

# University of Tennessee Spring 2006 Technical Report

Team Tennessee

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## ABSTRACT

As part of the Challenge X competition, Team Tennessee has developed a through the road (TTR) hybrid electric vehicle powertrain architecture to convert a 2005 Chevrolet Equinox into a more environmentally responsible vehicle. A 1.9 liter GM turbo diesel engine provides power to the front axle and an AC induction motor with an integrated transaxle powers the rear axle. The energy storage system is a nickel metal hydride (NiMH) battery pack provided by Cobasys. The vehicle supervisory controller employs a charge sustaining strategy with a focus on charge neutral operation. The integrated vehicle design is discussed, and the competition Vehicle Technical Specification (VTS) for the 2006 competition is listed.

## COMPETITION VEHICLE TECHNICAL SPECIFICATION

One of the most important aspects of the competition, and thus the vehicle design process, is the development of the VTS. The VTS is a reflection of how the team predicts and expects the vehicle to perform. The VTS continues to change over the competition's three-year duration as model and vehicle testing is performed. Vehicle simulations of Tennessee's vehicle design were performed, using the Powertrain Systems Analysis Toolkit (PSAT), to help in the component selection process for year-one development. After model refinement and final component selection was completed, the vehicle model was simulated to determine how various control strategies affected vehicle performance. These studies lead the team to choose and develop a control strategy for the 2006 competition vehicle, and consequently a refined VTS summarized in Table 1.

An important part of the on road test events for the 2006 vehicle competition is the performance prediction ability for the designed vehicle. With a final control strategy chosen, vehicle simulations using the competition drive cycle were performed to determine how Team Tennessee's vehicle would perform. A representative lap of the competition drive cycle is shown in Figure 1. The cycle, consisting of five (5) of the laps shown in the figure, will be executed twice during the competition event with a fifteen-minute break between the cycles. Engines on both the stock vehicle and Tennessee's hybrid vehicle were allowed to continue running to provide cabin cooling during the break in the vehicle simulation. As a result, the fuel economy results reflect a much lower performance than if the engines were shut

off during the fifteen-minute break. The stock Equinox simulation showed a fuel economy of 13.61 miles per gallon, while the Tennessee hybrid had a fuel economy of 17.29 mile per gallon gasoline equivalent. This represents a 27% increase in fuel economy over this particular drive cycle with the UTK hybrid vehicle.

Table 1 – University of Tennessee Competition Selected Vehicle Technical Specifications (VTS)

Description	Test Year	Modeling/Inspection/Testing	VTS (Team Selected)
IVM-60 MPH	1,2,3	M,T	≤9.5 sec
50-70 MPH	1,2,3	M,T	≤7.3 sec
Vehicle Mass	1,2,3	M,T	≤4200 lbs
MPG Combined EPA	1,2,3	M,T	≥32.0 mpg
Highway Range	1,2,3	M,T	≥200 mi
Passenger Capacity	1,2,3	M,T	5 passengers
Emissions Cert Level	2,3	T	Tier 2, Bin 5
Trailing Capacity	2,3	M,T	2500 lbs
Cargo Capacity	2,3	Inspection	60 Cu. Ft. behind front seat
Starting Time	1,2,3	T	<5.0 sec
Noise Emission	1,2,3	T	<75 dbA

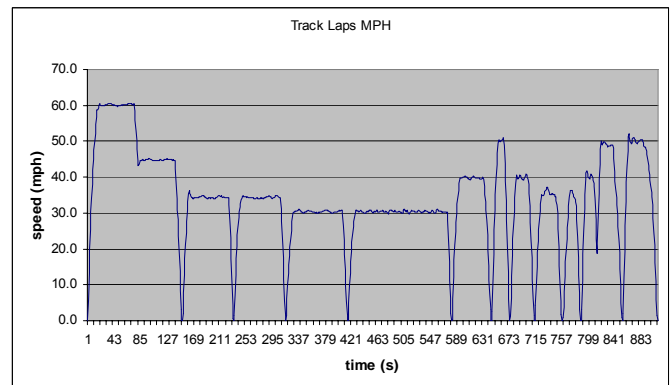


Figure 1 Competition on-road energy use representative test lap

## POWERTRAIN DESIGN

Team Tennessee has elected to pursue a TTR powertrain configuration for its entry in the competition. The most compelling factors influencing this selection were cost, packaging, and other features such as complete subsystem isolation and redundancy.

This concept is important to the team because the vehicle can operate independently from the high voltage system in a limited operating mode should problems arise. In addition, simulation of the system operating in the limited power mode shows that fuel economy would be minimally compromised while acceleration capability of the vehicle would be only moderately affected. Separation of the high voltage system from the heat engine yields greater flexibility for the design in terms of control strategies, packaging, and overall implementation. In addition, this approach represents a completely redundant system should one source of tractive power fail. The only perceived disadvantage to this approach is the inability to perform vehicle idle charging of the high voltage battery pack.

