Design, Modeling and Simulation of Power Train of an Electric All Terrain Vehicle

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ABSTRACT

This research article describes and evaluates the design, modeling and simulation of Electric All-terrain Vehicle (EATV). The source of petroleum products has been declining day by day and its price has been increasing. So, many alternative resources are being developed nowadays to recover from the possible conditions of energy scarcity. Since, electricity is regarded as a main alternative source, so we are focusing on designing Electric All-Terrain Vehicle. EATV uses battery as a main power source and is driven by motor. We performed computer modeling of power train in MATLAB and Simulink to find ideal requirement of parts involved. A simulation was modeled to calculate the average energy consumption of the EATV. The motor power requirement was found to be 10.563KW power, 52.43Nm torque and 4130 rpm. The battery total energy capacity of 24kW-hr seemed necessary. The use of the EATV can be made on various conservational area where the topography of the land is not similar and use of the IC engine vehicle causing the pollution and noises for the animals living in that area. For such use the projected manufacturing cost of the EATV is way below the normal electric vehicle cost and this will also promote the use of local resource as for the manufacturing and maintaining the vehicle while reducing the usage of petroleum product which is imported from other nations and are in the verge of ending the resource.

Keywords: Simulink Model, Battery Bank, Motor Controller, Drive cycle, Tractive force and Energy

1. INTRODUCTION

A powertrain is an assembly of every component that pushes vehicle forward. A car's powertrain creates power from the engine and delivers it to the wheels on the ground. The key components of a powertrain include an engine, transmission, driveshaft, axles, and differential.

In order to calculate tractive power requirement, the net force required after subtracting the external forces acting on the vehicle is calculated. The electric motor torque is calculated from the tractive force required. The external forces like rolling resistance, road grade are subtracted. The tractive effort that can be applied to the ground is directly related to the properties of the ground. Different surfaces such as sand, asphalt and ice will have different value of friction which will limit the maximum force that can be applied to accelerate the vehicle without spinning the wheels.

2. DESIGN AND CALCULATIONS

Sprung mass of vehicle with driver and passenger (Ms) = 450kg

Unsprung mass of vehicle (Mu) = 90kg

Total mass of vehicle (M) = 540kg

Coefficient of rolling resistance (Cr) = Cr = 0.045 (Chevrefils, 2008)

Rolling resistance (F_r) = C_r * W

= 0.045 * 540* 9.81 =238.38 N

Take Max. Velocity (v) = 60 km/hr = 16.67 m/s

Average running speed (v_{avg}) = 25 km/hr = 6.94m/s

Time to acquire (t_{avg}) = 10 sec

Acceleration (a) $= \frac{V(avg)}{t} = 6.94/10 = 0.694 m/s^2$

Acceleration Force (F_a) = M * a = 540 * 0.694 = 374.76 N

Grade (G) = 25 % = 14.036° (Assumed)

Grade force (F_g) = M*g*sin(α)

= 540 * 9.81 * sin(14.036)= 1284.79N

Total resistive force (F_{res}) = $F_a + F_g + F_r$

a. Calculation of Starting Torque

Initial force to start a vehicle at 25% grade

$F_i = F_r + F_a + F_g = (238.38 + 374.76 + 1284.79) = 1897.93$ N

Size of wheel = 0.3175 m

Torque required to move the wheel (T_{axle})

$T_{axle} = F_i$ * Radius of wheel = 1897.93 * 0.3175 = 602.60 Nm

b. Climbing the grade

Assume, Grade = 25 % at V= 30 km/hr

Grade Force (F_g) = $M*g*\sin(\alpha)$ = 1284.79 N

Rolling Resistance (F_r) = $M*g*C_r$ = 238.38 N

Total force (F_t) = $F_g + F_r$ = (1284.79 +238.38) = 1523.17 N

V = 25 km/hr = 6.944 m/s

Power required to climb the grade ($P^1_{required}$) = $F_t * V$

= 1523.17* 6.944

= 10572Watt

=10.57W

c. Continuous power required in plain road

Average Speed (V_{plain}) = 40 km/hr = 11.11 m/s

The force required to overcome resistance (F_t) = $F_a + F_r$

= 374.76 + 238.38 = 613.14N

Power required ($P^2_{required}$) = $F_t * V_{avg}$ = 613.14 * 11.11 = 6811.985 W= 6.81 KW

