

## ***Energy Storage and Management System in an Independent Hybrid Tractor***

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### ***Abstract***

*The modern farm tractor makes so many of the meals served in our country possible. So, although increasing productivity and reducing emissions will require the adoption of new methods, modern farming technology is more than ready to tackle the challenge.*

*Safer tractor operations and the use of protective equipment could prevent many of the deaths and injuries involving tractors. Owners, managers, and tractor operators all play a major role in making tractor operations safer. Owners have responsibilities for providing a safer environment and safer equipment. Managers coordinate maintenance designed to ensure the safety of equipment, as well as safety policies and programs. The final responsibility for making the operation of tractors safer lies with the tractor operators themselves. It's often only when an incident occurs that people become focused on what might have prevented injury or loss of life.*

*Making a tractor with good efficiency with optimum cost is a challenge. This can be done only when each component present in an independent hybrid tractor works reliably and these components must have long life. Design and selection of the components thus plays an important role. Our idea of independent-hybrid quarter scale tractor aims to cater the fuel efficiency norm as well as make an efficient system for the farmers to handle their various tasks. With the concept of Combustion engine running on gasoline along with*

*the electric motor as the secondary source, energy management becomes an integral part of the design.*

*In a parallel hybrid electric vehicle the single electric motor and the internal combustion engine are installed to deliver power in parallel to drive the wheels. As both the engine and electric motor are connected to the drive shaft through a mechanical coupling, they can propel the vehicle by the engine alone, by the motor alone, or by both together. The electric motor can be used as a generator to charge the energy storage devices (battery or ultra-capacitors) by regeneration braking or by extra power from the engine.*

*As the engine is connected to the wheels via mechanical coupling, it makes this type hybrid quite efficient on the highway. In addition, a parallel hybrid vehicle only needs two propulsion devices – engine and electric motor, which makes the system very compact.*

**Keywords:** *Hybrid electric vehicle (HEV), Independent Hybrid Tractor, Internal combustion engine (ICE)*

## INTRODUCTION

A hybrid electric vehicle (HEV) is a type of mechanical vehicle and electric vehicle that combines a conventional internal combustion engine (ICE) system with an electric propulsion system (hybrid vehicle drive train). The presence of the electric power train is intended to achieve either better fuel economy than a conventional vehicle or better performance. There is a variety of HEV types, and the degree to which each functions as an electric vehicle (EV) also varies. The most common form of HEV is the hybrid electric car, although

hybrid electric trucks (pickups and tractors) and buses also exist.

Modern HEVs make use of efficiency improving technologies such as regenerative brakes which convert the vehicle's kinetic energy to electric energy to charge the battery. Some varieties of HEV use their internal combustion engine to generate electricity by spinning an electrical generator to either recharge their batteries or to directly power the electric drive motors; this combination is known as a motor-generator. A hybrid-electric

produces less emissions from its ICE than a comparably sized gasoline car, since an HEV's gasoline engine is usually smaller than a comparably sized, pure gasoline-burning, vehicle and if not used to directly drive the car, can be geared to run at maximum efficiency, further improving fuel economy. (Natural gas and propane fuels produce fewer emissions.)

Hybrid vehicle drive trains transmit power to the driving wheels for hybrid vehicles. A hybrid vehicle has multiple forms of motive power. Hybrids come in many configurations. For example, a hybrid may receive its energy by burning petroleum, but switch between an electric motor and a combustion engine.

Electrical vehicles have a long history combining internal combustion and electrical transmission –as in a diesel-electric power train–, although they have mostly been used for rail locomotives. A diesel-electric power train fails the definition of hybrid because the electrical drive transmission directly replaces the mechanical transmission rather than being a supplementary source of motive power. One of the earliest forms of hybrid land vehicle is the 'trackless' trolleybus of the 1930s, which normally used traction current delivered by wire. The trolleybus

was commonly fitted with an internal combustion engine (ICE) either to directly power the bus or to independently generate electricity. This enabled the vehicle to manoeuvre around obstacles and broken overhead transmission wires. The power train includes all of the components used to transform stored potential energy. Power trains may either use chemical, solar, nuclear or kinetic or make them useful for propulsion. The oldest example is the galley that used sails and oars. A common modern example is the electric bicycle. Hybrid electric vehicles combine a battery supplemented by an ICE that can recharge the batteries or power the vehicle.

