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Design and SOC Determination of Electric Vehicle in Indian Scenario

Vinod Kumar Vishwakarma*, [1] and Swapnil Srivastava[+]

Abstract – *This paper discusses the problems pertaining to battery of electric vehicle (EV) design and state of charge (SOC) performance. EVs have become a practical way to reduce greenhouse gas emissions and dependency on fossil fuels, particularly in countries like India, where the transportation sector significantly contributes to pollution. This paper discusses the design considerations and state of charge (SOC) determination for EVs within the Indian context. It addresses the unique challenges posed by India's diverse climatic conditions, road infrastructure, and driving patterns. SOC determination is a critical aspect of EV operation that directly influences range and energy management. This paper presents various SOC estimation techniques, such as Coulomb counting, open-circuit voltage, and model-based methods and evaluates their applicability. The effect of temperature, driving cycles, and battery aging on SOC accuracy is also discussed. The aim of this approach is to contribute the widespread adoption of EVs in India that supports the country's transition to sustainable transportation. Aspects of the vehicle type configuration, energy storage system (ESS) related issues as SOC, ESS current etc. are analyzed.*

Keywords–Electric vehicle, energy storage system, ADVISOR, state of charge, Performance, Drive cycle.

1. INTRODUCTION

Electric vehicles (EVs) have garnered more attention lately as a possible remedy for the problems associated with transportation that relies on fossil fuels. The battery, motor, and power electronics are just a few of the components whose design and optimization have a significant impact on an EVs performance. Thus, enhancing the efficiency, range, and general performance of EVs requires fine-tuning the parameters of these parts and evaluating their effectiveness [1].

In vehicle simulations, driving cycles are patterns of a vehicle's acceleration and speed that mimic real-world driving circumstances. They are employed to evaluate the efficiency of the vehicle, emissions, and fuel economy in different driving conditions. Based on empirical measurements of the behaviour of vehicles under various driving conditions, a time series of acceleration data and vehicle speed data represents a typical driving cycle. Driving cycles can be customized for different scenarios, like driving in cold weather or at high altitudes, and can be based on the vehicle's intended use case, such as driving on highways or in cities. Driving cycles are necessary in vehicle simulation to compare the various vehicle designs or powertrains with their performance and to precisely predict how the vehicle will behave under various conditions [2].

A potent tool for developing and perfecting HEV and EV car components is the MATLAB Advanced Vehicle Simulator (ADVISOR). A wide variety includes various types of vehicles which are conventional, plug-in hybrid-electric vehicle (PHEV), hybrid-electric vehicle (HEV), and electric vehicle (EV), can be designed and simulated using ADVISOR.A collection of configurable component models, including motors, batteries, gearboxes, and engines, are included in the ADVISOR software, and can be used to build a comprehensive vehicle model. By using the ADVISOR tool options users can design optimized vehicle for objective which are very specific like range, performance, or fuel efficiency by vehicle performance modelling, fuel average, and different harmful emissions. The ADVISOR tool is useful for analyzing how well a vehicle design performs, fine-tuning its parameters, and determining how powertrain modifications affect the vehicle's overall performance. It is extensively utilized for HEV research, development, and optimization in both academia and industry [3].

In this paper four EVs as EV1, EV2, EV3 and EV4 are designed. In EV1 ESS_PB25 12V26Ah battery, MC_AC75 75-kW (continuous) AC induction motor; in EV2 ESS_NIMH28 28Ah NiMH battery and MC_AC75 75-kW (continuous) AC induction motor, in EV3 ESS_PB25 12V26Ah battery, MC_PM58 58 kW (continuous), permanent magnet motor, and in EV4 ESS_NIMH28 28Ah NiMH battery and MC_PM58 58 kW (continuous), permanent magnet motor are used. an Indian urban drive cycle is proposed in this work utilizing the MATLAB ADVISOR tool to evaluate the EV's performance.

The primary goal of this work is to analysis EVs under various driving circumstances in Indian scenario considering acceleration and grade test on all four EVs. Rest of the paper is organized as follows. Section 2

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briefly describes the mathematical modelling of EV and Section 3 discusses the ESS, SOC, acceleration test and grade test. In Section 4 simulation is done using MATLABADVISOR tool and Section 5 presents the results and finally conclusion is presented in Section 6.