From the calculation above, the overall tractive power requirement to run the EATV at average velocity of 25 km/hr on 25% grade is found to be 10.57kW. This value does not account for the losses accumulated in the drive train, heat losses and motor losses and thus a margin must be added to account for these losses.

d. Motor Torque and Rated Speed Calculation

Total Gear ratio of transmission (G) = 12.44 (Dana, 2020)

Efficiency of transmission (η_G) = 0.7

Wheel rotational Speed rpm @ 40 km/hr (V)

$$V = \frac{\pi DN}{60}$$

$$N_{axle} = \frac{V*60}{\pi D} = 332 rpm$$

Torque provided by the motor (T_{motor}) = $(1/G*\eta_G)*T_{axle}$ = (1/12.44*0.7)*456.576 = 52.43 Nm

Angular Velocity of the motor shaft (N_{motor}) = $G*N_{axle}$ = 12.44 * 332 = 4130 rpm

2.1.Selection of Motor Controller

The motor drive has multiple components that require selection. Based on axial flux motors Sinusoidal (sine wave) controllers such as the Sevcon Gen4 are to be used. The Gen4 range represents the latest design in compact controllers. These reliable controllers are intended for on-road and off-road electric vehicles and feature the smallest size in the industry for their power capacity.

Table Specification of the Sevcon Gen4 S4 110V 300A UVW Motor Controller 634A13210

Nominal Voltage	110 VDC
Operating Voltage	48-150 VDC
Current (120s)	300A

Boost (10s)	360A
Cont. (60min)	120A

2.2.Sizing of battery bank

Current drawn by motor to run at maximum power is given by the relations given below.

I = P/V

= Power of motor/ battery voltage

= 12000/96 =125 Ampere (A)

The range of the E-ATV is assumed to be 40km in once full charged. The average speed of the E-ATV is taken as 25 km/hr. The operating time of the vehicle can be calculated to be 1.6 hour. Since, the battery is discharged to only about 80% of its rated capacity. Discharging it below this point can damage the battery pack.

Take, Efficiency (η) = 80%

Battery Capacity required = (Amp*operating hour)/ η = (125*1.6)/0.8 = 250 A-hr

Battery Energy Capacity (kW-hr) = (Ah*V)/1000 = (250*96)/1000 = 24kW-hr

3. MODELING AND SIMULATION

The Figure below shows the Simulink model for calculation of energy consumption of the Electric All-terrain vehicle. The model shows how to model vehicle dynamics to obtain high level information about tractive force requirements for a given weight and drive cycle. A MATLAB Script is coded to initialize the Simulink model which contains all the main parameter of the vehicle.

The Simulink block diagram model is run for 2474 s, which is to total duration of the FTP75 drive cycle. The time step of 1 second is set because the input data (FTP 75) is sampled at 1 s. The speed profile is read from FTP75 drive cycle which is reduced by 2.25 to match maximum velocity requirement of our Electric ATV. Before running the simulation we need to initialize the MATLAB script.