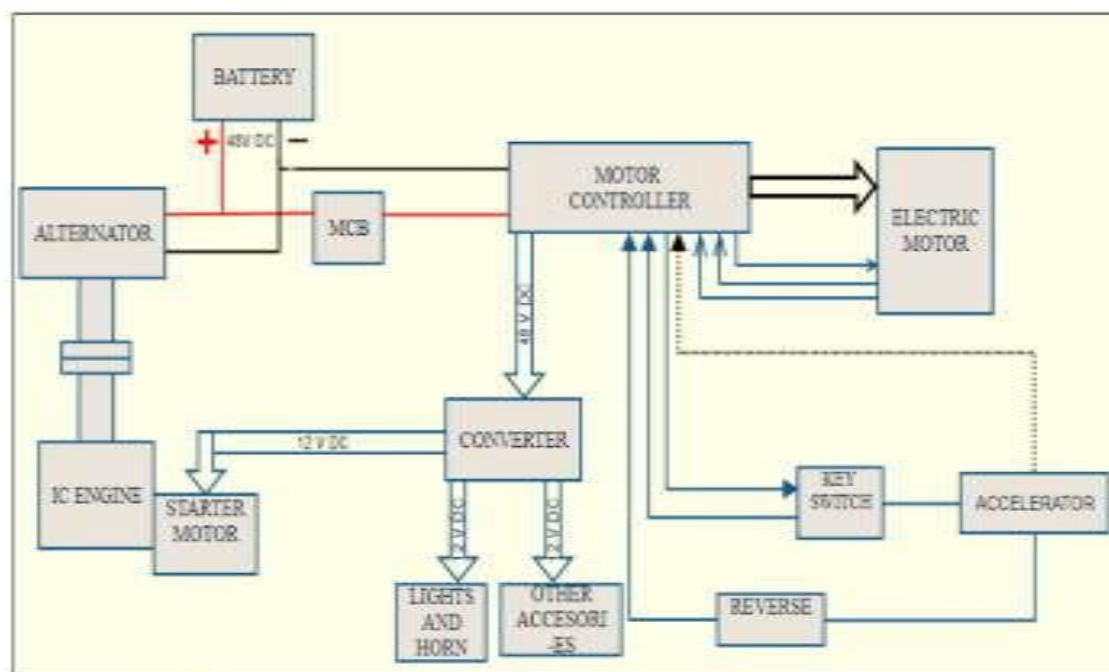
#### ***Independent Hybrid Tractor***

Among the different types of hybrid vehicles, only the electric/ICE type was commercially available as of 2016. One variety operated in parallel to simultaneously provide power from both motors. Another operated in series with one source exclusively providing the power and the second providing electricity. Either source may provide the primary motive force, with the other augmenting the primary. Other combinations offer efficiency gains from superior energy management and regeneration that are offset by expense, complexity and the battery limitations.

Combustion-electric (CE) hybrids have battery packs with far larger capacity than a combustion-only vehicle. A combustion-electric hybrid has batteries that are light that offer higher energy density that are far more costly. ICEs require only a battery large enough to operate the electrical system and ignite the engine. **See Figure: 1**

Regardless of the type of hybrid vehicle system, the propulsion system mainly comprises the following components: prime mover; electric motor with DC/DC converter, DC/AC inverter, and controller;

energy storage system; and transmission system. The prime mover of a hybrid vehicle is its main energy source, which generally is one of gasoline, diesel, or fuel cells. The electric motor is one of the most important components in a hybrid vehicle. The energy storage system, one of the most important subsystems in a hybrid electric vehicle (HEV), consists of an energy storage pack; a voltage, current, and temperature measurement (VITM) module; a cell balancing circuit; and a cooling system. In addition, battery-related estimation algorithms play key roles.

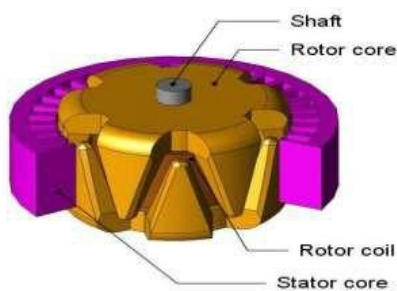


**Fig: 1 Block diagram of electrical system**

**WORKING, DESIGN AND SELECTION OF COMPONENTS**

**1] Claw Pole Alternator**

A claw pole alternator generates electricity in the coil on the stator side with the rotor side acting as an electromagnet. The excitation coil on the rotor side is a single phase, and the claw pole is arranged so that it wraps around this coil. The claws that extend from the inside of the coil and the ones that extend from the outside of the coil have poles with different polar characteristics, and they have the same polar structure as a magnet that is arranged with magnetization that alternates between North and South. Because the alternator needs to be designed with a 3D geometry to account for the claw poles and the analysis needs to consider eddy currents generated in the surface of the claw poles, which are made from a metal plate, an electromagnetic field analysis using the finite element method would be the most useful, as it can simulate detailed geometries and account for eddy currents.[1]