2. VEHICLE MODELLING

2.1 Vehicle Block Diagram

The three main subsystems of electric vehicle drive train system which are presently used are depicted in Figure 1 which represents the electric motor propulsion subsystem, auxiliary subsystem and energy source subsystem. Subsystem components of the electric propulsion system include the mechanical transmission, driving wheels, electric motor vehicle controller, and power electronic converter. The different parts of the energy source subsystem are energy refueling unit, energy management unit and the energy source. The auxiliary subsystem which is very useful in EV consists of auxiliary supply unit, the hotel climate control unit and power steering unit [4].

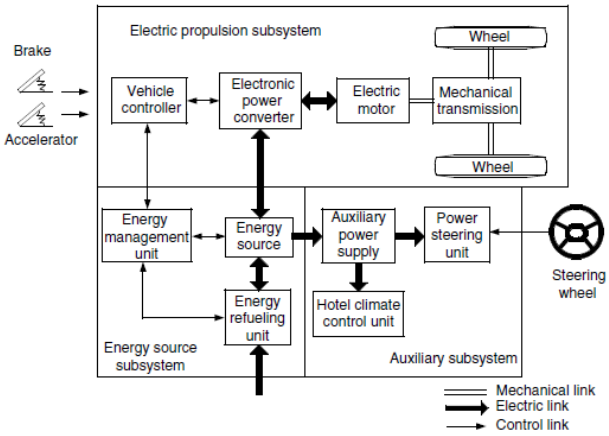

Figure 1. Block diagram of EV configuration [4].

2.2 Mathematical Modelling

In EV modelling, the relationship represents the forces that are applied to the vehicle (taking into account only the longitudinal forces) and that cause it to accelerate and move at a specific speed [5].

$$F_{acc} = F_{tr} - F_{ae} - F_{hi} - F_{rr} \quad (1)$$

Here F_{acc}– accel. force, F_{tr}– tract. force that moves the car, F_{ae}- force due to the friction of the vehicle body and air, F_{hi}–force required to move a vehicle uphill and F_{rr}– rolling. resistance force. The accel. force establishes the vehicle acceleration '*a*' and is dependent on the mass of the vehicle, m, including rotating masses.

$$F_{acc} = ma \quad (2)$$

The friction force is proportional to air density, ρ, frontal area *A* and vehicle velocity; *v* and is a function of vehicle shape and size, through drag coefficient, C_d.

$$F_{ae} = \frac{1}{2} c_d \rho A v^2 \quad (3)$$

The road's inclination angle (referred to as the road grade in ADVISOR), θ, vehicle mass, and gravity acceleration g all affect the climbing force.

$$F_{hi} = mgsin\theta \quad (4)$$

The mass of vehicle, inclination angle, and resistance of rolling coefficient C_{rr}, which is dependent on the tires and road surface, are the factors that determine the rolling resistance force, also known as a friction force [6].

$$F_{rr} = C_{rr} mgcos\theta \quad (5)$$

2.3 ADVISOR Tool

MATLAB/Simulink is very important tool to create the vehicle models that needed for the simulation purpose by using the advanced vehicle simulator tool (ADVISOR) whose interface is shown in Figure 2. The many intricate parts or subassemblies required to set up the vehicle models are made using the fundamental parts found in the Simulink libraries [7].

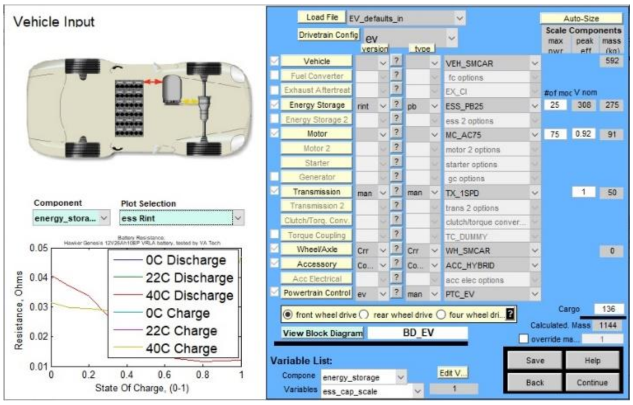

Figure 2. Vehicle input to the ADVISOR.