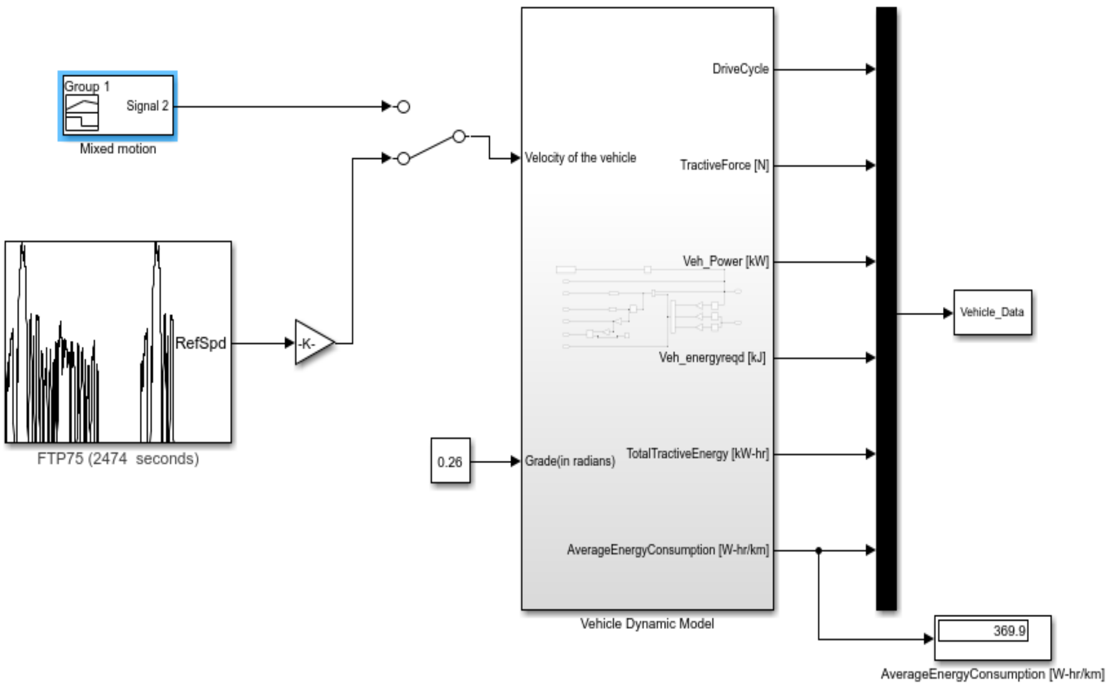


Figure MATLAB Simulink Model for Energy Consumption

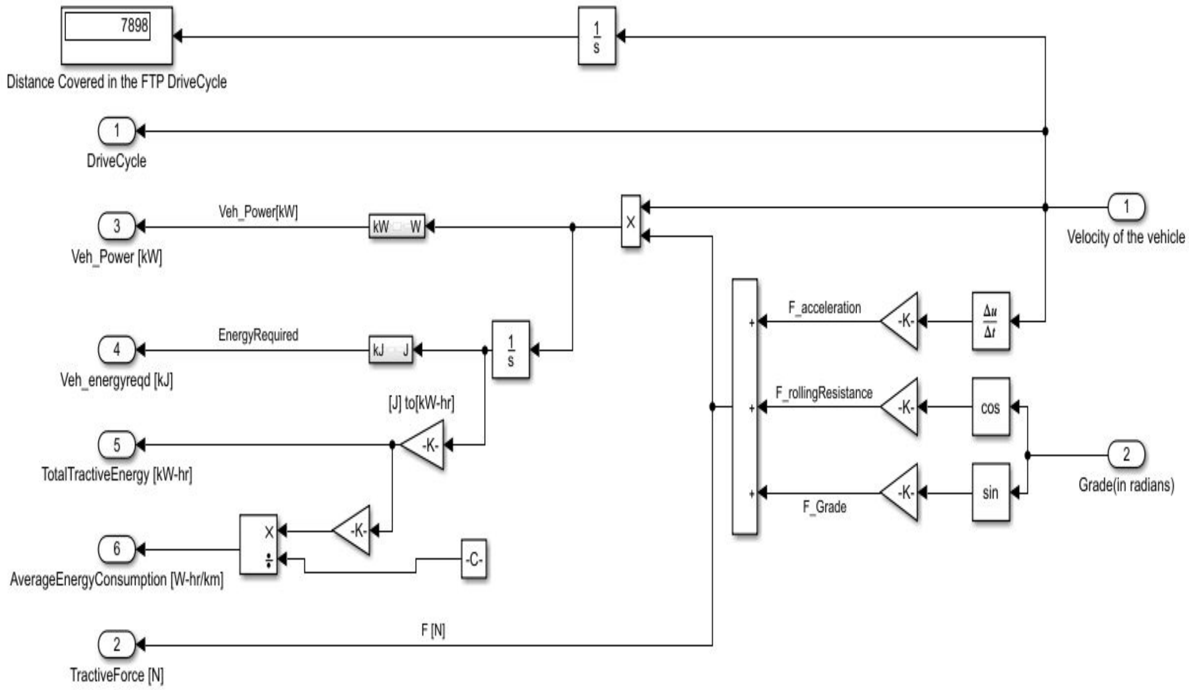


Figure Simulink Vehicle Dynamic Model for Energy Consumption

From the above model, we have found the total length of the drive cycle was 7898 m in the time interval of the 2474 seconds of the drive cycle.