**Fig. 2: D model of rotor and stator of claw pole alternator**

**2] Battery**

**(A) Construction and Working of Lead Acid Battery**

The grid structure of the lead acid battery is made from a lead alloy. Pure lead is too soft and would not support itself, so small quantities of other metals are added to get the mechanical strength and improve electrical properties. The most common additives are antimony, calcium, tin and selenium. These batteries are often known as -lead-antimony|| and -lead calcium.|| Adding antimony and tin improves deep cycling but this increases water consumption and escalates the need to equalize. Calcium reduces self-discharge, but the positive lead-calcium plate has the side effect of growing due to grid oxidation when being over-charged. Modern lead acid batteries also make use of doping agents such as selenium, cadmium, tin and arsenic to lower the antimony and calcium content.[2]

**Table 1: Cycle performance of starter and Deep-cycle batteries**

Depth of Discharge	Starter battery	Deep-Cycle battery
100%	12-15 cycles	150-200 cycles
50%	100-120 cycles	400-500 cycles
30%	130-150 cycles	1,000 and more cycles

A discharge of 100% refers to a full discharge; 50% is half and 30% is a moderate discharge with 70% remaining.

**(B) Lithium Ion Battery**

Li-ion is a low-maintenance battery, an advantage that most other chemistries cannot claim. The battery has no memory and does not need exercising (deliberate full discharge) to keep it in good shape. Self-discharge is less than half that of nickel-based systems and this helps the fuel gauge applications. The nominal cell voltage of 3.60V can directly power mobile phones, tablets and digital cameras, offering simplifications and cost

reductions over multicell designs. The drawbacks are the need for protection circuits to prevent abuse, as well as high price.[4]

**3] Battery Design and Selection**

**1. Voltage Rating:-** The selected voltage rating of the battery is 48 volt. Because the rated voltage of the controller is 48 volts

**2. Ah Rating:-** To find the Ah rating of the battery use the following formula-  
 $(Kwh) / (Wh/m) = \text{Distance in miles.}$   
 where  
 Kwh is the Kilo watt hour rating of the battery.

**Table 2: Shows the comparison of lithium ion and lead acid battery**

	Flooded lead acid	VRLA lead acid	Lithium-ion (LINC)
Energy Density (Wh/L)	80	100	250
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Initial Cost (\$/kWh)	65	120	600 <sup>1</sup>
Cycle Life	1,200 @ 50%	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	50%	80%
Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	2 V	3.7 V

Wh/m is the watt hour per mile rating.

**Distance is the range which the battery can give in one charge.**

In the above formula, assume the desired range for our applications, and then find wh/m of the vehicle and find Kwh rating of the battery. Then find Ah using :- Ah = (Kwh) / Voltage rating of the battery.

Distance to be covered=15km

1 mile= 1.60934 km

15km= 9.32059 mile

Hence, get 9.32059 miles/charge

For an hour=  $30/1.60934= 18.64118$  miles/hour

**Wh/mile usage** =  $(V*I)/ \text{range} = (48*150)/18.64118 = 386.24164$  wh/mile

**To find Ah/mile**

Volts \* (amp drawn/MPH) = wh/m

Ah/mile = wh/mile/volts =  $386.24164/48 =$

8.0467 ah/mile

For 15 km range, i.e., 9.32059 mile,

$8.0467*9.32059=75\text{Ah}$  is obtained

C-rate

Continuous safe discharge current=50A

80Ah at 0.6 C = 6 A

(Ah\*c-rate= discharge current the discharge current=6A

For a 80ah battery, c-rate=  $50/75= 0.6$ )

Hence battery pack required= 12V, 80ah , 3840W

Distance to be covered=15km

1 mile= 1.60934 km

15km= 9.32059 mile

Hence, 9.32059 miles/charge is obtained for an hour =  $30/1.60934= 18.64118$  miles/hour