Four EV configurations are designed by considering 26 Ah lead acid batteries and 28 Ah NiMh batteries with two motors 75 kW AC induction motor and 58 kW permanent magnet motor. The issues related ESS (SOC), ESS current etc. have been presented under Indian driving condition as shown in Figures 3 and 4.Figure 3 shows the CYC_INDIA_URBAN drive cycle, which is characterized by frequent starts and stops, with lower top speeds. Figure 4 displays the Indian drive cycle with constant grade of 1.5. The specification of CYC_INDIA_URBAN drive cycle is given in Table 1.

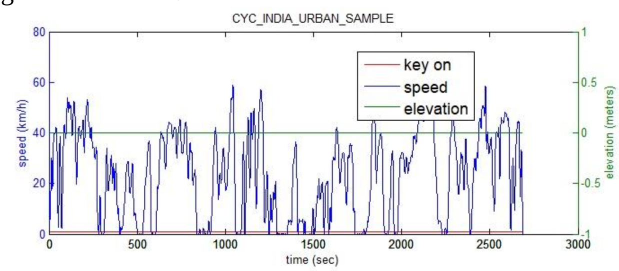

Figure 3. CYC_INDIA_URBAN.

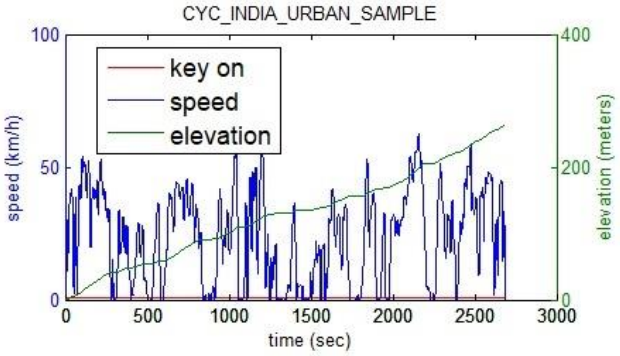

Figure 4.CYC_INDIA_URBAN with constant grade of 1.5.

Table 1. CYC_INDIA_URBAN cycle features.

Drive Cycle Features	CYC_INDIA_URBAN
Time (s)	2689
Distance (km)	17.49
Max Speed (km/h)	62.56
Average Speed (km/h)	23.41
Max acceleration (m/s^2)	1.73
Max deceleration (m/s^2)	-2.1
Avg. acceleration(m/s^2)	0.32
Avg. deceleration(m/s^2)	-0.39
Idle time (s)	267
No. of stops	52

3. METHODOLOGY

3.1 State of Charge (SOC)

For the process of charging batteries to go smoothly and effectively, careful thought and practical precautions must be taken. As a measure of charge in relation to battery capacity, the SOC is an important component of battery operation. SOC shows how much energy is left in an EV battery to power the vehicle, much like a fuel gauge in a car that runs on gasoline. SOC has a major impact on a number of important performance factors, including range and fuel economy. SOC (0% = empty, 100% = full), is a commonly used metric to describe the current status of a battery during operation [8].

$$SOC\ \% = 100 \times \frac{Q_0+Q}{Q_{max}} \tag{6}$$

Eq. (6) can be used to calculate the SOC, with Q_0 (mAh) representing the battery's initial charge. The amount of electricity supplied to or delivered by the battery is denoted by Q (mAh). It is positive when charging and negative when discharging. The maximum charge that a battery can hold is known as Q_{max} (mAh). One essential component of battery management system (BMS) is the determination of battery SOC. For the best control system design and vehicle energy management, accurate and trustworthy SOC estimation is essential [9].

3.2 Energy Storage System (ESS)

Two or more electric cells connected to one another make up an ESS, or battery. In the ESS or battery cells, electrical energy is produced by chemical energy. The electrolyte serves as a link between the cell's positive and negative electrodes. When the electrodes and electrolyte undergo a chemical reaction, DC electricity is created. The chemical reaction in secondary or rechargeable batteries can reverse by reversing the current so that restoring the battery to a charged state [10].