## COMPONENT OVERVIEW

### ENGINE ANALYSIS

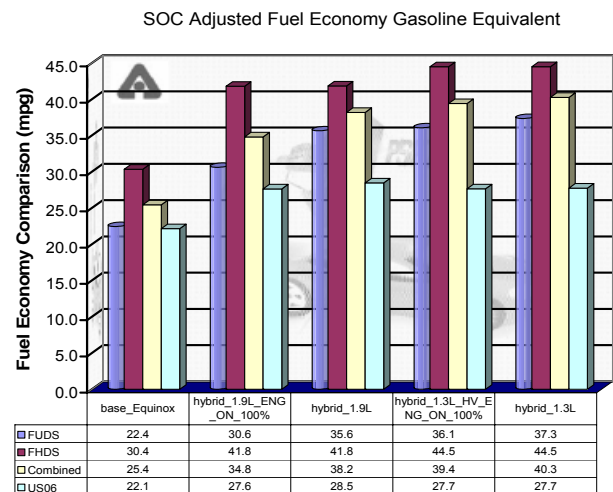
Team Tennessee has chosen to utilize diesel engine technology as the heat engine for the vehicle. The original vehicle design used the GM 1.3 liter engine. There are two versions of this engine, the high value (HV) and the high feature (HF). The HV version of the 1.3L is rated at approximately 70HP power output and the HF produces 90HP. The team first received the HV version of the engine in order to begin the initial subsystem development process. Later, the team was to receive the HF version to be used for 2006 competition. However, the team was informed the 1.3L HF engine would not be available in time for the 2006 competition. The HV engine does not produce enough power to allow the Equinox to meet the VTS targets for acceleration set by the team, and was deemed unacceptable. This prompted the consideration of using the 1.9L GM diesel that was made available as one of the GM supported components during year one. A comparison of the IVM-60 MPH performance data is shown in Table 2. While the HF engine did not meet our initial VTS target, it was deemed acceptable when coupled with the high fuel economy that it afforded. The PSAT performance parameter would have been updated to reflect this in this document had the engine been made available. Although the PSAT predicted IVM-60 mph time is less than the current VTS value of 8.9s, the VTS target will remain as is – better than the stock vehicle.

**Table 2 Performance comparison for candidate engines**

Engine	1.3L HV	1.3L HF	1.9L
IVM – 60 MPH (s)	10.8	9.7	6.6

In order to quantify the effects on an engine change to the overall design and VTS targets, the new engine was modeled in a vehicle context. The 1.9L GM diesel engine component model was inserted into the PSAT vehicle model for the UT version of the TTR configuration hybrid Equinox. The vehicle was evaluated on various driving cycles to determine what impact this

engine would have on the fuel economy and acceleration of the vehicle. The team is considering two (2) methods for controlling the engine. The first approach forces the engine to run 100% of the time, just as a conventional vehicle would. The second strategy allows the engine to shut down during periods of prolonged vehicle idle conditions. The results of these analyses are illustrated in Figure 2. For the final (current) control algorithm selection, the engine will remain on 100% of the time. This supports the powertrain philosophy of traction system isolation and redundancy since there will be no DC-DC to power the low voltage system that must rely on the high voltage system being active. This approach comes with only a small decrease in fuel economy as indicated from the simulation results depicted in Figure 2.



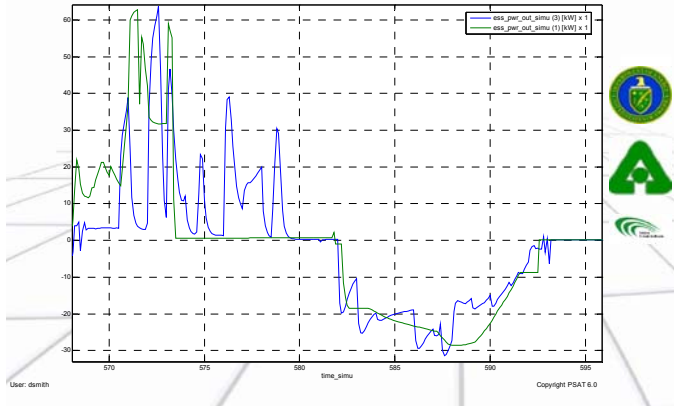
**Figure 2 Vehicle comparison of the 1.3L and the 1.9L diesel engines**

An important observation made during this analysis hinged on the fact that while the 1.3L HF engine provided high fuel economy estimates for most drive cycles, the 1.9L engine gave higher results for the US06 driving schedule. This is extremely significant due to the fact that the UDDS cycle is somewhat lax in evaluating a vehicle's real-world fuel economy numbers. The US06 is much more aggressive in terms of acceleration requirements and vehicle speeds, and can be considered *more* representative of how a vehicle might actually operate in real situations. The reason for this variation in fuel economy between the two candidate engine is the fact that the 1.3L HF cannot provide the necessary power for the hard accelerations required by the US06 cycle, and therefore must rely more upon the high voltage system to supplement the power requirement. This can be shown graphically in Figure 3, where a portion of the US06 is shown comparing the energy storage power use for the two 1.3L and the 1.9L vehicle simulations.