**Wh/mile usage** =  $(V*I)/ \text{range} = (48*150)/18.64118 = 386.24164$  wh/mile

**Table 3: Final Design Values**

SL NO	PARAMETERS	RATING
1	Voltage rating	48 V
2	Ah rating (capacity)	75 Ah
3	Maximum Discharge current (C rate)	150A (2C Discharge)
4	Max Charging current (C rate)	50A(0.6C Discharge)
5	Max discharge current time in secs	Yet to design
6	SOC usage window	Yet to design
7	Operation thermal Ambient range	Yet to design

#### **4] Battery Management System**

A BMS may monitor the state of battery as represented by various items such as:

- 1) Voltage: total voltage, voltages of individual cells, minimum and maximum cell Voltage or voltage of periodic taps.(When the battery chargers are charging the cells, some get overcharged and some undercharged which might destroy the cells. To prevent it from getting overcharged or undercharged BMS can be used.)
- 2) Temperature: average temperature, coolant intake temperature, coolant output temperature, temperature of individual cells.
- 3) State of charge (SOC) or depth of discharge (DOD), to indicate charge level of the battery.
- 4) State of health (SOH), a variously-defined measurement of the overall condition of the battery.
- 5) Coolant flow: for air or fluid cooled batteries.
- 6) Current: current in or out of the battery.

7) Additionally, a BMS may calculate values based on above items such as:

1. Maximum charge current as a charge current limit (ccl)
2. Maximum discharge current as a discharge current limit (DCL).
3. Energy (kWh) delivered since last charge or charge cycle.
4. Internal impedance of a cell (to determine open circuit voltage)
5. Charge (ah) delivered or stored
6. Total energy delivered since first use.
7. Total operating time since first use
8. Total number of cycles

#### **SIMULATION**

When we use MATLAB and SIMULINK together, we combine textual and graphical programming to design your system in a simulation environment.

#### **LEAD ACID BATTERY**

Figure 3 shows the simulating model of lead acid battery. In this simulation,

initially the battery is discharged at a constant current of 10A. The battery is then recharged at a constant 10A to its initial state of charge. A simple thermal model is used to monitor the battery temperature. It

is assumed that the cooling is via convection, and the heating is primarily by battery internal resistance. A standard 12V battery can be modelled by connecting 6 cells of 2V each in series.

