Electric Vehicle (EV) Power Consumption (Battery) On Uphill Road Conditions

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ABSTRACT

Electrical Vehicle (EV) has been developing since the mid-18th century and reached its peak at the end of the 18th century. Dwindling fuel reserves and environmental damage caused by exhaust emissions from millions of fossil-fuel vehicles are the driving factors for the development of electric cars. Technological developments in the battery sector have also contributed to the development of electric cars. One of the important components in an electric car is the battery which will provide resources to the system, so determining the capacity and knowing the performance of the battery used is very important. To find out the battery performance, the model can be made using MATLAB/SIMULINK. The model built consists of electric (DC motor, control and battery) and mechanical (transmission, wheels, brakes and body) parts. The models made for speeds of 35, 40, and 45 km/h on level ground, the distances that can be covered are 2,292, 2,597, and 2,899 m, while the remaining battery capacity (SoC, %) is 92.93%, 91.16%, and 89.17%. This is proportional to the distance traveled which also proves that the model made is appropriate. Uphill roads affect the use of battery capacity, the greater the angle of incline, the greater the battery capacity used.

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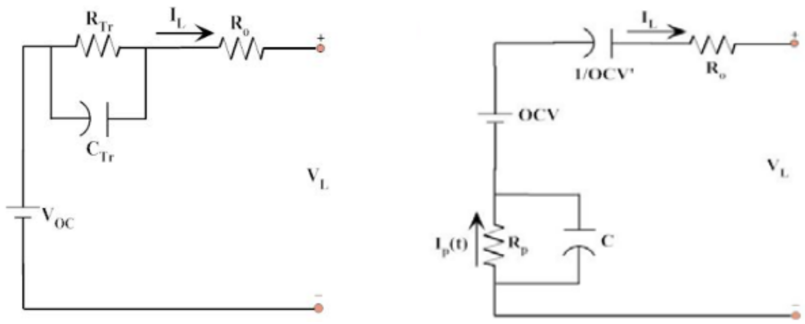
1. INTRODUCTION

Transportation electrification is a promising solution to address the problem of climate change. The use of electric vehicles has had a significant impact in various fields. Various policies have been produced to encourage the spread of electric vehicles and the trend of increasing use of electric vehicles in recent years. The development and use of electric cars (EV) will increase rapidly in the future, this development will also have an impact on electrical energy storage media in the form of batteries. Electric cars that use batteries are expected to be able to replace vehicles that use fossil fuels so that they can be more efficient and environmentally friendly[1]. The design of electric vehicles is a complex process including energy distribution, vehicle transmission, road characteristics and so on[2].

Knowing battery performance in various operating conditions is very important, especially in electric cars. There are several accurate and efficient battery models that can be used in electric car models, such as the first or second order Thevenin battery models, "**Fig. 1**"[3]. By making an electric car model using MATLAB/SIMULINK it is expected to be able to find out the performance of the battery used in an electric car on uphill road conditions, one of the battery performance parameters can be described by the state of charge (SoC) parameter.



(a) (b)

Fig. 1. Battery model: (a) first order; (b) second order

MATLAB/SIMULINK is used to form an electric car system so that speed can be observed due to the influence of the slope of the road angle, assuming the car's specifications are set to get the desired torque on uphill and downhill roads[4]. There are several terms related to mechanics that are used in MATLAB to represent variables when designing electric cars. Permanent Magnet DC Motor (PMDC) is used to simulate the characteristics of the ratio of torque to motor speed, which is then connected to a wheel that converts rotational torque to the wheel so that the electric car can move. The generic battery model is a dynamic simulation model, where this model only uses the State of Charge (SoC) as a variable that can represent the general behavior of the battery[5].

When the vehicle moves uphill at an angle of two or three degrees with the horizontal axis it will require greater torque where the speed will slow down[6]. Furthermore, the battery inside the car is used to power the electric motor[7], whereas, in petrol-powered vehicles, the gas tank is not part of the design model[8]. The electric motor as a driving force consumes energy from the battery, apart from being a driving force the electric motor can function as a generator that generates voltage during braking[9] which is used to charge the battery. Batteries are generally made of lithium cells which have a high current capacity, based on monitoring of the main parameters of the battery, control is carried out using a power electronics unit that converts the DC battery voltage into three-phase AC voltage at the appropriate frequency and voltage so that the motor meets the required speed and torque[10]. PI control is used to control the amount of voltage and current to meet the power requirements used when the electric car goes uphill or downhill[11].

