FDU-RU4474

Dual-Drive Production Prototype Project

FINAL REPORT
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Submitted by

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16. Abstract

This project was an initiative to engineer, develop and build a plug-in hybrid-electric vehicle using the Dual-Drive system. The project aimed to build a plug-in hybrid utilitarian vehicle on a light commercial vehicle platform. The hybrid vehicle will have a range of 35-40 miles and will have the ability to switch between pure electric drive and pure gasoline drive. The vehicle's electric drivetrain will enable the vehicle to run efficiently at very low speed conditions and will also give the user the flexibility to switch to pure gasoline driving and thus drive at highway speeds.

17. Key Words	18. Distribution Statement
Hybrid, dual-drive, fuel efficiency, plug-in, alternate fuels	.

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Project Objectives:

- To design and engineer a pre-production vehicle platform using the dual-drive conversion system
- To demonstrate the viability of using an electric drivetrain in low-speed applications
- To design and engineer a simple, reliable and effective conversion system for converting a light commercial vehicle to run as a plug-in hybrid
- To engineer and build a conversion system that does not affect passenger safety or vehicle utility
- To ensure that the converted vehicle does not exceed the vehicle platform's stipulated Gross Vehicle Weight Rating (GVWR)
- To ensure that the converted vehicle maintains its original handling and performance characteristics to a large extent

Basic Overview of the Dual-Drive System

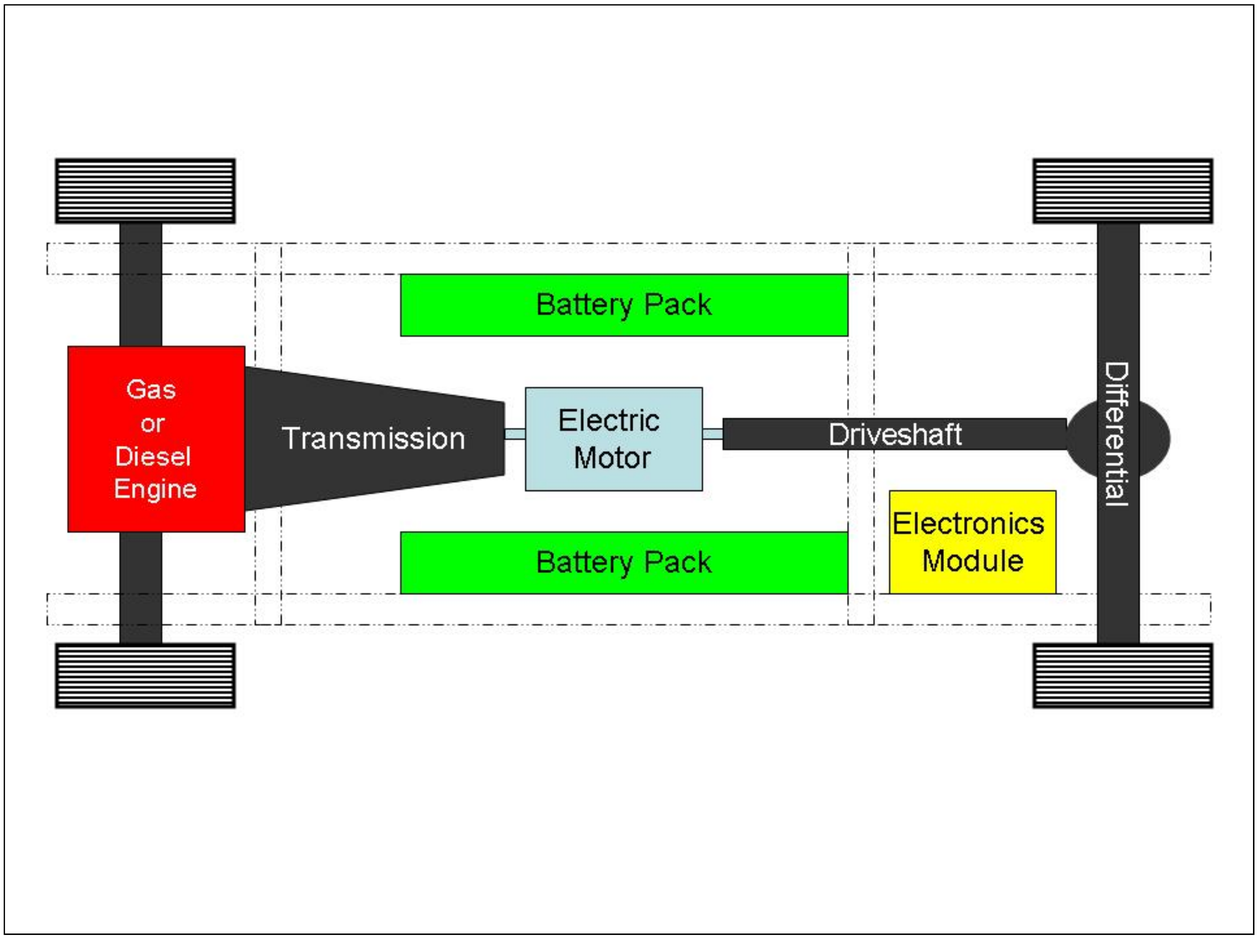
The project began in July 2007 as an initiative to develop fuel-efficient vehicle retrofits, using as much off-the-shelf technology as possible, thereby reducing the developmental engineering costs. Several alternative fuel options were considered and a thorough analysis yielded that the best way to move forward would be the use of an electric-gasoline combination to power the vehicle.