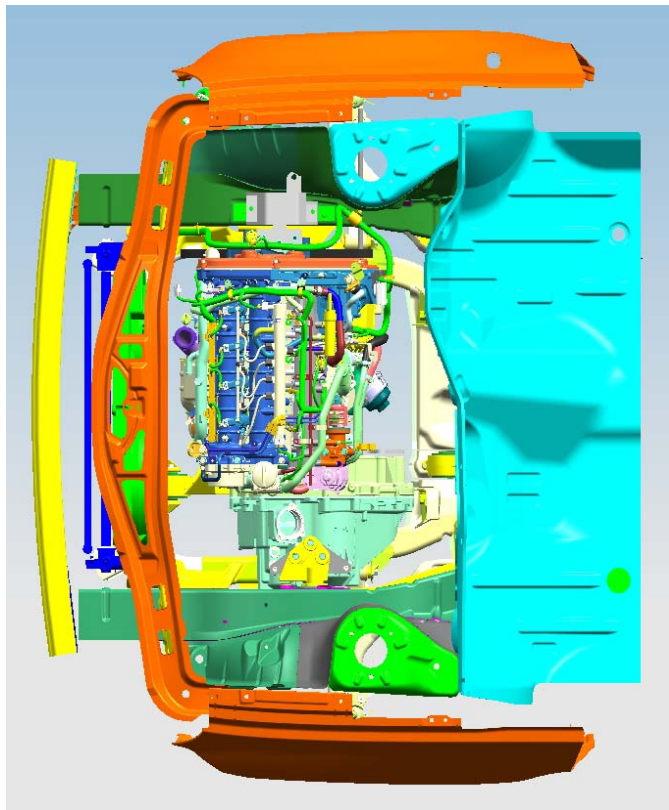
The extra electrical energy used during maneuvers such as these must be accounted for when calculating fuel economy (through charge balancing, etc.). This results

in the engine being run more to make up for the electrical energy loss.

The engine is packaged in the engine bay as in the stock vehicle. Figure 4 shows the CAD packaging diagram of the engine. The half shafts and CV joints are modified to provide proper travel and performance.



**Figure 3 Comparison of 1.3L HF and 1.9L engines during US06 cycle**



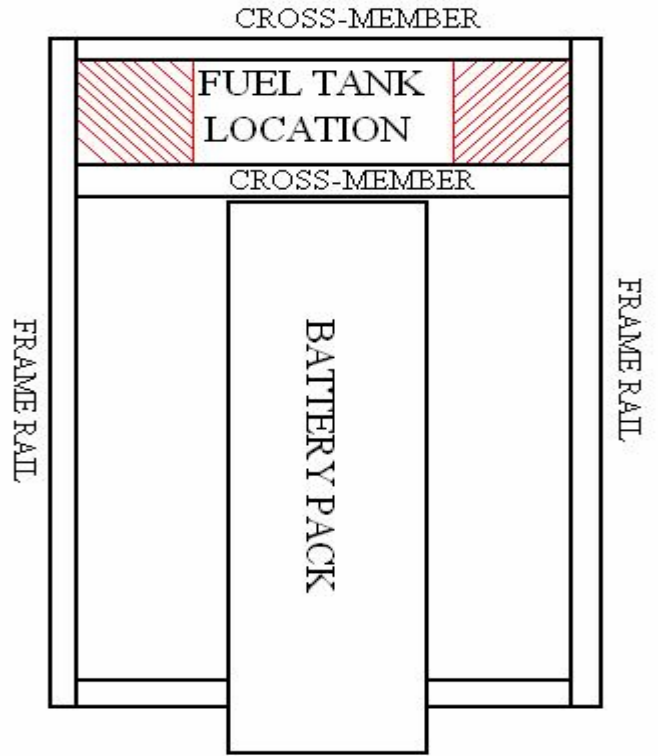
**Figure 4 - 1.9 liter GM diesel integration model**

**FUEL SYSTEM OVERVIEW**

Due to the location of high voltage battery pack, packaging of the fuel tank in the stock location was compromised. Three (3) options were discussed for mounting of the fuel tank: 1) make a very complicated

and hard to fabricate tank that could run along the side of the battery pack but still inside the “frame rails,” 2) use a multi-tank system, or 3) place a custom design tank in the volume of space located near the front of the battery pack.

After considering packaging, cost, and time constraints, the third option listed above emerged as the best choice. Figure 5 represents a simple diagram of the location of the fuel tank. The material used to construct the fuel tank is 1/8” thick aluminum sheet. The design of the tank will hold the required volume of eight gallons.



NOTE: DRAWING NOT TO SCALE

**Figure 5 - Fuel tank schematic**

**ELECTRIC MOTOR INTEGRATION**

The stock Equinox rear sub-frame was the best option for supporting the electric motor. This ensures the correct location of the chassis mounting points, as well as maintaining the stock suspension geometry and account for any clearance issues with the Equinox chassis. The stock sub-frame was modified by removing the front cross-member to make clearance for the motor. The left and right members are notched as well. Additional reinforcements are present to support the modified left and right members.