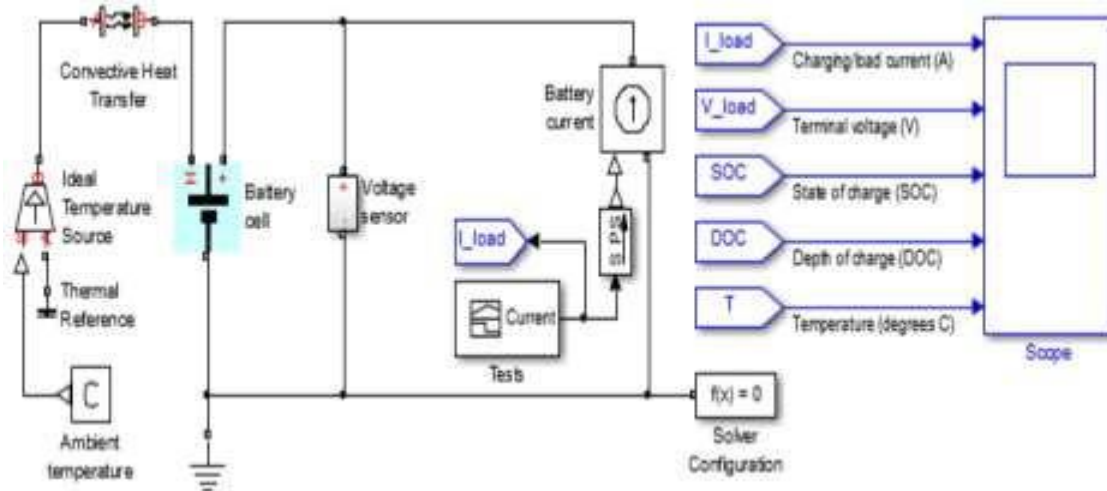


Fig. 3: Lead acid battery

### Battery Cell

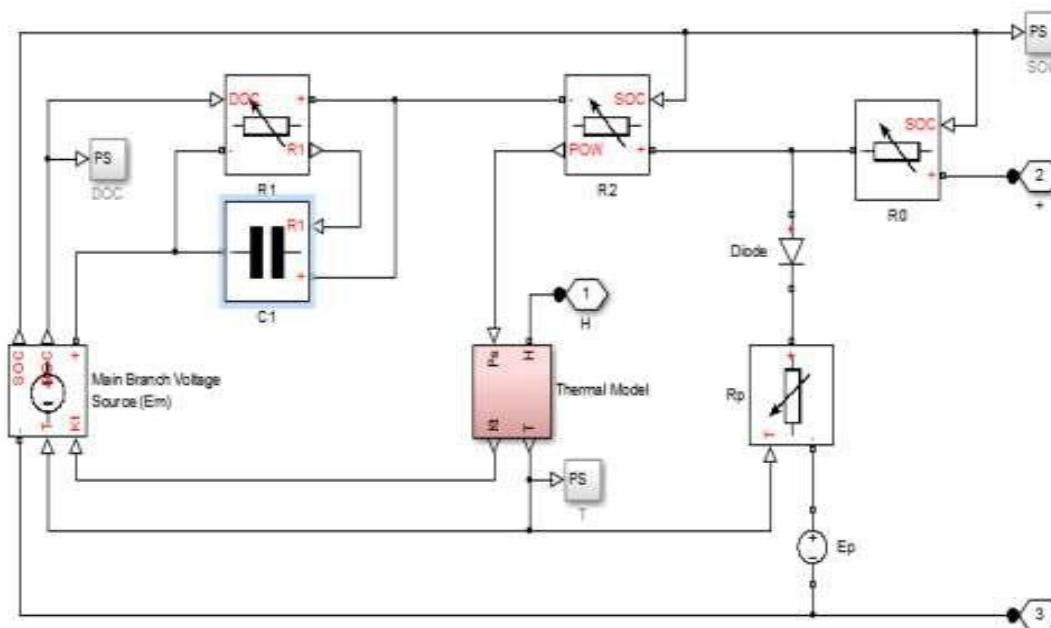
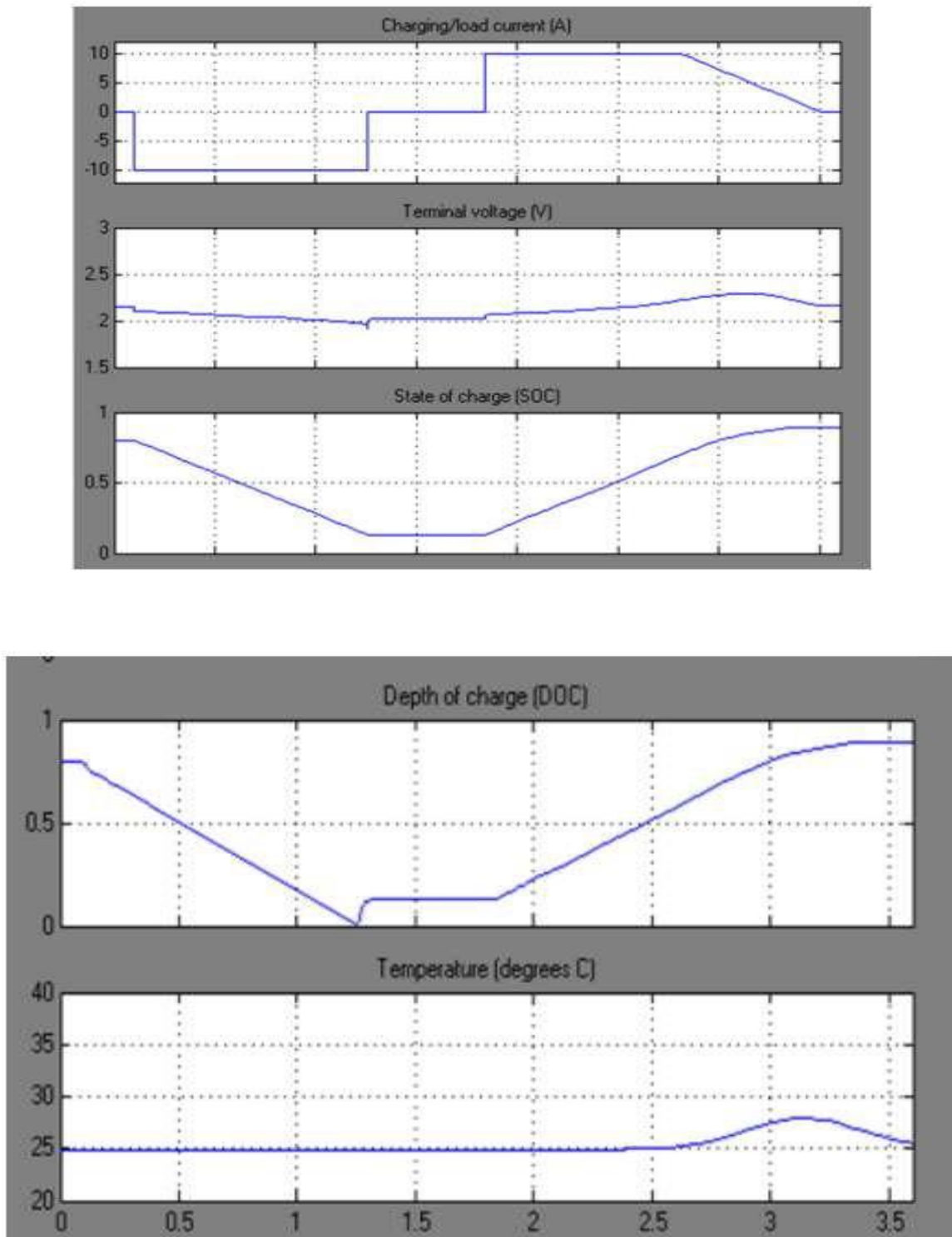