The very popular and very much used battery is lead-acid battery and frequently utilized in electric vehicles. Since lead-acid batteries are frequently found in vehicles with internal combustion engines, they are well known. But stronger lead-acid batteries that can tolerate deep cycling and that employ a gel electrolyte rather than a liquid are utilized in electric cars. Producing these batteries costs more [11].

The final ten years of the 20th century saw the commercial introduction of nickel metal hydride (NiMH) batteries. Its operation is similar to the NiCad battery, with the primary distinction being that the negative electrode of the NiMH battery uses hydrogen that has been absorbed in a metal hydride, which releases cadmium, a significant benefit [12]. The negative electrode of this battery type behaves exactly like a fuel cell, which is an interesting feature [13].

In this paper we have used ESS_PB25 12V26Ah battery in two EV configurations and ESS_NIMH28 28Ah NiMH battery in remaining two EV configurations. The resistance and SOC characteristics of these two batteries are shown in Figures 5 and 6.

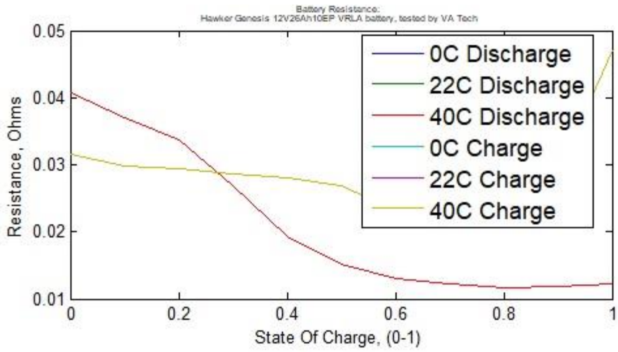

Figure 5. Rinvs SOC characteristic of ESS_PB25.

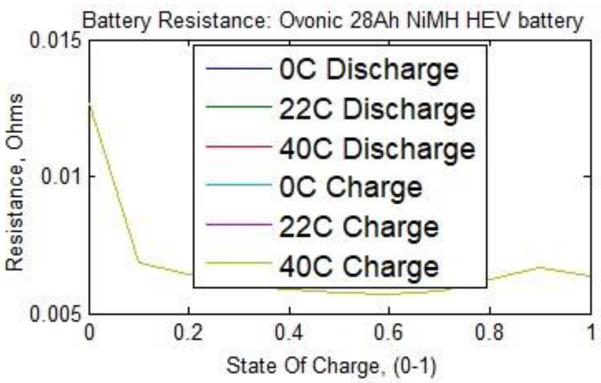

Figure 6. R vs SOC characteristic of ESS_NIMH28.

3.3 Motors used in EV Configuration

The first motor used in EV configuration is the MC_AC75 refers to a specific model within the ADVISOR software, representing the Westinghouse 75-kW AC induction motor/inverter system. This motor model is used for simulating EV performance within ADVISOR and provides insights into how such a motor might perform in a real-world EV application. The key features of this motor are given below:

1. *AC Induction Motor:* The MC_AC75 model is based on an induction motor, which is common in various EV applications due to its robustness, simplicity, and relatively low cost.
2. *Power Output:*75 kW (continuous). This means the motor can continuously deliver 75 kW of power during operation.
3. *Inverter:* Paired with an inverter to control the motor's speed and torque by adjusting frequency and amplitude of AC power supplied to the motor [14].

The second motor used in EV configuration is the MC_PM58 is a 58 kW (continuous) permanent magnet motor. This type of motor is commonly used in EVs due to its high efficiency and compact size. The key features of this motor are given below:

1. *Power Output:* 58 kW continuous, which means the motor, can sustain this power output during operation.
2. *Motor Type:* Permanent magnet motor, which uses magnets in the rotor to create a magnetic field. This design typically results in higher efficiency and power density compared to induction motors.
3. *Applications:* MC_AC75andMC_PM58 are commonly used in vehicle simulations to model EV performance, especially in scenarios where high efficiency and compact motor design are critical.

3.4 Acceleration Test and Grade Test

An acceleration test measures how quickly a vehicle can increase its speed from a standstill or a lower speed to a higher speed. This is important for understanding the vehicle's performance in scenarios like merging onto highways or overtaking other vehicles. A grade test evaluates a vehicle's ability to climb a slope or hill, which is essential for understanding how it will perform in hilly or mountainous terrain. These tests are critical for determining the suitability of a motor for specific vehicle applications and for optimizing vehicle design to meet performance targets [15].The parameters of acceleration test and grade test are given in Tables 2 and 3.