The motor is centered side-to-side based on output shaft location to ensure minimal CV joint deflection. This led

to suspension interference which will be addressed later in this document. It was positioned as low as possible to reduce chassis cross-member interference as well as to improve handling, while still accounting for CV joint movement and ground clearance. The rear of the front sub-frame cross-member was removed and reinforced to allow for CV joint clearance.

Motor mounting plates were fabricated to not only support the motor but reinforce the modified sub-frame as well. The mounts were designed to facilitate installing the motor from the bottom of the sub-frame. The mounts for the lower control arms had to be moved outward 1.5 inches so the interference could be eliminated. This resulted in the need to shorten the lower control arms by the same amount. Parts of the lower mounts were attached to the left and right sub-frame reinforcements. Once this was accomplished, the control arms were reinforced from the bottom. Since the lower control arm remained longer than the upper, the wheel still cambers inward upon compression but not to the degree of the stock configuration. Additionally, this allows part interchangeability with the rest of the suspension components.

## BATTERY PACK INTEGRATION

Three (3) locations for the Cobasys 336 VDC high voltage battery pack were explored. The initial location was the area of the spare tire well. Integrating the pack into this area would have involved cutting into the frame rails aft of the rear mounts of the rear sub-frame. This location proved to be undesirable because the geometry of the pack would not fit into the approved cutting zones of the vehicle.

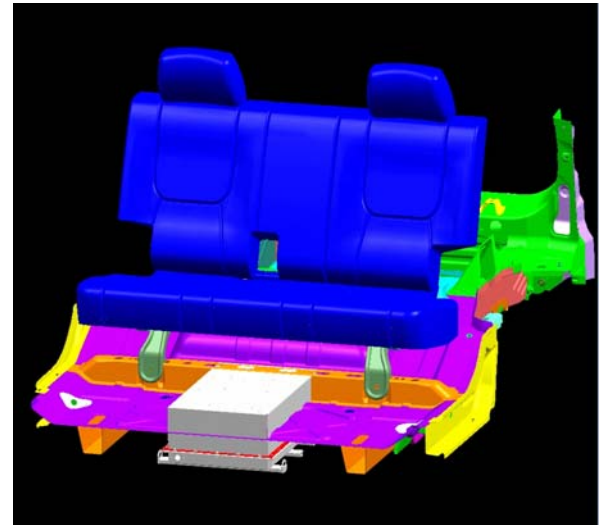
The second location discussed for the pack location was inside the cabin behind the rear seat. This location was also proved undesirable because of pack geometry and customer acceptability.

Our final option was to orient the pack coinciding with the geometry of the rear drive shaft location. The pack is located just aft of the cross member securing the front seats and extends just fore of the cross member directly over the rear sub-frame. In order to protect the pack and gain additional ground clearance, the pack protrudes into the rear floor pan of the rear seat by 3-1/2 inches.

Locating the pack in this area required cutting the front cross member that the rear seat is secured to. Restructuring this area was done by adding reinforcing plates around the remaining sides of the existing cross member and welding a bridge to the plate steel, which extends over the pack reconnecting the structure.

Plate steel was welded to the inside of the frame rails where the pack is located to provide a base to weld mounts on. The pack is supported by two main modes of support. The front of the pack is suspended from a cross member welded to the frame rail plates. The rear

of the pack is suspended from the restructured cross member. Additional supports were also added to increase structural integrity of the floor area.



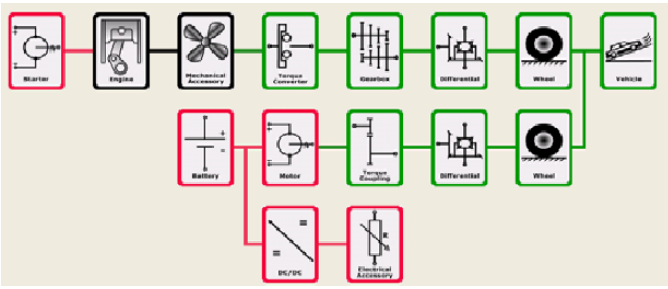
**Figure 6 Battery pack installation**

In restructuring the cross member, the rear seat mounts would not align to the original location. This problem was solved by cutting the forward mounts off the seat rails and extending the rails to meet the top of the cross member bridge where they fasten and orient the seat to the original position.