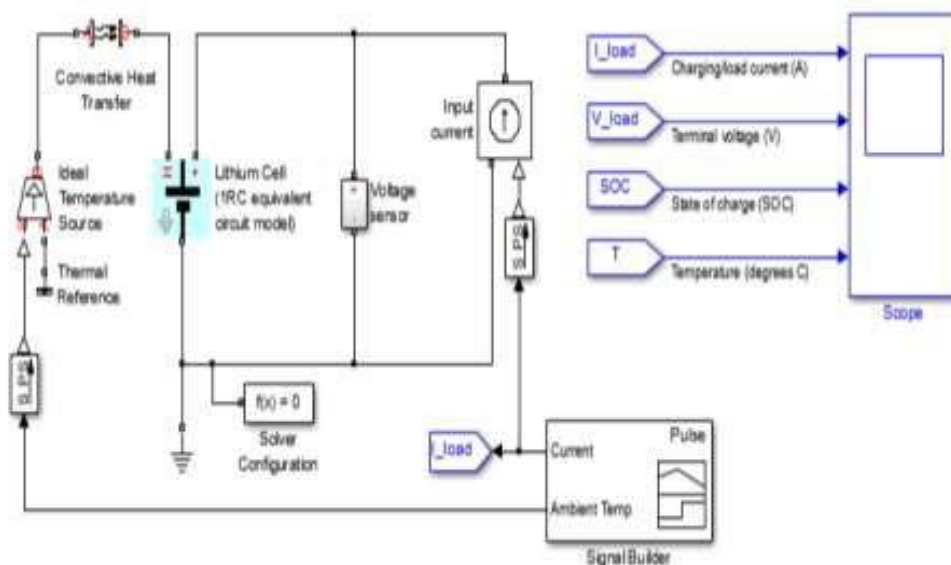
Fig. 4: Battery Cell

The variation of charging current, terminal voltage, State of charge, depth of charge and temperature with respect to time is observed as shown in the figure 5