In mid-August 2007, the basic engineering work on a plug-in electric vehicle was initiated and completed by the end of December 2007. The aim was to create a plug-in electric vehicle with a range of 30-40 miles. Actual fabrication and installation of the kit on a 94 Chrysler Voyager began in January 2008 and was completed by May 2008. Rigorous field tests were conducted to ensure reliability and the vehicle has been put through over 200 cycles of testing.

The reliability of the components used in the plug-in conversion enabled us to begin furthur engineering work to ascertain the appropriate type of gasoline-electric interface and interface methodology. Several alternatives including serial hybrids were considered but the most promising technology that seemed to emerge from the analysis was the Dual-Drive system.

A few unique features of the Dual-Drive system are as follows:

- Allows the two sources of propulsion to operate independently
- Allows the gasoline engine to operate vital ancillary systems such as power steering etc., while the vehicle is being propelled by the electric motor
- Provides an on-demand 30-40 miles of all-electric range that helps increase the fuel-efficiency of vehicles in slow-speed conditions by upto 300%
- Significantly reduces carbon emissions of the vehicle in slow-speed conditions
- Does not alter the vehicle's safety or emission characteristics
- Offers owners of existing vehicles the opportunity to retrofit their vehicles without incurring the substantial cost of replacing the entire vehicle to improve fuel economy



Basic Layout of the Dual-Drive System

Vehicle Platform Selection:

In order to ensure a successful conversion to the dual-drive system, the selection of an adequate vehicle platform was critical. Two basic vehicles were selected based on their utilitarian capabilities and also due to their high sales volumes in the North American market. These vehicles were then critically analyzed to ensure that they met the requirements for a convertible vehicle. The method of analysis is given below:

Requisite Characteristics	**Vehicle Platform**	
	Ford E-150 Series Passenger Van (5.4L V8)	**Ford F-150 Series Pickup Truck (5.4L V8)**
Frame on body construction (ladder chassis not unit-body)		
High Gross Vehicle Weight Rating (GVWR)	 (GVWR = 8500lbs)	 (GVWR = 8500lbs)
Available Space Under Frame Rails	 The E-150 has much more free space under the chassis due to the absence of an extra cab and bed. Will allow for better packaging of the system.	The F-150 has less space under the chassis but has much better ground clearance for the installation of larger motors and battery packs.
Current EPA Fuel Economy Ratings (City/Highway)	14/18 MPG	14/19 MPG
Impact of Reduction of Greenhouse Gases Due to Increased Efficiency	 High: Due to the capacity of the van to carry upto 10 passengers and thus displace the greenhouse gas emissions involved in transporting those persons	Moderate: The greenhouse gas reductions achieved by converting such a vehicle would be significant. However, due to its ability to only carry cargo and lesser numbers of passengers, the vehicle's converted impact would be far lower than that of the E-150
	  Chosen due to the higher amount of space beneath the chassis and the net. impact of greenhouse gas reduction	