## VEHICLE CONTROL STRATEGY

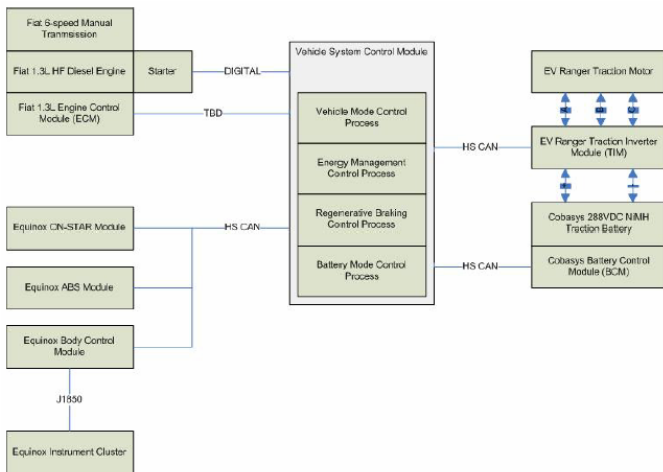
### UTK VEHICLE POWERTRAIN AND CONTROLS ARCHITECTURE PRIMER

The University of Tennessee has applied the systems engineering approach to determine the appropriate advanced powertrain architecture for their entry into the Challenge X competition. Based on their analysis, the team has elected to design a charge sustaining, through-the-road, parallel hybrid electric vehicle with small displacement diesel engine and low storage requirement (LSR) high voltage system. A PSAT block diagram representation of the selected powertrain architecture is shown in Figure 7. Perhaps one of the greatest benefits of this powertrain configuration versus others is the high voltage system (traction motor and battery pack) is completely isolated from the heat engine. As stated earlier this provides a redundant system with the ability for reduced-power operation under possible subsystem failures.



**Figure 7 - PSAT TTR block diagram**

The basic components of this powertrain that must be controlled by the supervisory vehicle control system are the Cobasys Nickel Metal Hydride high voltage battery, EV Ranger traction motor/transaxle and 1.9 L GM diesel engine. The basic vehicle system control architecture is illustrated in Figure 8. Note that the foundation for the supervisory controller is represented as the Vehicle System Control Module (VSCM). This architecture houses four (4) fundamental control processes necessary for the operation and control of the hybrid electric drivetrain. These processes include the Vehicle Mode Control Process (VMCP), the Battery Mode Control Process (BMCP), the Regenerative Braking Control Process (RBCP), and the Energy Management Control Process (EMCP). The functionality of each of these processes is described in greater detail in subsequent sections of this document.



**Figure 8 - Basic block diagram for UTK vehicle controller**

### VEHICLE SYSTEM CONTROL OBJECTIVES

The overall function of the University of Tennessee Challenge X control system is to coordinate the interaction of the heat engine, the traction motor, and the energy storage system. The manner in which the control system carries out this function relies on several factors.

#### Translate driver intent

The most fundamental objective of the vehicle system control is to translate the intent of the driver. The control system must interpret what the driver is trying to do, and

to deliver what is expected up to the limitations of the entire system. The primary interfaces for the driver to the vehicle are the accelerator and brake pedals. These inputs are transformed into control signals for the traction motor and heat engine. These two primary motive forces work together to provide the necessary torque to satisfy the demands of the driver.

#### Maintain state-of-charge (SOC) of HV battery

Since the design philosophy of this control system employs a charge-sustaining approach, the hybrid control system must maintain the state of charge of the high voltage battery pack. This function must be integral to the control algorithm and, more importantly, be transparent to the driver. Fluctuations to the delivered torque to the drive wheels are not desired from a consumer acceptability and drivability point-of-view.

There are two (2) basic methods, or sources of energy in the powertrain, to charge the battery pack. The first method, dubbed regenerative braking, is to make use of the otherwise wasted kinetic energy from a braking event. Regenerative braking can lead to a more efficient drivetrain. Regenerative braking can be applied in two (2) basic versions. The most efficient means of regenerative braking is referred to as series regenerative braking. In this approach, the traction motor absorbs all of the energy from the wheels to slow the vehicle up to a charge limitation on the battery. At this point, the foundation brakes are then applied. While this is the best system to use, it is inherently more difficult to implement. The second approach to regenerative braking is referred to as parallel regenerative braking. The basic difference with this version versus the series approach is the traction motor and foundation brakes work in parallel to slow the vehicle down. For this reason, it is less efficient since less energy is returned to the high voltage battery pack. Parallel regenerative braking is much easier to implement. However, due the overall system efficiency gains that can be attained and the powertrain configuration chosen by the team, the series regenerative braking approach will be incorporated in the UTK controls design.

The second method for charging the battery pack is to use the traction motor as a generator that utilizes energy from the heat engine. Due to the architecture selection of the UTK team, this can only be accomplished when the vehicle is moving. Idle charging of the high voltage battery pack is not possible in this configuration.

#### Protect high voltage (HV) battery

One of the key items for HEV durability is the life span of the high voltage battery pack. The vehicle control system should provide a means of limiting available battery power based on the limitations of the pack itself. In order for the battery to survive for a predetermined warranty period, strict adherence to battery pack manufacturer limitations should be maintained. Such items as charge and discharge limitations, maximum

module temp, and state of charge limitations must be taken into account when coordinating the interactions of the traction motor and the heat engine.

## CONTROL STRATEGY DESIGN CONTENT

The high level control strategy objectives have been established. The control system features developed to deliver these objectives are presented in the following sections.