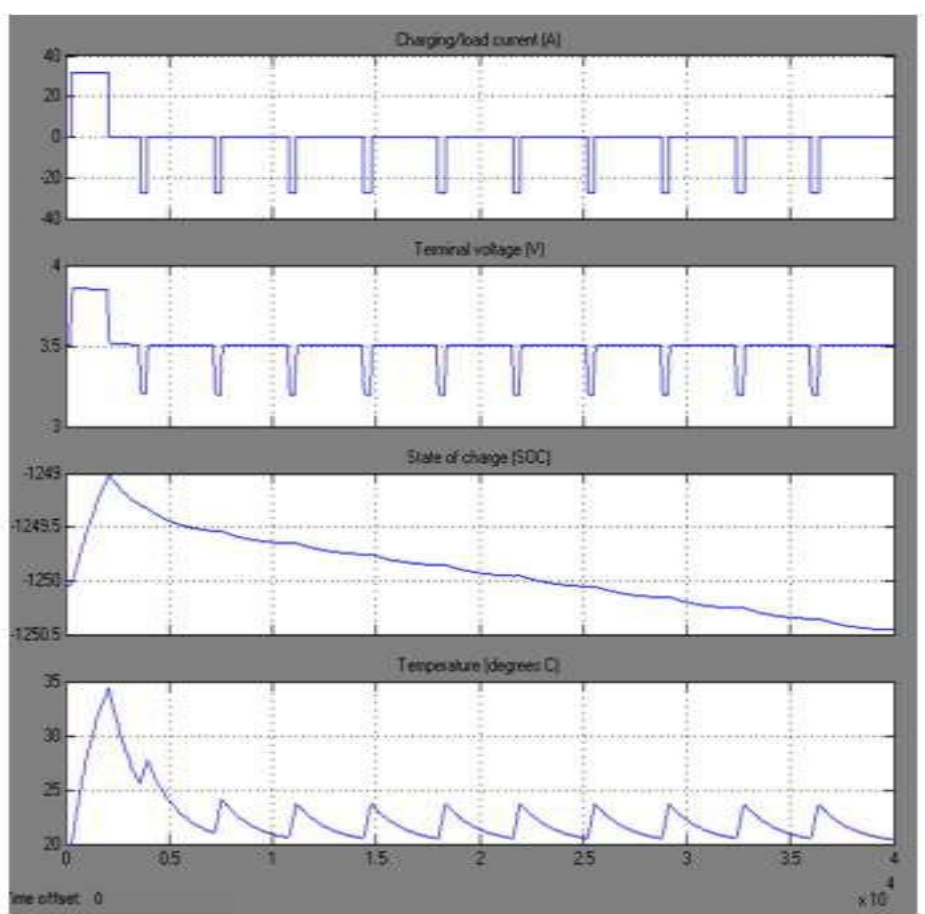


**Fig. 5: Simulation results of lead acid battery**

**LITHIUM ION BATTERY**



*Fig. 6: (a) Lithium battery cell-one RC branch equivalent circuit*



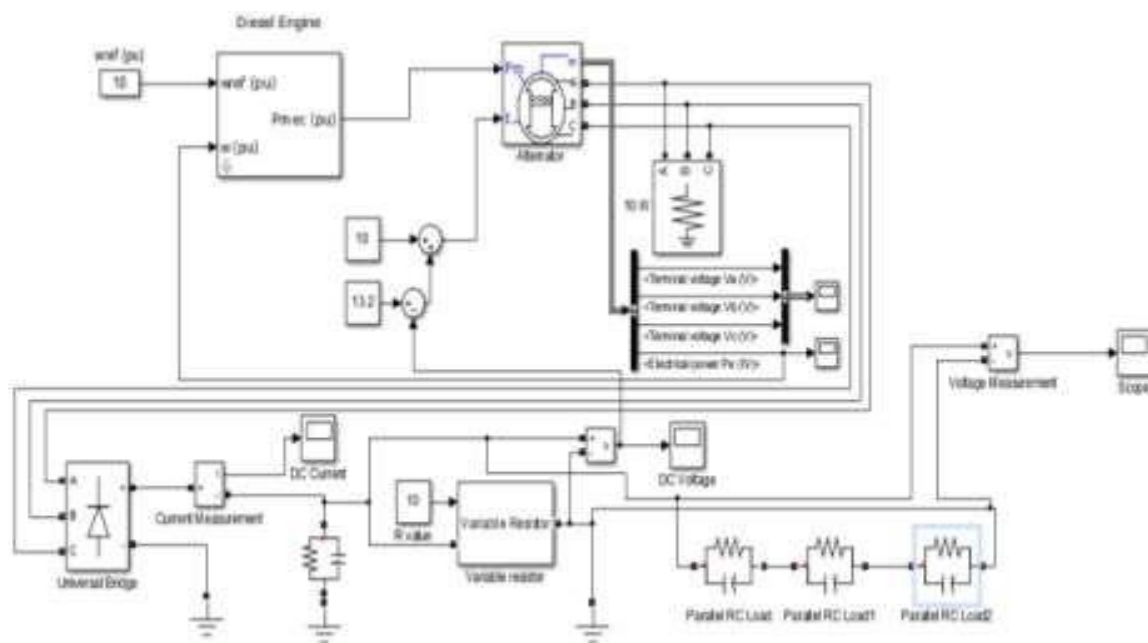
*Fig. 7: Simulation results of lithium ion battery*

The graphs show the variation of charging current, terminal voltage, SOC and temperature with respect to time.