2. METHOD

2.1. Battery Modeling

The battery is modeled as a voltage source with internal resistance, so the model can account for the battery's internal power loss. The Coulomb Counting method can be used to calculate the electric charge (coulomb) entering or leaving the battery so this method can be used to determine the value of battery capacity (SoC). The equation for calculating SoC is shown by equations "(1)," and "(2)," where C_n is the nominal capacity of the battery, I is the battery current, SoC_0 is the initial SoC and dt is the time interval[12]:

$$SoC = SoC_0 + \frac{1}{C_n}\int_{t_0}^{t} |I| \cdot dt \quad \rightarrow \text{ charge} \tag{1}$$

$$SoC = SoC_0 - \frac{1}{C_n}\int_{t_0}^{t} |I| \cdot dt \quad \rightarrow \text{ discharge} \tag{2}$$

"**Fig. 2a**" is a battery model in MATLAB/SIMULINK using a first-order battery model of the Lithium-ion with a capacity of 15 Ah, to get an output voltage of 100.8 Volts, 24 battery models are needed to be connected in series "**Fig. 2b**". Then the output of the battery module is connected to the generic battery model "**Fig. 2c**" which is the generic dynamic model of the most popular rechargeable battery, this model can show SoC parameters, current and voltage consumption.

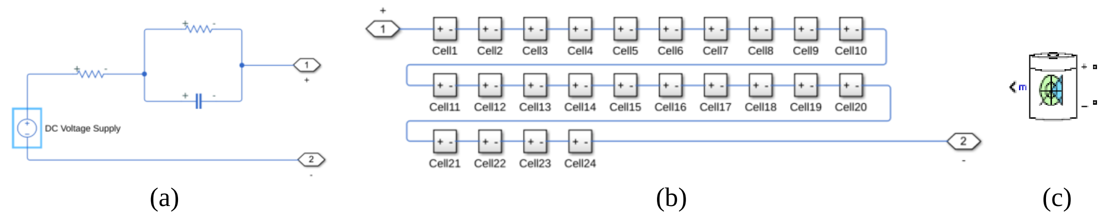


Fig. 2. Battery modeling with SIMULINK: (a) first order; (b) 24 batteries connected in series; (c) SIMULINK generic battery model

2.2. Driving Modeling

The drive consists of a PWM system and a DC motor "**Fig. 3**". The type of DC motor used is a Permanent Magnet DC motor, with an armature resistance of 0.0093 Ohm, an armature inductance of 172 uH, a constant torque of 0.19 Nm/A and a rotor inertia of 0.001 kg m^2.

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a method of reducing the average power (average voltage). The average voltage (or current) is clipped by using high-speed (ON-OFF) switching. The longer the switch is on (ON) compared to the period it is off (OFF), the higher the total power supplied to the load. PWM is best suited for use with inertial loads such as motors, which are not easily affected by these discrete switches, as their inertia reacts slowly. In PWM, the term duty cycle is known which describes the proportion of ON and OFF time[13] "**Fig. 4**". Equation "3," is used to calculate the amount of duty cycle.