Table 2. Acceleration test parameters.

Initial SOC	0.5
Current mass	1144 kg
Accel time # 1	0 - 60 km/h
Accel time # 2	20 - 60 km/h
Accel time # 3	10 - 60 km/h

Table 3. Grade test parameter.

Grade in %	6
Speed	37 km/h
Duration	10 sec

4. PERFORMANCE ANALYSIS

In this paper four EV configurations in MATLAB ADVISOR are designed. The design parameters of all four EV configurations are given in Tables 4-7. These parameters include vehicle type, ESS type, and type of EV motor and overall mass in kg.

Table 4. EV1 parameters.

Version	Type	Mod	V_{nom}	Mass (kg)
Vehicle	VEH_SMCAR			592
ESS rint	ESS_PB25	25	308	275
Motor	MC_AC75	75 kW	0.92 (PE)	91
Transmission	Manual	Tx-1SPD	1 (PE)	50
Cargo mass				136
Total Mass				1144

Table 5. EV2 parameters.

Version	Type	Mod	V_{nom}	Mass (kg)
Vehicle	VEH_SMCAR			592
ESS rint	ESS_NIMH28	65	436	234
Motor	MC_AC75	75 kW	0.92 (PE)	91
Transmission	Manual	Tx-1SPD	1 (PE)	50
Cargo mass				136
Total Mass				1103

Table 6. EV3 parameters.

Version	Type	Mod	V_{nom}	Mass (kg)
Vehicle	VEH_SMCAR			592
ESS rint	ESS_PB25	25	308	275
Motor	MC_PM58	58 kW	0.92 (PE)	70
Transmission	Manual	Tx-1SPD	1 (PE)	50
Cargo mass				136
Total Mass				1123

Table 7. EV4 Parameters.

Version	Type	Mod	V_{nom}	Mass (kg)
Vehicle	VEH_SMCAR			592
ESS rint	ESS_NIMH28	65	436	234
Motor	MC_PM58	58 kW	0.92 (PE)	70

Transmission	Manual	Tx-1SPD	1 (PE)	50
Cargo mass				136
	Total Mass			1082

These four EV configurations mainly differ in battery used and type of motor used in EV. After configuring four EV configurations a novel Indian urban drive cycle for performance analysis of four types of EVs in various conditions is introduced. In this acceleration test and grade test in Indian scenario are also performed. The simulation output of SOC, ESS current and ESS_MOD_TMP are shown in Figures 7-10 for four EV configurations.

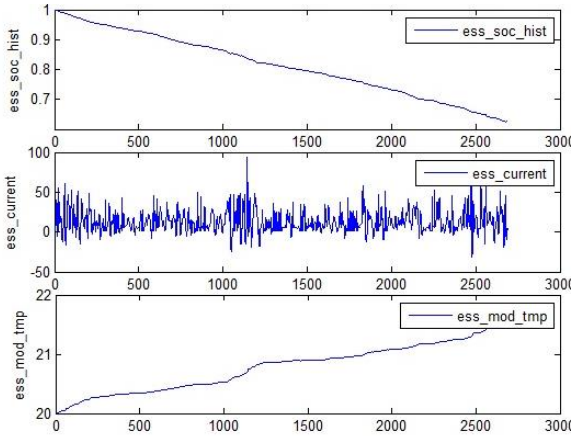

Figure 7.EV1 (SOC, ESS Current and ESS temp).

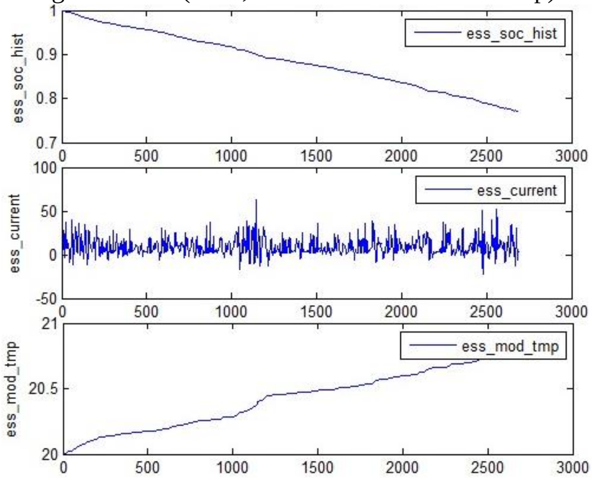

Figure 8. EV2 (SOC, ESS current and ESS temp).