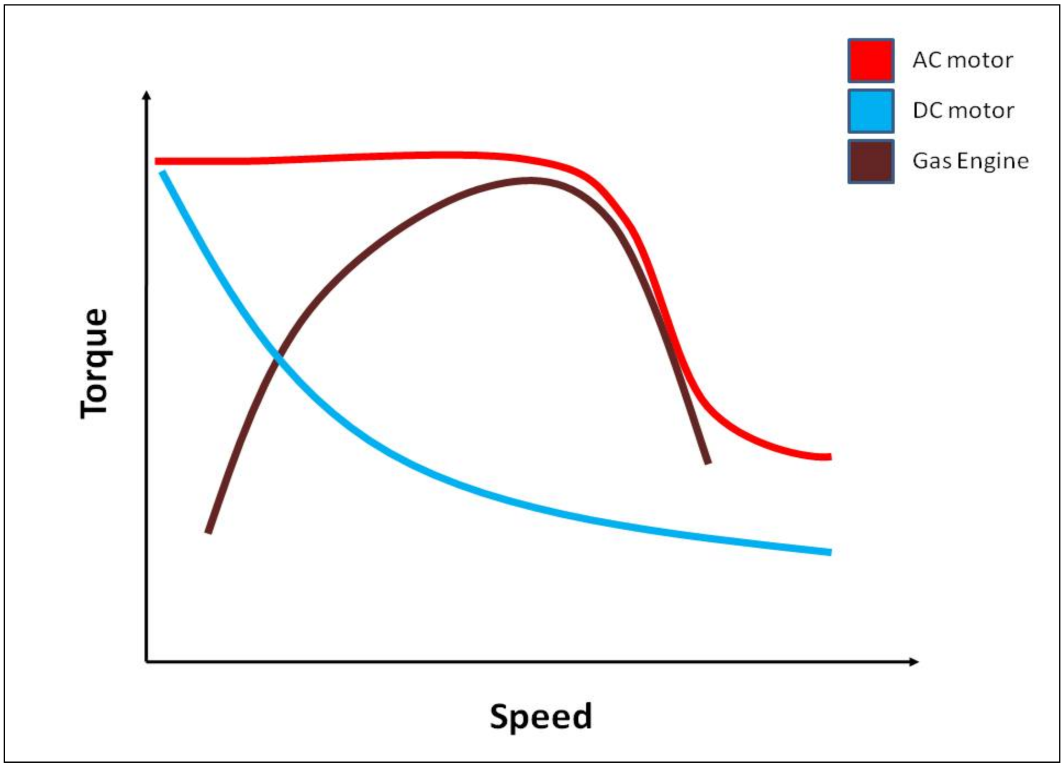
An early photograph of the 2007 E-150 Van on the four-post lift

Motor Drive Selection:

In our last attempt at equipping a vehicle with an electric drive system, we encountered a few major problems with the drivetrain:

- Low torque output at the higher spectrum of possible speeds
- High current draw when climbing slopes due to very low torque output at higher speeds
- Controller overheating due to the high current draw at higher speeds

In order to solve these technical issues, we had to re-examine the basic torque-speed characteristics of AC and DC (our previous motor type) motors and then compare their torque curves to the torque curve of the gasoline engine to ensure that the characteristics of the electric drivetrain closely matched the characteristics of the gasoline engine:



Generic Torque-Speed Curves for Various Drivetrains

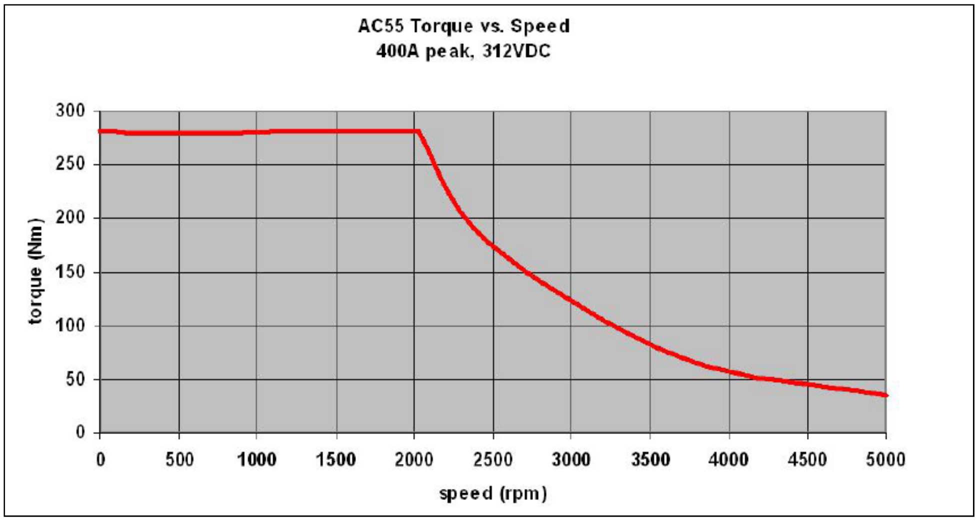
Such a direct comparison of the three drivetrains demonstrated that all three of our previous problems emanated from the inherent characteristics of the DC motor. The DC motor had a very high torque output at low speeds but had significantly lower torque output in the speed band where the gasoline engine puts out its peak torque. However the AC system closely matched the torque output of the gasoline engine at higher speeds and maintained the ability to put out a very high amount of torque at very low speeds. Thus, we decided to use an AC motor-controller combination to power the electric drive system of the vehicle.