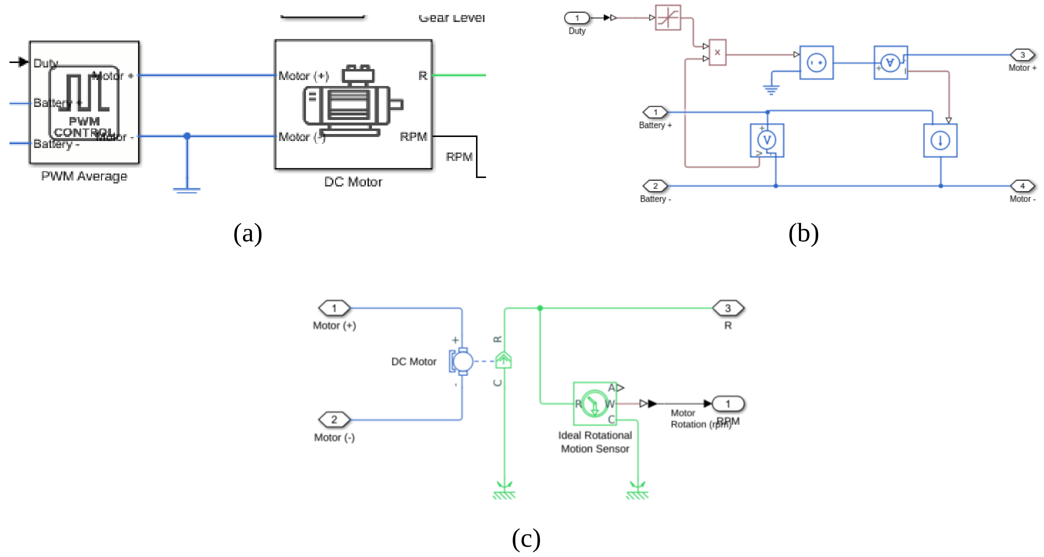


Fig. 3. (a) drive system; (b) PWM sub-system and; (c) DC motor sub-system

$$Duty\ cycle = \frac{T_{ON}}{T_{ON} + T_{OFF}} \quad (3)$$

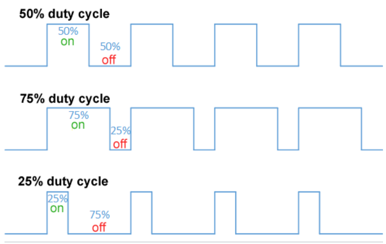


Fig. 4. PWM duty cycle

2.3. Transmission Modeling

The transmission part “Fig. 5” is used to connect the driving part with the wheel part on the body, so that the car body can move at a certain speed. Drive transmission (propulsion) is a mode of transmission and control of engine drive.

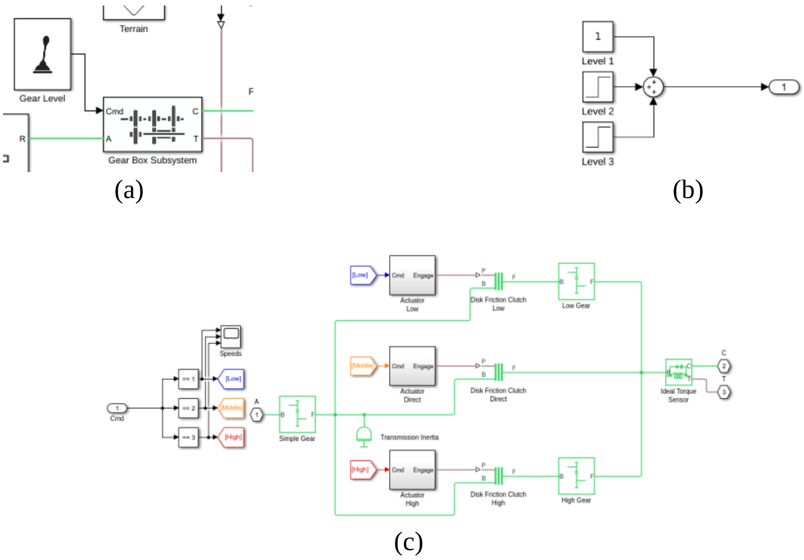


Fig. 5. The transmission part which consists of: (a) gear level (shifting gear lever) and gear box (a box containing a set of gears); (b) Gear level subsystem; (c) gear box subsystem

2.4. Vehicle modeling (Body and Wheels)

Vehicle parts consist of the body block, wheels, braking system, and sensors “**Fig. 6**”. The vehicle body subsystem is used to simulate the vehicle body with the parameters of weight, slope, and wind resistance equipped with 18" diameter wheels. The total weight is the sum of the weight of the vehicle (237 kg) and its payload (80 kg) so the total weight is 317 kg. the front surface of the vehicle when the vehicle is moving which is affected by the wind when it is zeroed out. Meanwhile, the terrain parameters are used as road contour input with values 0^o (for flat roads), 5°, 10°, 15°, 20°, and 25°, all parameters/variables are made based on the model as shown in “**Fig. 7**”. Angle β shows the slope of the road (uphill).

The term transmission refers to the entire drivetrain, including the clutch, gearbox, differential, and final drive axles. The transmission reduces the higher engine revs to the slower wheel speeds, increasing torque in the process. The transmission is also used to adjust for different rotational speeds and torques. Often, transmissions have multiple gear ratios with the ability to switch so the speed can be varied. This shift can be done manually (by the operator) using a gear level or automatically (by the control unit). Transimi is also designed to provide motion direction control (forward and reverse). The ratio transmission is used only to change the speed and torque (and sometimes the direction) of the drive motor output in response to speed and throttle (gas pedal)[14]. The transmission used has 3 choices of follower gear ratio (F) to base (B) (NF/NB), namely: 1.5 (low), 1 (medium) and 0.87 (high).