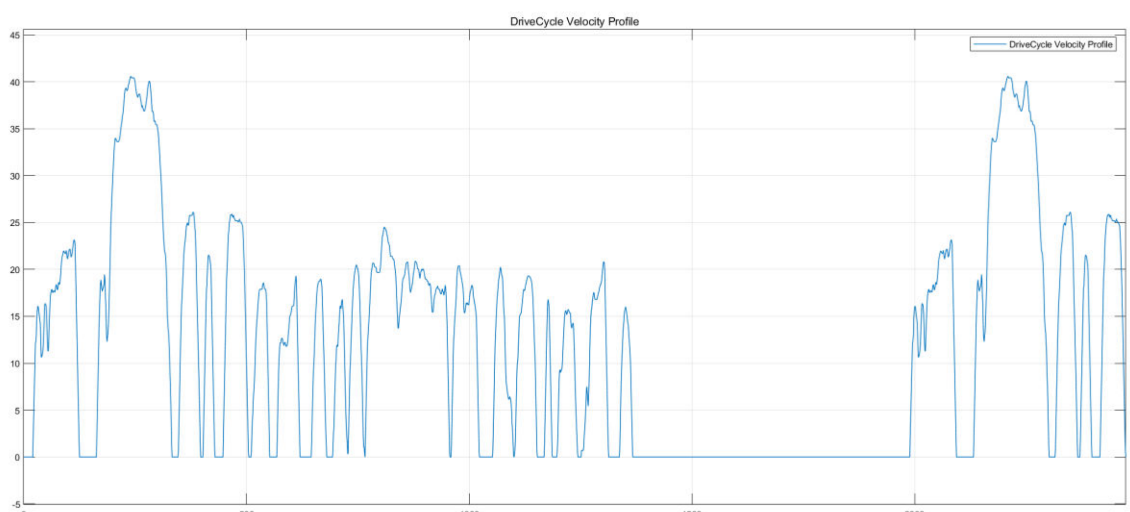


Figure Reduced FTP75 Velocity Drive-cycle Profile

The above drive cycle profile shows that the maximum velocity is taken as 40 km/hr.