An AC 55 motor-controller combination manufactured by Azure Dynamics was purchased, as it was rated to handle vehicles with Gross Vehicle Weight Ratings (GVWR) similar to the one we selected. The system also ran at significantly higher voltages which ensured lower current draw when climbing steep grades and also prevented premature controller over-heating. The controller unit was also forced air-cooled and thus operated much more reliably than our previous DC controller which was naturally air cooled.

Peak Torque	Nm	280
Continuous Torque* at Nominal Speed	Nm	140
Nominal Speed	Rpm	2000
Maximum Mechanical Speed	Rpm	8000
Maximum Current	A rms	250
Continuous Shaft Power* at 1500-2500 rpm	kW	25
At a voltage of	VDC	312
Peak Efficiency	%	87
Peak Shaft Power	kW	59
At a voltage of	VDC	312
Weight AC55	kg	106
Weight DMOC445	kg	14.7
Diameter AC55	mm	343
Length AC55	mm	447
Length DMOC445	mm	450
Width DMOC445	mm	228
Height DMOC445 (with fan)	mm	238
Minimum Recommended Nominal Battery Voltage	VDC	312
Maximum Nominal Battery Voltage	VDC	336
Minimum Operational Voltage	VDC	100
Maximum Operational Voltage	VDC	400
Maximum Voltage "On Charge"	VDC	450
Minimum/Maximum Operating Temperatures	˚C	-40 to 60

*At 25˚C

AC 55 Motor and DMOC 445 Controller Specifications (Courtesy Azure Dynamics, Inc.)



Torque-Speed Characteristics of the AC 55 Motor (Courtesy Azure Dynamics, Inc)

Battery Selection:

We also faced some serious problems with our previous battery pack. The technical problems were as follows:

- Maintenance of the battery was required frequently
- The battery's capacity reduced significantly with each charge- discharge cycle
- The batteries in the pack would leak and spill corrosive electrolyte in the event of collision or impact
- The batteries lost 30- 40% of capacity in temperatures below 0 degrees Celsius
- The batteries sulphated frequently if left uncharged for over 30 days
- The batteries lost almost 50% of their rated amp hour capacity due to high current draw at lower voltages

As a result of the technical problems we faced with our last iteration of the technology, we decided to set some basic requirements for the selection of the battery type and the arrangement and construction of the battery pack. The requirements were as follows:

- A solid cell battery to ensure that the electrolyte does not spill in the event of impact or collision
- A high cycle life even in deep-discharge usage conditions (approximately 400-600 cycles)
- A sealed cell to eliminate battery maintenance
- A broad range of operating temperatures to ensure suitability to the climatic conditions of the North-East
- Very low self-discharge and the absence of any sulphation when stored and not charged
- A high pack voltage to ensure lower current draw and thus increase the usable capacity of each cell in the battery bank

Several lead-acid battery packs were examined and an Odyssey PCL 925 was selected to handle our requirements. A pack voltage of 300V formed through connecting 25 PCL 925 batteries in series was constructed. The specifications of the PCL 925 are as follows:

- 925 cranking amps for 5 seconds
- 870 cranking amps for 10 seconds
- 765 cranking amps for 20 seconds
- Short circuit current of over 2400A
- 28 amp hours
- 50 minute reserve capacity with 25amp load
- Length: 6 15/32"
- Width: 6 7/8"
- Height: 4 7/8"
- Weight: 24 lbs
- Rugged dry-cell sealed design
- Military grade
- Deep discharge reserve power
- 2 year storage life
- 8-12 year design life