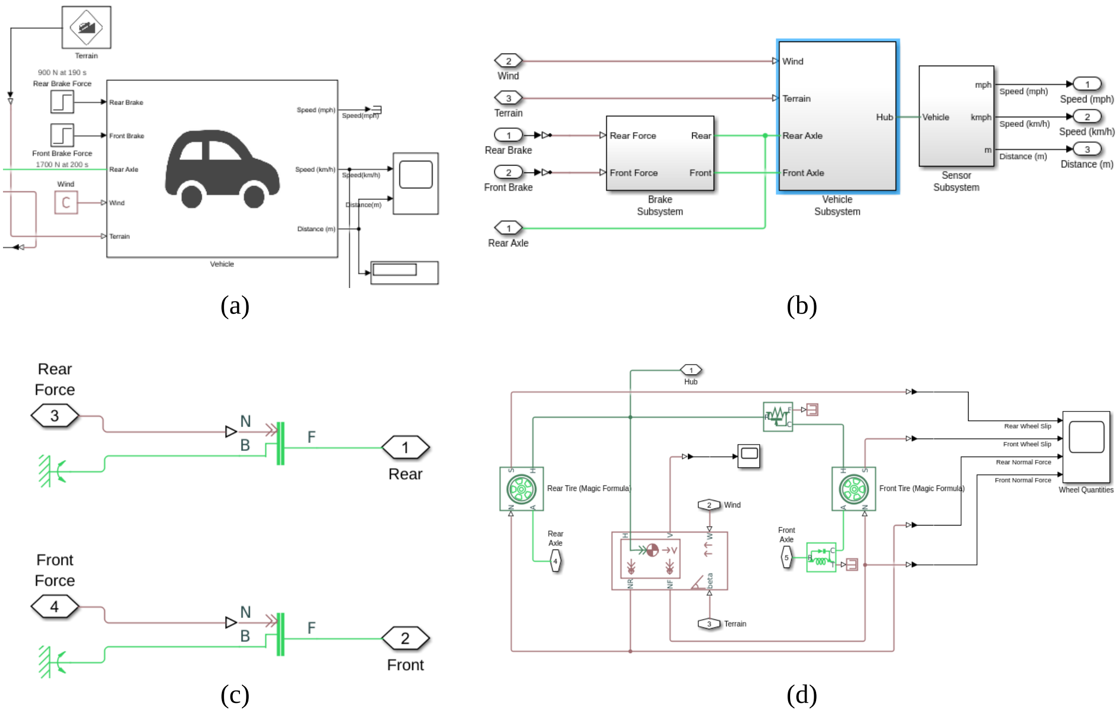


Fig. 6. (a) Vehicle/vehicle parts; (b) Consists of the braking subsystem (brake), vehicle body subsystem, and sensor subsystem; (c) Braking subsystem ; (d) Vehicle body subsystem

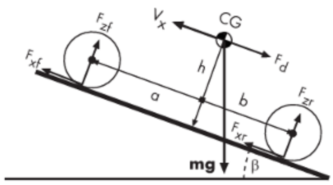


Fig. 7. vehicle model on a road with a slope

The sensors in the vehicle modeling section record the vehicle speed in M/H (miles per hour), KM/H (kilometers per hour) and the distance traveled in meters. The electric vehicle system is also equipped with PI control so that the speed can be set constant at a certain value (at 35 km/h, 40 km/h and 45 km/h). A complete electric vehicle system as shown in "**Fig. 8**".