### BASIC DESIGN STRATEGY FEATURES AND ALGORITHMS

Each control process of the UTK VSCM plays a major role in defining and executing the control strategy for the overall vehicle. Engine ON/OFF conditions are determined by the VMCP (Vehicle Mode Control Process). The operation of the engine for this vehicle is very basic in the sense that it is allowed to shut off only during idle periods. This comes as a result of the powertrain architecture being developed as a through the road parallel. Idle charging of the high voltage battery pack is simply not possible in this configuration. The vehicle must be moving in order to charge the battery. The engine can be shut down during periods of “prolonged” braking events at low speeds where the vehicle is assumed to be coming to rest.

The Battery Mode Control Process (BMCP) has the responsibility for reporting the appropriate and corrected HV battery power limits to the Energy Management Control Process for further manipulation. The strategy makes use of a calibrateable table to determine the additional power required of the engine to maintain the state of charge (SOC) of the HV battery pack. This power, termed  $P_{soc}$ , is a one-dimensional function of battery SOC. An example of this is illustrated in Figure 9. Here, a negative value for  $P_{soc}$  indicates that the battery needs to be charged towards the target SOC. Conversely, a positive value means that the HV battery should be discharged to utilize stored energy in the pack. It should be noted that the power necessary to maintain the SOC can be calculated in a variety of methods. The method presented in Figure 9 is merely a baseline. An optimization involving the efficiencies of the battery pack and traction motor should be employed in such as way as to determine the optimal value for  $P_{soc}$  for a given set of pertinent conditions. The BMCP is also responsible for modifying the battery power limits that are calculated inside the BCM. The BMCP corrects these limitations for such conditions as high SOC, low SOC, high module temperature, and low module temperature. Figure 10 represents a typical discharge power curve for the Cobasys NiMH battery pack that will be used in the UTK Challenge X Equinox. This is the type of data that will be output from the internal battery control module (BCM).

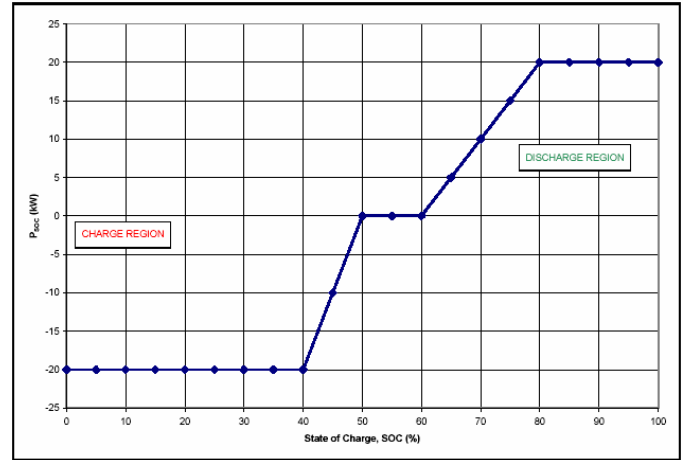


Figure 9 - Determination of battery SOC maintenance power for BMCP

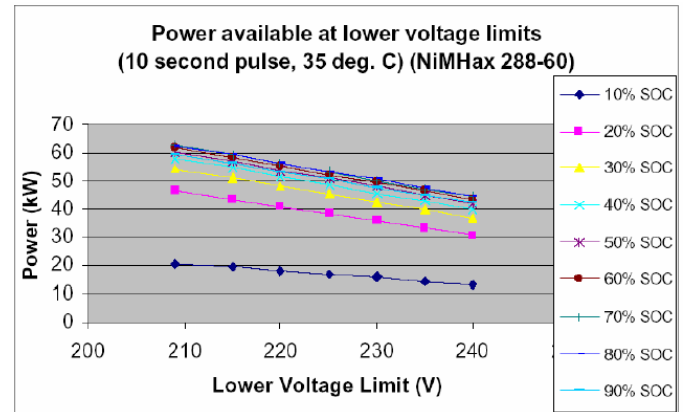


Figure 10 – Typical physical power limitations for Cobasys high voltage battery pack as a function of pack SOC

The Regenerative Braking Control Process (RBCP) is responsible for coordinating the necessary traction motor braking torque values during braking events. The RBCP must monitor such vehicle parameters as wheel speed, SOC, and brake pedal demands to determine the appropriate amount of negative torque to request from the motor. This brake torque command becomes an input to the EMCP for further processing. In addition, the RBCP must constantly monitor the existing anti-lock braking system (ABS) on the vehicle. The RBCP must cancel any traction motor brake torque request during an ABS event so that the positive effects of ABS are not cancelled and no wheel lock-up occurs.