Charger Selection:

There are two main ways of charging a large battery bank:

1. Charging the entire battery bank in series at a high voltage
2. Charging each individual battery using separate chargers

From our prior experience with building electric vehicles, we have found that charging each battery separately using specialized individual chargers helps lengthen battery life and detect faults that might arise with individual batteries in the pack. However, this method increases the complexity of installation and increases the chances of charger failure. In our previous electric vehicle, we were able to isolate some major causes of charger failure:

- Vibration: electronic components and switches were often dislodged due to heavy vibration levels
- Corroded terminals: corroded terminals caused the charger to display incorrect results or stop working
- Unreliable charger processor algorithms

As with the batteries, we outlined certain specifications that the selected charger would have to meet:

1. The ability to charge 12V Absorbed Glass Mat (AGM) deep-cycle batteries
2. Fully Automatic
3. Sealed and waterproof
4. The ability to display state of charge and battery faults
5. The ability to use a smart-charging algorithm to determine current input into the battery
6. Plated terminals to avoid terminal corrosion
7. Vibration resistant and well-packaged

Several charger options were examined and the search was narrowed down to marine dual-bank chargers. The Dual-Pro Marine RS2 Dual-Bank charger was selected, since it met almost every specification that was stipulated. The specifications of the RS2 charger are as follows:

- Universal AC Input: 115VAC; 60 HZ
- Total Output: 12 Amps
- Amps Per Bank: 6
- Size: 3"(H) X 7.25"(L) X 6.25"(W)
- Battery System: 12 Volt, 24 Volt
- Fully Waterproof
- Independent Outputs
- Fully Automatic / Complete Shut-Off
- Overcharge Protection
- True Reverse Polarity Protection
- Return to Charge Maintenance Mode
- Over Current Protection
- Temperature Compensated Charging Technique
- Short Circuit Protection
- LED Readouts of state of charge and battery faults
- Meets FCC 15 Parts A & B
- Advanced Microprocessors
- CE Approved "ISO 8846-Marine"
- Ignition Protected (US Coast Guard 33 CFR183-410)
- AGC 30 amp fuse

Since the nominal pack voltage is 300V, a total of 13 dual-bank chargers were purchased.

High-Power Cabling Selection:

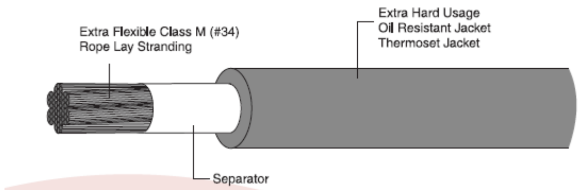
The high power cabling used to connect the electric vehicle drivetrain components to the battery pack are an essential part of ensuring the reliability of the vehicle. Our previous experience with high power cable has enabled us to define the basic requirements of such wiring cable. The basic requirements are as follows:

1. Flexible cabling to ensure tight bends when wired under the chassis
2. Stranded copper core to ensure flexibility
3. Water, heat and oil-resistant jacket to ensure cable longevity under harsh conditions
4. Adequate current and voltage capacity

Most high power cables are rated to 600V and since our maximum system voltage is approximately 325V (due to the variable nature of the voltage of lead-acid cells), the maximum current capacity of the cable decided cable size. The high-power cable needs to have the capacity to handle about 1.25 times the peak current through the system. The maximum current of the system is 250A at 312V, as stipulated by the motor manufacturer. Thus the required current capacity of the cable should exceed 312A. Using standard American Wire Gauge (AWG) tables, we were able to ascertain that the lightest cable capable of handling over 312 A is AWG size 3/0. AWG size 3/0 can handle up to 328A at 600V and is manufactured in several stranding types and jacket specifications. We selected a stranded welding cable with an oil-resistant jacket. The cable lengths were cut to the sizes required and the lugs crimped with fully insulated heat-shrink jackets.