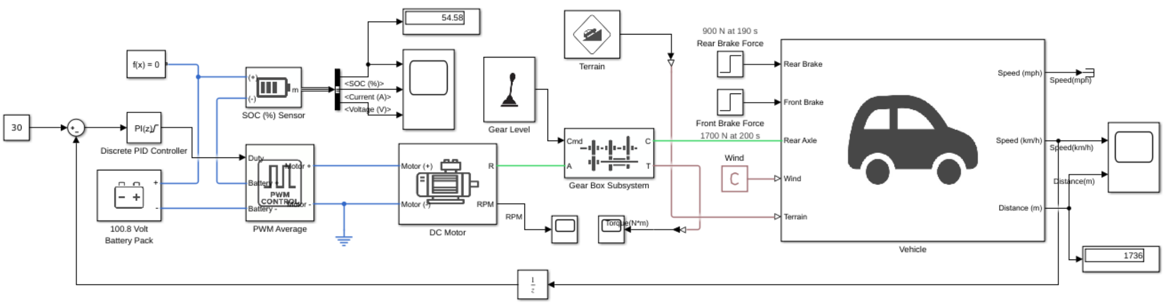


Fig. 8. Complete electric vehicle (EV) model

3. SIMULATION AND RESULTS

The first scenario of the simulation of the model was carried out at speeds of 35, 40 and 45 km/h with flat road conditions (β = 0°), the simulation was carried out for 240S seconds, the results can be seen in "**Fig. 9**".

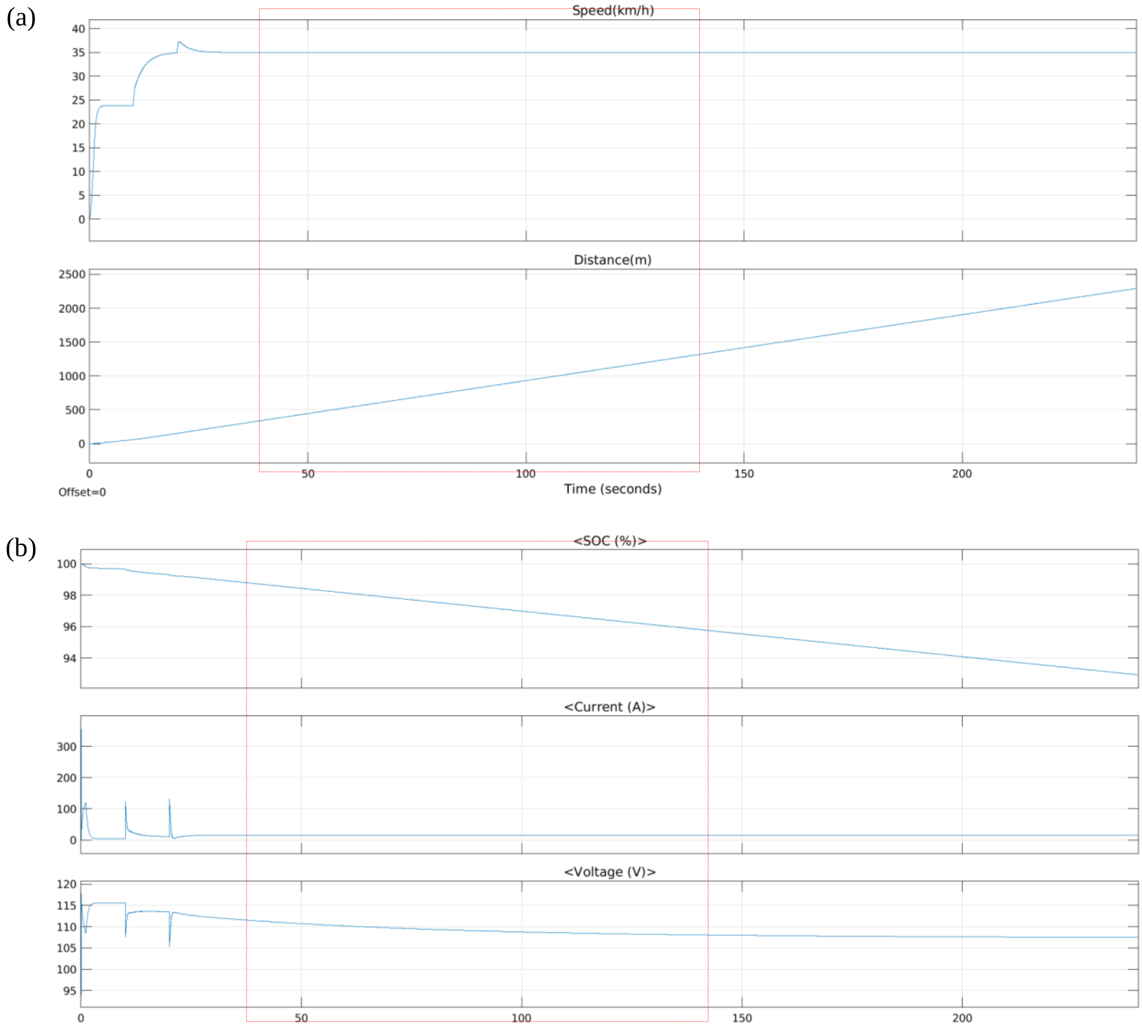


Fig. 9. (a) Speed, distance traveled; (b) SoC, voltage, and current at a vehicle speed of 35 km/h on level road for 240 seconds