The Energy Management Control Process (EMCP) is the most critical process within the VSCM. The EMCP is responsible for coordinating the interaction of the heat engine and the traction motor. The EMCP must ensure that the driver demanded power is satisfied while at the same time maintaining the state-of-charge of the HV battery pack. The EMCP must deliver these items while also administering overall system limitations for subsystem component protection. The EMCP joins the outputs from the BMCP, the VMCP, and the RBCP to determine what is required of the heat engine and the traction motor. The root output of the VMCP is the driver

demanded power, dubbed  $P_{drv}$ . The prime output of the BMCP is the power necessary to maintain the SOC of the HV battery pack, referred to as  $P_{SOC}$ . These variables together form the total power required of the engine in HEV mode. It is worth noting that  $P_{SOC}$  is ignored in a ZEV mode. The total engine power desired, designated  $P_{tot}$ , thus becomes  $P_{tot} = P_{drv} - P_{SOC}$  where,  $P_{SOC} < 0$  indicates power to CHARGE battery  $P_{SOC} > 0$  indicates power to DISCHARGE battery.

The primary function of the EMCP is to deliver the appropriate torque commands to the engine and traction motor that a) satisfy the driver demand and SOC maintenance demand and b) apply overall system limitations and constraints. Figure 11 is a flow diagram that outlines how the respective system limitations are applied in a hybrid mode of operation. The flow diagram starts with  $P_{drv}$ , since meeting the driver demand is the most important characteristic of the VSCM as a whole.

For a ZEV mode of operation, the flow diagram (Figure 11) is modified to remove references to the engine. Basically, the bottom half of the diagram is used. The general outputs from this flow diagram are a modified engine power desired and traction motor power desired (filtered through the system limits). These values are divided by each respective speed to give a torque command to the engine and traction motor. However, certain further adjustments to these values must be made in order to compensate for electrical system power losses (conversion of electrical energy to mechanical energy). This is also accomplished in the EMCP. One of the most important functions that the EMCP must include is to protect the high voltage system, particularly the battery pack. The EMCP utilizes

the modified charge and discharge power limitations determined in the BMCP and calculate the corrected traction motor torque command, based on the previously determined  $P_{elec\_des}$ , to ensure that the current drawn from the battery pack does not violate its maximum system limits. The EMCP offsets the  $P_{elec\_des}$  command by filtering  $P_{elec\_des}$  (set-point) and  $P_{battery\_actual}$  (response) through a PI controller. The resulting desired electrical power is what is actually requested from the traction motor. This approach ensures that the high voltage system limitations are never exceeded.

## MAXIMIZING FUEL ECONOMY THROUGH VEHICLE CONTROL

The control strategy has been developed to maximize fuel economy in the following ways:

1. **Electric power assist** – The high voltage system can provide efficient supplemental power during periods of hard acceleration, effectively reducing the fuel consumption of the diesel engine.

2. **Opportunistic battery charging during cruise** – The battery can be charged during periods of low power demand when the engine can supply excess power to accomplish such. The operating envelope of the engine and traction motor will be thoroughly mapped on an engine dynamometer in order to gain a better understanding of the most efficient operating points for a given speed for each machine. The supervisory controller is tasked with determining how much energy is required to charge the high voltage pack and at what conditions the engine and traction motor should operate together to attain this goal in the most efficient manner. This system optimal approach attempts to operate the system more efficiently than simply taking the easier path of an engine optimal approach, although the operation of the engine is a dominant factor.

3. **Series regenerative braking**– The system will employ a series regenerative braking system in order to maximize recapture of kinetic energy during braking events. This type of electronic braking reduces fuel consumption by relying on vehicle dynamics rather than the heat engine to partially charge the high voltage battery pack. The driver must maintain the ability to engage the foundation brakes of the stock vehicle when implementing an electric brake system. In order for the team to implement a series brake strategy, which attempts to stop the vehicle using solely the electric motor, the dual-braking system in the vehicle must be coupled using a modified brake pedal assembly, as shown in Figure 12. The new system uses two brake pedals to accomplish the system separation needed to allow the electric system to act first during a braking event. When the driver presses the brake pedal, the regenerative brake system (RBS) is first engaged through the actuation of the RBS pedal and pedal position sensor. The pedal position sensor sends a 0-1 signal to the vehicle controller, where the controller