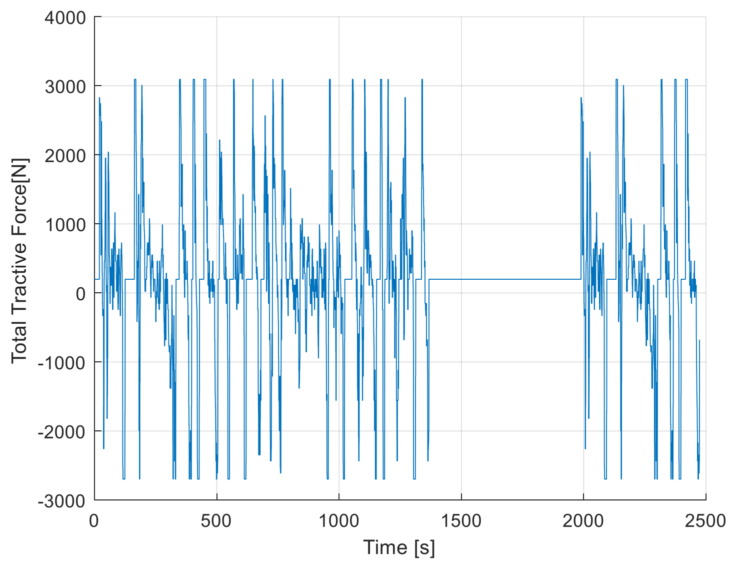


Figure Tractive Force versus time at Grade 0%

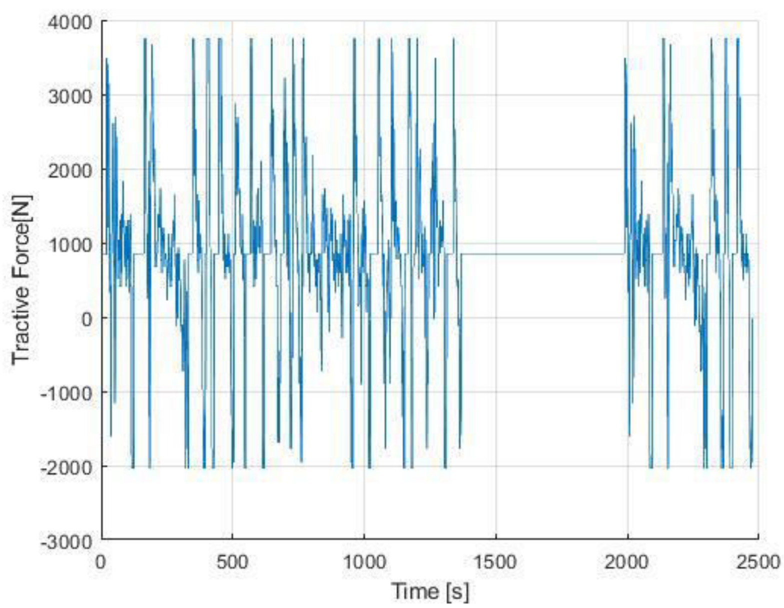


Figure Tractive Force versus Time Graph at Grade 25%

The above graph show the tractive forces and time graph. The maximum tractive force is observed to be 4179N at 169 seconds of the drive cycle. The negative tractive force of 1568N at 116 seconds is due to deceleration of the vehicle during the drive cycle.

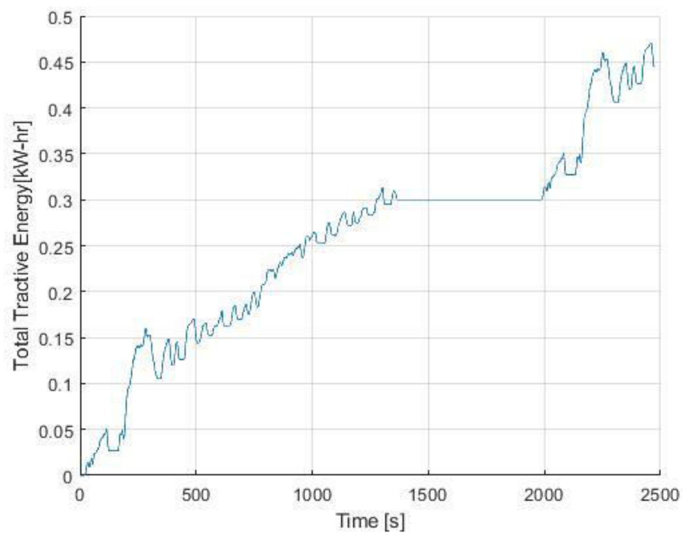


Figure Total Tractive Energy at Grade 0%

From the above graph, it is observed that the maximum tractive energy requirement in the given drive cycle is found to be 0.4702 kW-hr. By dividing the last calculated value of the total energy (470.2 W-h) to the total length of the FTP75 drive cycle (7.898km), we get the average energy consumption during the given drive cycle provided the 0 % grade throughout the cycle was found to be 59.53 W-hr/km.