The simulation results that have been carried out can be seen in "**Fig. 9a**" in the low transmission position (NF/NB = 1.5) for 10 seconds the speed is 23,829 km/h, 10 seconds later the speed rises to 34,658 km/h at medium transmission position (NF/NB = 1) and 10 seconds (NF/NB = 0.87) then speed had jumped to 37,037 seconds but then remained constant at 35 km/h until the end of the simulation. The distance traveled in 240 seconds is 2292 m (2292 km). In "**Fig. 9b**". It can be seen that the amount of energy absorbed so that at the end of the simulation the remaining battery energy is 92.93%, it also displays the voltage and current absorbed by the DC motor. "**Table 1**" shows the effect of the set vehicle speed on the distance traveled and the remaining battery energy for 240 seconds.

Table 1. Distance and remaining battery energy (SoC) on a flat road for 240 seconds

No.	Speed (km/h)	Distance (m)	SoC (%)
1	35	2,292	92.93
2	40	2,597	91.16
3	45	2,899	89.17

The models built for speeds of 35 km/h, 40 km/h, and 45 km/h the mileage on level ground is 2292 m, 2597 m, and 2899 m, while the remaining battery energy (% SoC) is 92.93%, 91.16%, and 89.17% this is comparable with the distance traveled. This also proves that the model made is appropriate.

The second scenario is done by adding an uphill road at 50 to 150 seconds (for 100 seconds) with a slope angle of 5°, 10°, 15°, 20°, and 25°. "**Fig. 10**" is a graph for an angle of 15° at a speed maintained at 40 km/h. Observations were focused on the 50 to 100 seconds, then the length of the incline taken at various speeds is tabled in "**Table 2**" and graphed as shown in Figure 13. It can be seen from "**Fig. 11**" that for the same speed with an increasing inclination angle, the length of the incline taken is getting shorter.

(a)

(b)

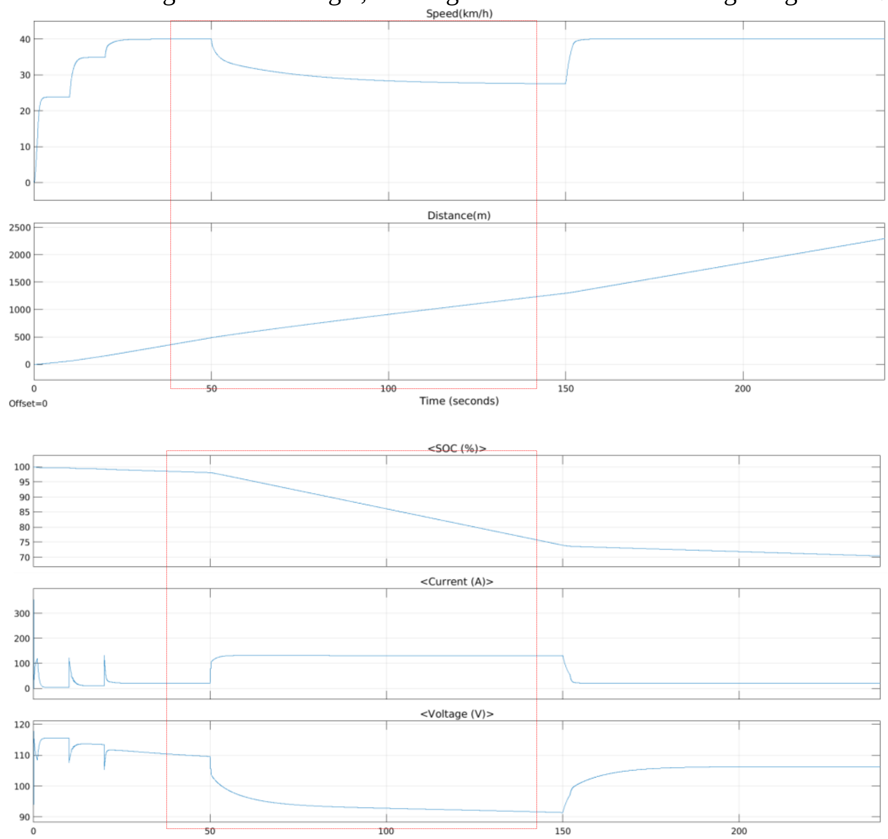


Fig. 10. (a) Speed, distance; (b) SoC, voltage, and current at a vehicle speed of 35 km/h for 240 seconds with an incline angle of 15° for 100 seconds

