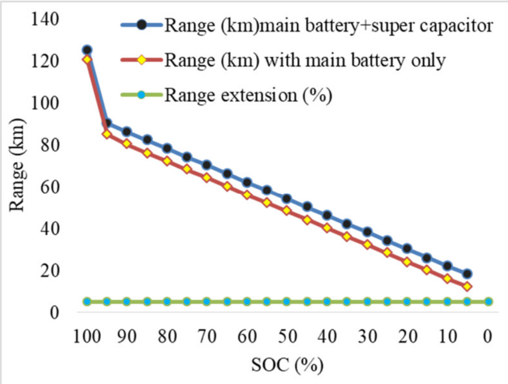


Fig. 5. SOC vs range and range extension.

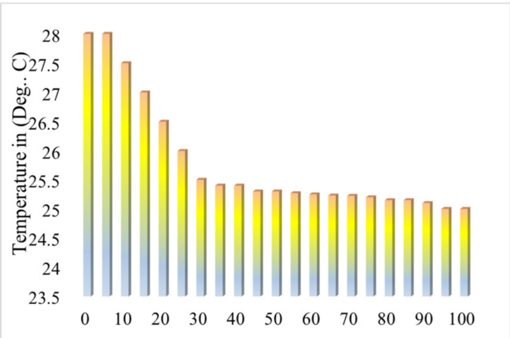


Fig. 6. Temperature variation graph.

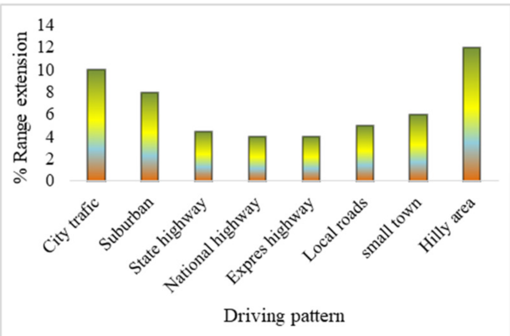


Fig. 7. Range Extension vs driving pattern.

TABLE VI. MODEL RANGE EXTENSION

Running time without controller (hr)	Running time with controller (hr)	Extension (%)
1	1.03	3

TABLE VII. RANGE EXTENSION COMPARISON

% Range extension in hardware model	% Range extension in simulation model	% Extension variation
3	4.13	1.13

VIII. CONCLUSIONS

The proposed methodology generated satisfactory results when compared to the ones acquired by an electric vehicle without following it. Tables VI and VII illustrate the simulation and hardware model comparison of range expansions in the proposed controller for electric vehicles. In the simulation model, when the discharge duration was prolonged by 4.13%, the range extension was raised by 4.13%. However, in the hardware model, the range extension was increased by 3%. Future work will include the integration of intelligent controllers on road vehicles.

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