### TRACTOR ELECTRICAL SYSTEM

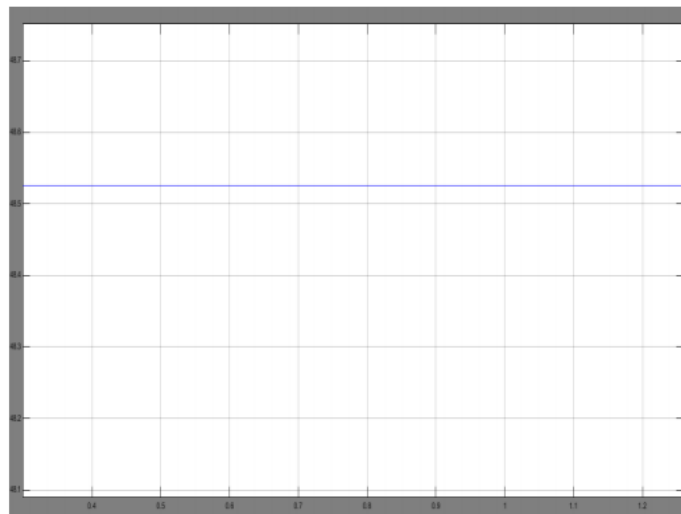
Figure 8 shows the simulation model of tractor electrical system. This model consists of a diesel engine governor which acts as a prime mover of the synchronous generator or the alternator. The alternator converts the mechanical energy into electrical energy. This electrical energy is

three phase voltage. The alternator is present to charge the battery; therefore the battery here acts as a load. The voltage required to charge the battery must be in the form of direct voltage. In order to convert the 3 phase voltage to single phase, we make use of a bridge rectifier. The rectified voltage is fed to the battery. As the battery acts as a load here, we consider equivalent R-C network of the battery.



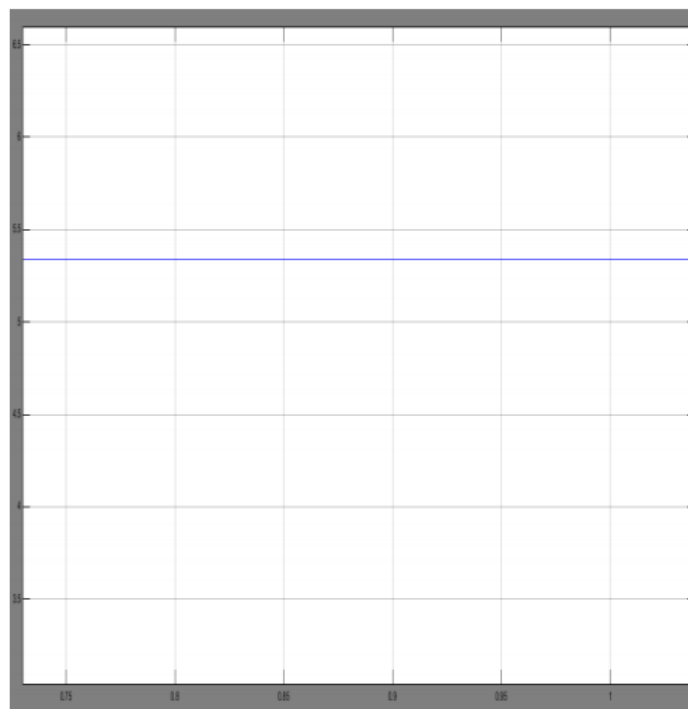
**Fig. 8: Simulation model of tractor electrical System**

The direct voltage at the input of the battery is shown in figure 9(a) with a peak voltage of 12.8V.



*Fig. 9 (a) direct voltage at the battery terminal*

The current at the rectifier is seen in the graph below in fig 9(b).



*Fig. 9 (b) rectifier output*

## CONCLUSION

The novel Independent hybrid configuration's electric propulsion system was designed for a mini tractor. The

design considerations and steps to calculate battery rating such as, maximum and continuous discharge current, ampere hour, power and voltage ratings is also

shown. Also, suitable battery management system was selected for the proposed requirements. Results shown in chapter 3 clearly show the following:

1. Lithium ion battery is proved to be better than the lead acid battery.
2. Battery management system monitors the voltage and the temperature of individual cells and prolongs the life of the battery.
3. Independent hybrid configuration proves to be much more fuel efficient and environmental than other types of hybrid configuration. Economics and environmental impact associated with the use of Hybrid and Electric vehicles mainly substantially on the source of electricity. As the source of power for the electric motor in hybrid configuration is from on board generation of electrical power, it is also more advantageous.

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