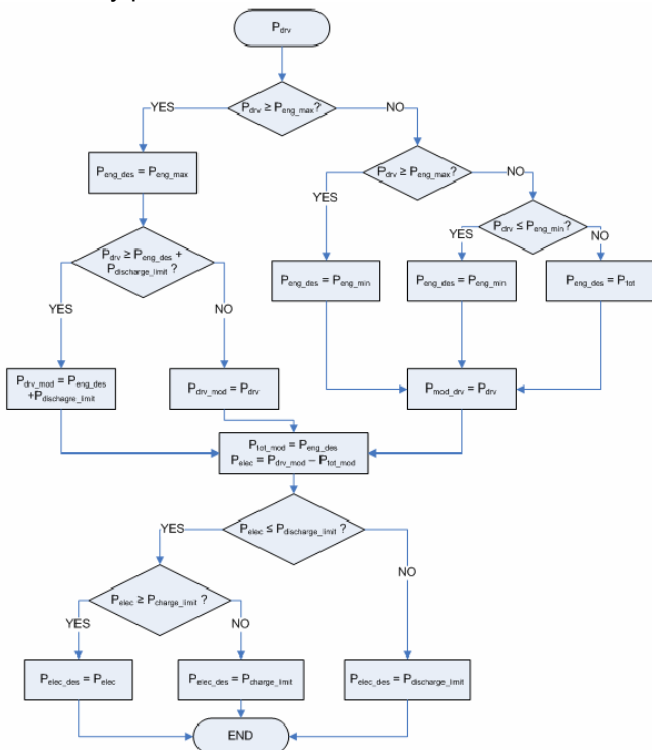
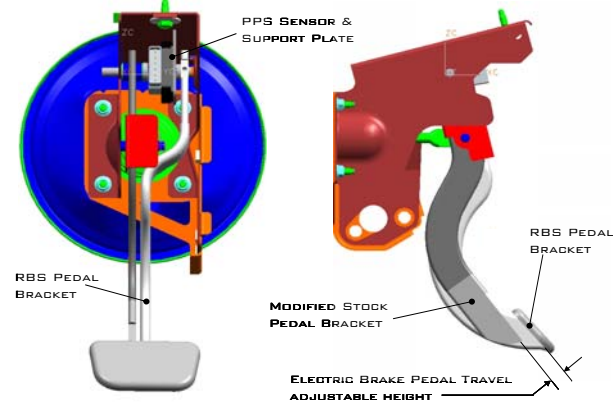


Figure 11 - Energy blending methodology for the EMCP

demands a regenerative torque from the motor relative to pedal position of the RBS bracket. If the driver requires additional brake power, the brake pedal can be depressed further until the foundation brake pedal bracket actuates the friction brakes of the Equinox. During emergency braking in which the stock ABS system is engaged, the RBS system is rendered inoperable.



**Figure 12 - Regenerative brake pedal assembly**

## MINIMIZING EMISSIONS THROUGH VEHICLE CONTROL

The control system is also responsible for helping reducing tail pipe emissions. The engine idle stop operation previously described plays a significant role in the reduction of emissions simply due to the fact that the engine is off. The team has plans to incorporate a lean NO<sub>x</sub> trap (LNT) in year three as a means of active exhaust aftertreatment. The control system will be responsible for managing the regeneration of the LNT.

## SATISFACTION OF VTS TARGETS

The fuel economy and emissions targets have already been addressed in preceding sections. The performance items are indirectly handled by the control strategy. Recall that one of the prime objectives established for the UTK control system is maintain the integrity of the high voltage system. The control strategy contains features in the EMCP to deliver full system power while not violating crucial system limitations, maximum discharge power from the high voltage pack. The starting time requirement is handled by efficient code development and hardware considerations.

## CONTROL STRATEGY DEVELOPMENT PROCESS

The baseline control strategy for Team Tennessee is currently complete and ready for system testing. The development of this code is an extension of the work carried out by previous efforts during the FutureTruck series of competitions.

## STRATEGY DEVELOPMENT PROCESS

The initial control strategy is an adaptation of the University of Tennessee FutureTruck control system. The premise for starting here is that this system is a fully functional and tested control system that contains many of the desired features that have been designed into the Challenge X VSCM architecture. The strategy planned for use in the Challenge X vehicle is very similar to the operation of the UTK FutureTruck, with a few notable exceptions. The Challenge X design does not permit idle charging of the high voltage battery pack as the FutureTruck did, so this feature will be removed. The modular design of the FutureTruck control system allows only parts of the strategy that need to be modified to be changed, while preserving the basic architecture and functionality of the rest of the control features. The control strategy will be modified and adapted to accommodate the nuances of the Challenge X powertrain configuration. The legacy code that serves as the foundation for the development of the Challenge X control strategy is written using National Instruments LabVIEW software. The software in the loop plan outlines porting this code into the PSAT simulation environment; however, this has not been fully realized. Once this has been successfully achieved, fine tuning of the control strategy can be executed. The controller will be exercised using numerous drive cycles to determine the impact of various calibratable parameters and the sensitivity of these to respective powertrain operating conditions. In addition, the PSAT component models will be refined using actual dynamometer data for the candidate engine, battery pack, and traction motor. The effects of these changes can also be validated and incorporated into the control strategy. Such issues as drive quality will be addressed during preliminary vehicle implementation and testing. However, simulation can be used to limited degree to evaluate basic drivability and NVH factors. One such source of NVH concern is engine start/stops. Each drive cycle evaluated during simulation must be assessed for engine stops and starts. The harshness of the engine starts and stops has not been determined as of yet due to hardware acquisition delays. However, the minimization of engine starts and stops will aid the drivability and NVH issues that most likely will become and issue when the hybrid powertrain is implemented into the actual vehicle.

## CONCLUSION

The design for the conversion of the 2005 Chevrolet Equinox into a more environmentally friendly vehicle has been achieved. Subsystem components have been analyzed and their impact on the performance of the vehicle has been completed. The VTS is finalized and shows current performance predictions. The hardware implementation of the conceptual powertrain design is nearing completion and will soon be ready for testing