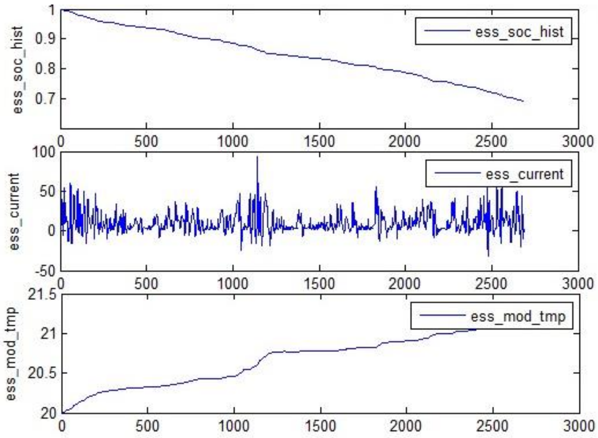

Figure 9. EV3 (SOC, ESS current and ESS temp).

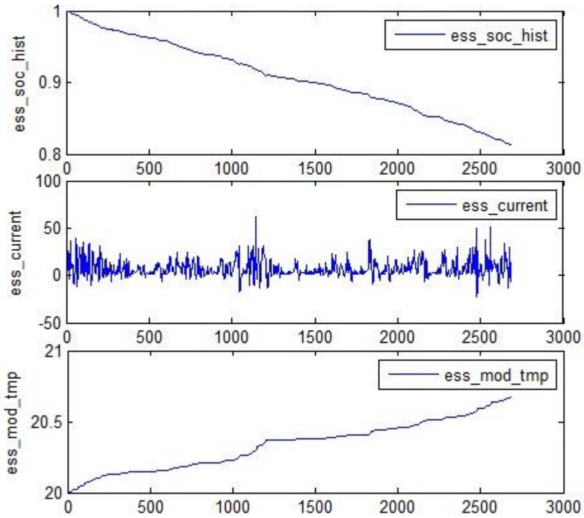

Figure 10. EV4 (SOC, ESS current and ESS temp).

5. RESULT AND DISCUSSION

This section presents the performance, acceleration test and grade test results of four EV configurations. In performance result the gasoline equivalent fuel consumption is shown as in EV there is no fuel consumption. From the performance result it can be observed that when constant grade of 1.5 is applied in drive cycle then there is more fuel consumption as compared to normal.

5.1 Performance Result

The performance results of four EV configurations are given in Tables 8-11. These results show the gasoline equivalent fuel consumption of all four EV types.

Table 8. EV1 performance.

Parameters	Normal	Grade 1.5	Accel/Grade test
Fuel Consumption (l/100 km)	0	0	0
Gasoline Equivalent	2.2	2.8	2.2
Distance (km)	17.5	17.5	17.5

Table 9. EV2 performance.

Parameters	Normal	Grade 1.5	Accel/Grade test
Fuel Consumption (l/100 km)	0	0	0
Gasoline Equivalent	2	2.5	2
Distance (km)	17.5	17.5	17.5

Table 10. EV3 performance.

Parameters	Normal	Grade 1.5	Accel/Grade test
Fuel Consumption (l/100 km)	0	0	0
Gasoline Equivalent	1.9	2.5	1.9
Distance (km)	17.5	17.5	17.5

Table 11. EV4 performance.

Parameters	Normal	Grade 1.5	Accel/Grade test
Fuel Consumption (l/100 km)	0	0	0
Gasoline Equivalent	1.6	2.2	1.6
Distance (km)	17.5	17.5	17.5

5.2 Acceleration and Grade Test Result

The acceleration and grade test results of four EV configurations are shown in Tables 12-15. After analyzing Tables 12-15 it can be observed that the acceleration test and grade test of EV2 configuration has better result as compared to other EV configurations.

Table 12. Acceleration test result of EV1.