Table 2. The length of the incline taken based on the angle of the road and speed

Incline angle	Length of road at a speed of 35 km/h (m)	Length of road at a speed of 40 km/h (m)	Length of road at a speed of 40 km/h (m)
0°	972.17	1,111.04	1,249.70
5°	971.17	1.110.04	1,169.70
10°	967.17	989.04	991.70
15°	809.17	812.04	813.70
20°	633.17	636.04	637.70
25°	459.85	462.10	464.09

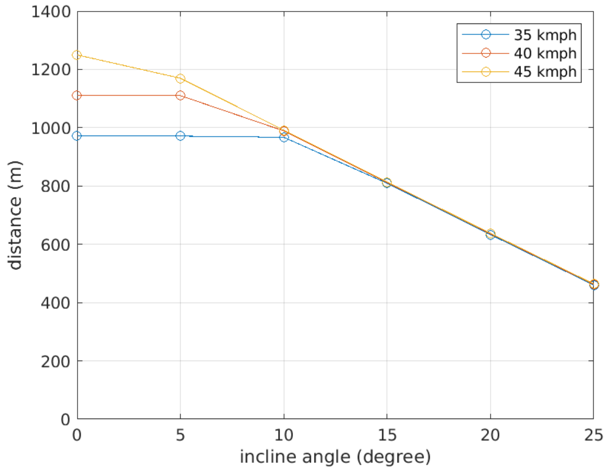


Fig. 11. The graph between the angle of inclination and the length of the incline traveled at speeds of 35, 40, and 45 km/h for 100 seconds

"**Table 3**" shows the amount of battery capacity (SoC, %) used with the addition of variations in the angle of the road for 100 seconds. "**Fig. 12**". shows the use of battery capacity in the case of roads with the addition of varying inclination angles. It can be seen that the capacity of the batteries used from the addition of 6 variations of the slope of the road with varying speeds has a very significant difference. The greater the angle of inclination of the road at the same time, the shorter the length of the road (according to "**Table 2**") and the greater the use of battery capacity ("**Table 3**").

Table 3. Battery capacity is used based on the angle of the road and speed

Incline angle	Battery capacity is used at a speed of 35 km/h (SoC,%)	Battery capacity is used at a speed of 40 km/h (SoC,%)	Battery capacity is used at a speed of 45 km/h (SoC,%)
0°	2.90	3.66	4.51
5°	10.41	11.16	11.43
10°	17.82	17.82	17.70
15°	24.26	24.15	24.04
20°	30.59	30.48	30.37
25°	36.87	36.76	36.64

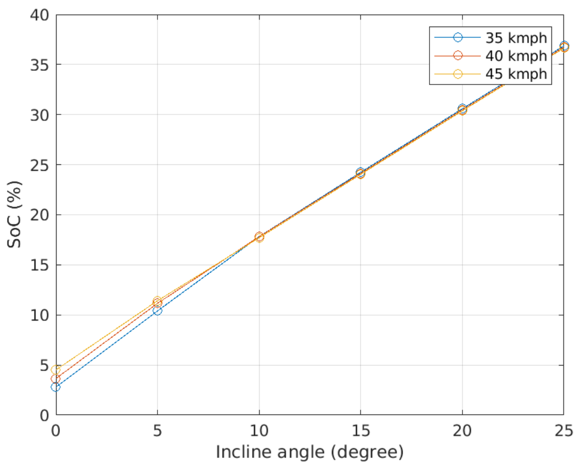


Fig. 12. The graph between the angle of inclination and the used battery capacity at 35, 40, and 45 km/h for 100 seconds

4. CONCLUSION

The models made for speeds of 35, 40, and 45 km/h on level ground, the distances that can be covered are 2,292, 2,597, and 2,899 m, while the remaining battery capacity (SoC, %) is 92.93%, 91.16%, and 89.17%. This is proportional to the distance traveled which also proves that the model made is appropriate. Uphill roads affect the use of battery capacity, the greater the angle of incline, the greater the battery capacity used.

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