AWG gauge	Conductor Diameter Inches	Conductor Diameter mm	Ohms per 1000 ft.	Ohms per km	Maximum amps for chassis wiring
OOOO	0.46	11.684	0.049	0.16072	380
OOO	0.4096	10.40384	0.0618	0.202704	328
OO	0.3648	9.26592	0.0779	0.255512	283
0	0.3249	8.25246	0.0983	0.322424	245
1	0.2893	7.34822	0.1239	0.406392	211
2	0.2576	6.54304	0.1563	0.512664	181

American Wire Gauge Specifications for High Power Cables- Courtesy of Powerstream.com



Welding Cable Cross-sectional Diagram- courtesy Pittsburgh Wire and Cable Inc.

The finished 3/0 Cable assembly with crimped lugs and insulated heat-shrink tubing

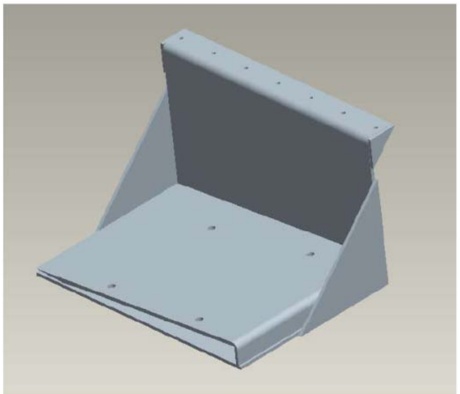
Mount Design, Modeling and Fabrication:

A very critical element in the development of a hybrid vehicle is the design, engineering, modeling and fabrication of mounts and housings for the various components added to the vehicle. These mounts and housings have to handle vibration, harsh climatic conditions and should be easy for technicians to install. We will use the case of the motor mount to describe the process we used to design, model and fabricate these mounts and housings.

The basic requirements for the motor mount were as follows:

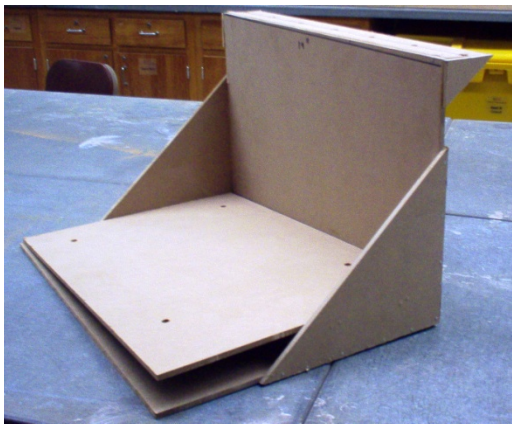
- Able to handle a weight of over 300lbs
- Easily attach to the vehicle frame rails
- Isolate the motor from vehicle vibration
- Simulate the driveshaft angle to ensure that both the motor and the driveshaft are in phase
- Have a corrosion resistant coating to survive the harsh climatic conditions and road debris impact
- Allow for adequate air cooling of the motor

After rigorous measurement sessions and after considering several alternative designs, a basic 3-D model of the motor mount was developed using PRO/Engineer Wildfire to simulate the motor.



A screen snapshot of the 3-D model of the motor mount

In order to ensure proper fit and placement on the vehicle, a solid medium density fiber model was constructed and the fit on the vehicle was tested. Minor dimensional changes were made to ensure correct fit and placement.



The medium density fiber model

Finished steel mount with a powder-coated finish

The final dimensions were then transferred to an AutoCAD drawing and were sent out to our manufacturer. The part was then punched and welded. A powder coated finish was also applied to the mount to ensure resistance to corrosion and debris impact.

Conclusions:

- The project is still underway and we are moving into the assembly phase of the vehicle
- We hope to complete the assembly of the vehicle by the end of July 2009 and intend to have our first road tests shortly thereafter
- We have found that there is a need to reduce the package size and weight of the controller unit and motor
- The current motor's package size, due to its cooling fins, slightly reduces the ground clearance of the vehicle. Thus the next iteration of such a vehicle would require a lighter motor that is water-cooled.
- The battery pack currently weighs in at approximately 625lbs. Although this does not affect the payload capacity of the vehicle substantially, we believe that the use of Lithium Ion batteries will enable us to reduce battery pack weight by upto 60%
- The use of Finite Element Analysis (FEA) and 3-D simulation in future iterations will help save design time and reduce the net. weight of the mounts and enclosures
- The next iteration of the vehicle will also require a Graphical User Interface (GUI) that acquires data from the charging system, the battery pack and the controller and displays it for accurate user information.
- We will be testing the reliability and feasibility of the system in the coming months and making modifications to ensure optimum system performance and vehicle handling.