0 – 60 km/h	5.75 sec
20 - 60 km/h	4.5 sec
10 - 60 km/h	5.1 sec
Gradeability at 59.5km/h	17.5%

Table 13. Acceleration test result of EV2.

0 – 60 km/h	3.4 sec
20 - 60 km/h	2.3 sec
10 - 60 km/h	2.9 sec
Gradeability at 59.5km/h	38.5%

Table 14. Acceleration test result of EV3.

0 – 60 km/h	6.6 sec
20 - 60 km/h	4.7 sec
10 - 60 km/h	5.6 sec
Gradeability at 59.5km/h	17.6%

Table 15. Acceleration test result of EV4.

0 – 60 km/h	5.5 sec
20 - 60 km/h	3.7 sec
10 - 60 km/h	4.6 sec
Gradeability at 59.5km/h	28.2%

The ESS results of four EV configurations with constant grade of 1.5 are shown in Figures 11-14.In each figure there are four results, i.e., speed in km/h; SOC, ESS current and ESS module temperature. The SOC level of four EV configurations at the end of Indian drive cycle is given in Table 16.

From above discussion we can say that EV2 has better result under gradeability and acceleration-performance test. But EV4 achieved better SOC level at the end of Indian urban drive cycle so as a result EV4 performs better in driving range and EV2 performs better in acceleration and gradeability test.

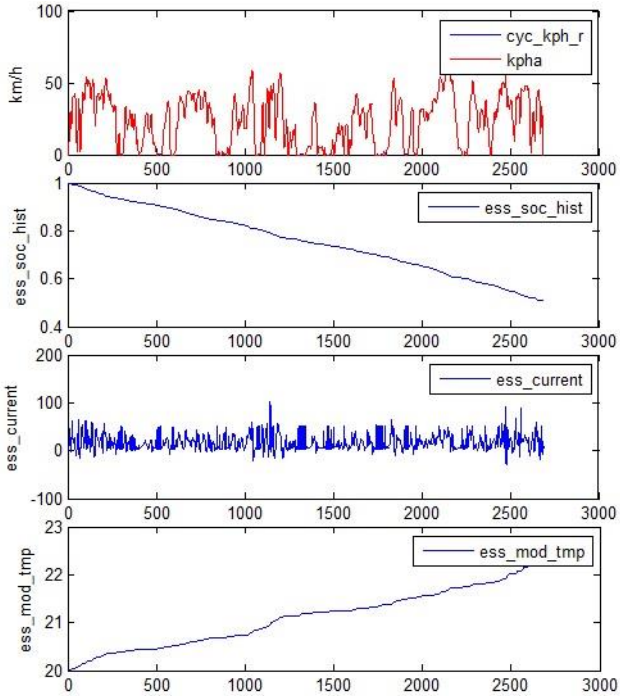

Figure 11. EV1 results(ESS with constant grade of 1.5).

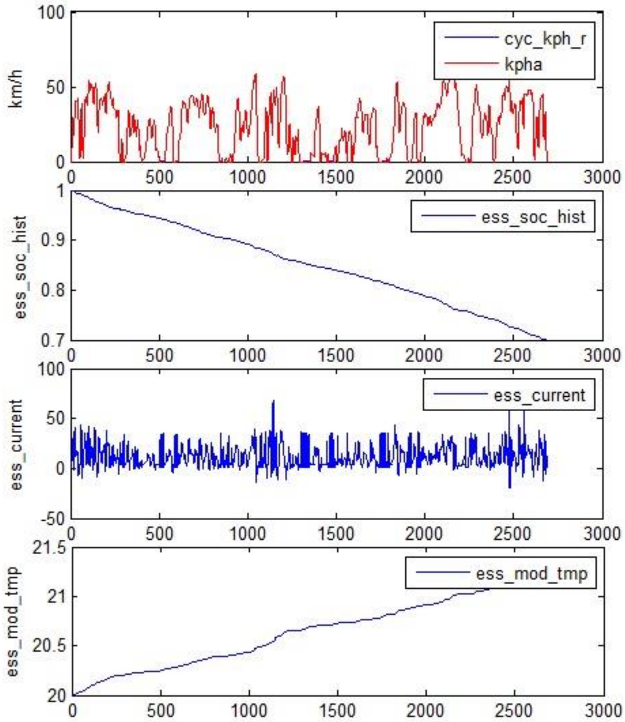

Figure 12. EV2 results (ESS with constant grade of 1.5).