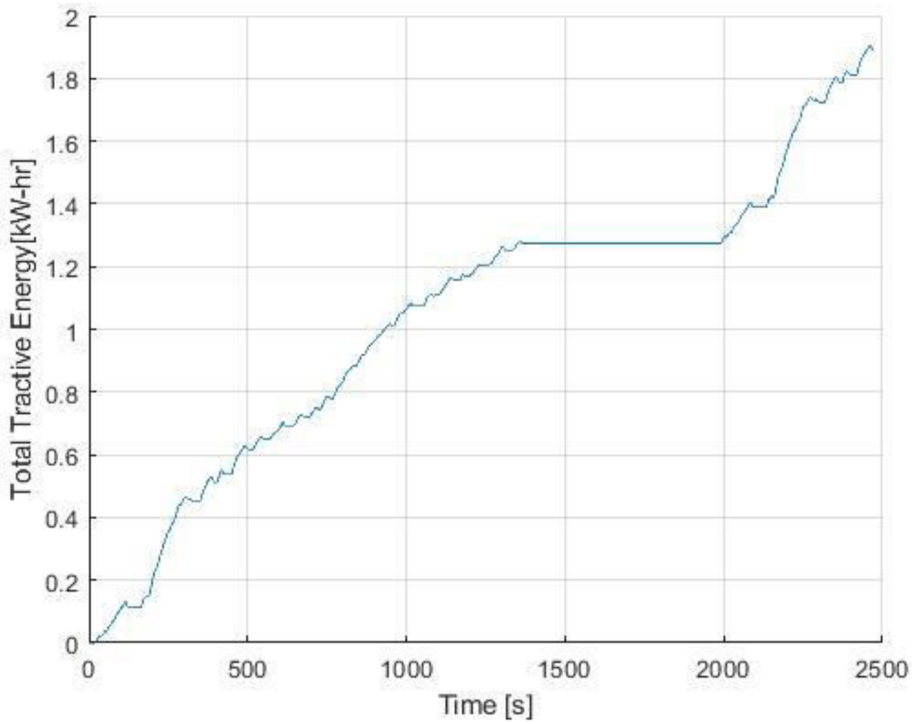


Figure Tractive Energy vs. Time Graph at 25% Grade

By integrating the total power over time (for the whole duration of the cycle), we get the total energy consumption (J). From the above graph, it is observed that the maximum tractive energy requirement in the given drive cycle is found to be 2.932 kW-hr.

By dividing the last calculated value of the total energy (2932W-h) to the total length of the FTP75 drive cycle (7.898km), we get the average energy consumption during the given drive cycle provided the 25% grade throughout the cycle was found to be 371.23 W-hr/km. This value will be used to calculate the total energy required for the high voltage battery.

3.1.Result

From the Simulink Simulation, it is found that the average energy consumed by the Electric ATV for the provide drive cycle is 59.35 Wh/km for 0 % grade condition and 371.23 Wh/km for uphill 25% grade condition.

3.2.Selection of motor and battery

The electric motor has the primary purpose of supplying mechanical torque to the drive wheels of the automobile. The secondary function of the motor is to generate electric energy through a generation mode by accepting mechanical torque from the drive wheels. There are different types of electrical motors that can be used for EVs and HEVs.

After the comparative study of properties of induction, permanent magnet synchronous motor and brushless DC motor, we used brushless DC motor for designing E-ATV selection of motor. Based on the calculation of Power and torque requirement, the selection of the motor is carried out. Since the minimum power requirement is found to be 10.563kW, the BLDC motor of rated power of 12kW is selected. The table below describes the electrical and mechanical parameter of the selected motor (Electric Motorsport, 2021).

Table Specification of Selected BLDC Motor

Parameters	Values
Rated Voltage	96V
Current	125 Amps (180 Amps DC into the motor control)
Peak Current	420 Amps for 1 minute (600 Amps DC into the motor control)
Rated Power	12kW
Peak Power	30kW
Speed	5000rpm
Rated Torque	80Nm
Peak Torque	160Nm
Efficiency	> 90%
Dimensions	30*30*25cm
Weight	16kg
Cooling	Open Frame

Similarly, we used lithium ion battery as compared to lead acid and nickel metal hydride due to following reasons as described below.

In most cases, lithium ion battery technology is superior to lead acid due to its reliability, efficiency and other attributes such as: -

- Capacity: We can store more energy within a lithium ion battery using the same physical space. So, we can discharge more energy and thus power appliances for longer periods of time which is required for EATV.
- Efficiency: Higher efficient batteries charge faster and similarly to the depth of discharge, improved efficiency means a higher effective battery capacity. Most lithium ion batteries are 95 percent efficient or more than lead acid battery whose efficiencies vary between 80 to 85 percent.
- Lifespan: Lithium ion batteries generally last for several times the number of cycles as lead acid batteries, leading to a longer effective lifespan for lithium ion products.