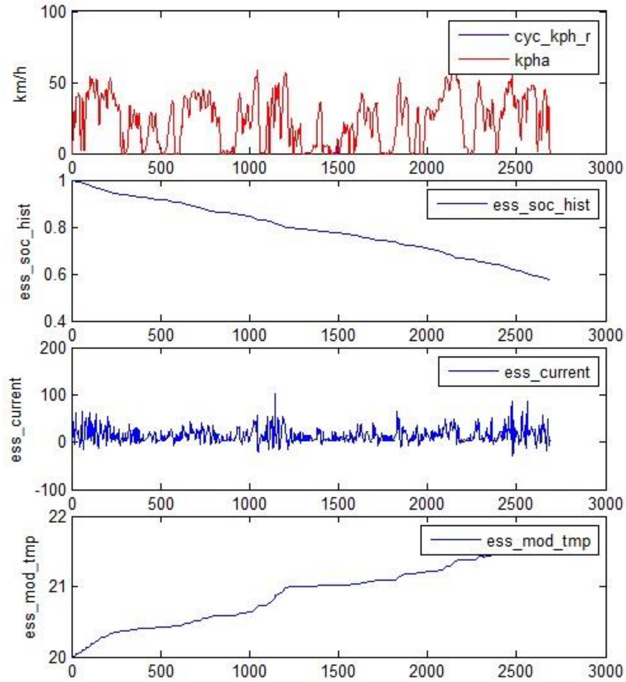

Figure 13. EV3 result (ESS with constant grade of 1.5).

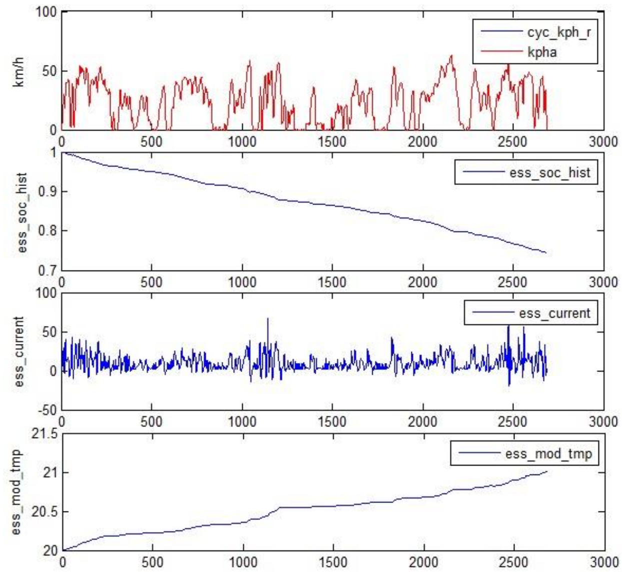

Figure 14. EV4 result (ESS with constant grade of 1.5).

Table 16. SOC level of four EV configurations.

Vehicle type	SOC at the end of drive cycle
EV1	0.5
EV2	0.7
EV3	0.6
EV4	0.75

6. CONCLUSION

In this study, the design and SOC determination of four EV configurations is presented for Indian urban drive cycle. The four EV configurations namely EV1, EV2, EV3 and EV4 are designed using two battery types ESS_PB25 12V26Ah and ESS_NIMH28 28Ah NiMH battery. The choice between different motor types (e.g., induction motors like the MC_AC75 or permanent magnet motors like the MC_PM58) should be based on performance needs, cost, and availability.

Accurate SOC determination is essential for efficient energy management and range prediction. Techniques like Coulomb counting, model-based estimation, or machine learning can be used, considering the vehicle's operating environment. Indian driving conditions, characterized by stop-and-go traffic and variable terrain, significantly influence SOC. The EV's battery management system must account for these factors to ensure accurate SOC estimation. According to the simulations, EV2 has better result under gradeability and acceleration-performance test. But EV4 achieved better SOC level at the end of Indian urban drive cycle.so as a result EV4 performs better in driving range and EV2 performs better in acceleration and gradeability test.

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