Table Comparison of EV batteries at "deep cycle" condition

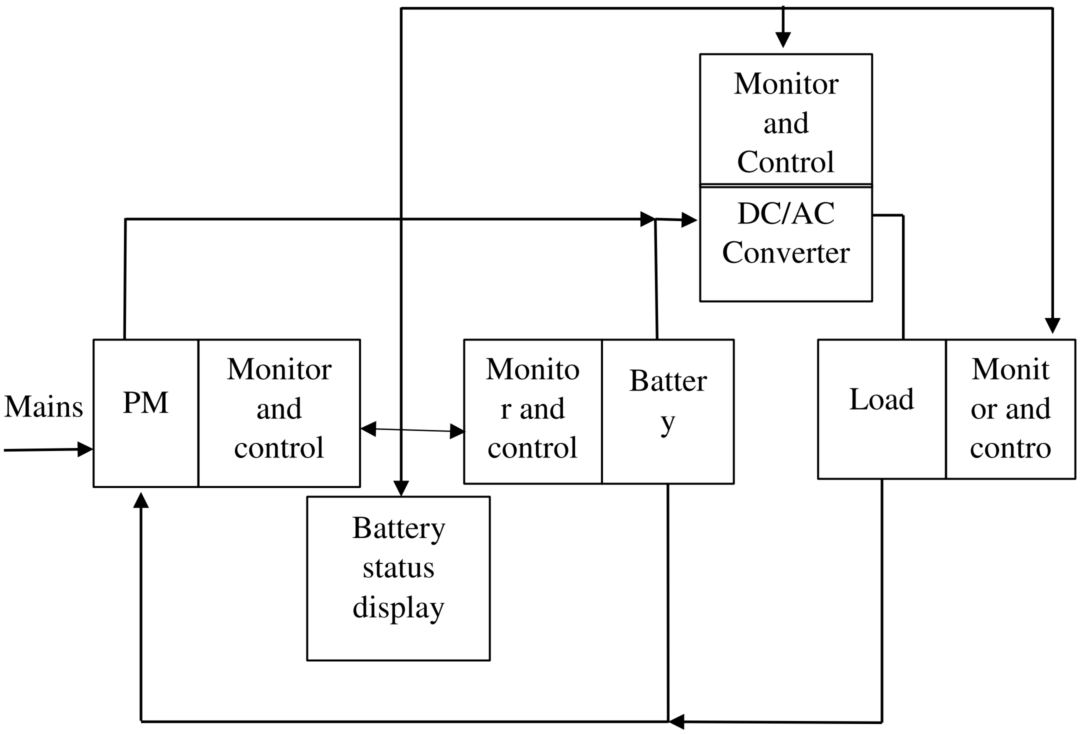
High Energy Design in Deep Cycle Applications(Units)	Lead Acid	Nickel Metal Hydride	Lithium-Ion
Energy density (W-hr/Kg)	35	70	>90
Power density (W/Kg)	150	200	600
Life time (number of cycles) At 80% depth of charge	125	3,000	2,500

3.3.Battery management system

3.3.1. Introduction

We are using lithium ion battery for our EATV. The lithium ion batteries can be used only in specified conditions. These batteries are large capacity and are rechargeable. The process of charging and discharging should be constantly monitored and controlled. So battery management system should be used to monitor battery state of charge and ensured safety of operations. BMS is an electronic system that manages the rechargeable batteries to ensure it operates safely and efficiently.

3.3.2. General BMS system



4. CONCLUSIONS

The main objective of our research project was to design, model and simulate power train of Electric All-Terrain Vehicle. Various parameter was considered and calculated for better performance of the Electric all-terrain vehicle.

The power requirement of the vehicle for the system was calculated. For the vehicle of 540kg mass, the overall tractive power requirement to run the EATV at average velocity of 25km/hr on 25% grade was found to be 10.57kW. The torque and rpm requirement of the motor was found to be 52.43Nm and 4130 rpm revolution. Assuming the range of the E-ATV to be 40km in once full charged and the average speed of the E-ATV is taken as 25 km/hr, the operating time of the vehicle can be calculated to be 1.6 hour. For the aforementioned condition, the battery energy capacity was required to be 24kW-hr analytically.

From the Simulink Simulation, it is found that the average energy consumed by the Electric ATV for the provide drive cycle is 59.35 Wh/km for 0 % grade condition and 371.23 Wh/km for uphill 25% grade condition.

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