

University of Tennessee Spring 2007 Technical Report

Courtney Lindwurm and Shaun Hinds

Team Leaders

David Irick

Faculty Advisor

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ABSTRACT

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 L 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 Specifications (VTS) for the 2007 competition are listed.

INTRODUCTION

The Challenge X program is a four year collegiate design competition where 17 universities vie against one another by redesigning a GM Equinox to minimize energy consumption, EPA regulated emissions, and green house gasses while maintaining or exceeding the performance and utility specifications of the original vehicle. Years one and two focused on modeling, simulation, testing and construction of a functional "test mule." The current year's focus is to finalize and polish the year two design into a vehicle that is 99% ready for production.

A second aspect for all years of the competition is to increase outreach and consumer awareness of alternative vehicle technologies, such as bio-fuels and hybrid vehicles. This effort is focused on community, youth, sponsors, media, and a team website.

VEHICLE ARCHITECTURE

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 complete subsystem isolation and redundancy, among others. 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, once again, 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.

MODELING AND TESTING

VEHICLE TECHNICAL SPECIFICATION GOALS

One of the most important aspects of the competition and 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 four-year duration as modeling 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 led the team to choose and develop a control strategy for the Year 2 "test mule" vehicle, and consequently a refined VTS summarized in

Table 1. An important part of the on road test events for the 2007 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 Year 2 competition drive cycle is shown in Figure 1. The cycle, consisting of five (5) of the laps shown in the figure, was 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% improvement 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/Insp ection/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

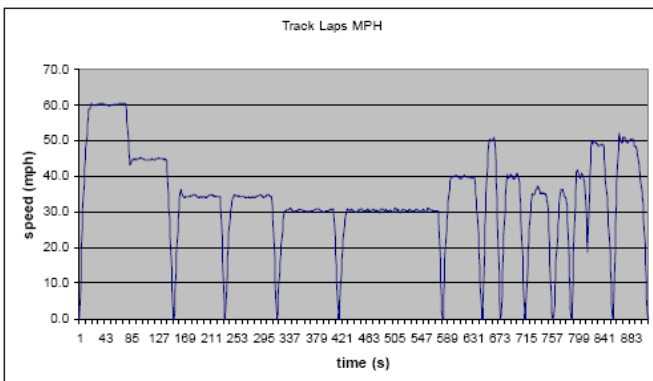
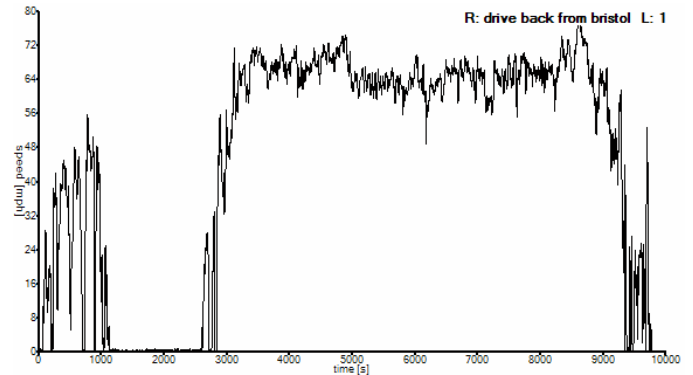


Figure 1 - Year 2 competition on-road energy use representative test lap

PERFORMANCE TESTING RESULTS

Due to limited space, Tennessee was forced to design a diving schedule suitable to the roads and terrain of the surrounding area. This schedule, shown in Figure 2, consisted of approximately 20 minutes of city driving followed by 25 minute break, roughly 2 hrs of highway driving, and an additional 10 minutes of city driving. The total length was 127 miles during which time approximately 3.65 gallons of fuel was used, yielding an average consumption of 34.5 mpg



COMPONENT OVERVIEW

ENGINE

Team Tennessee has chosen to utilize diesel engine technology as the heat engine for the vehicle. In order to quantify the effects an engine change would have to the overall design and VTS targets, the diesel engine was modeled in a vehicle context. The 1.9 L GM diesel engine component model was inserted into the PSAT vehicle model for Tennessee's 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 was 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 3. 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 3.

SOC Adjusted Fuel Economy Gasoline Equivalent

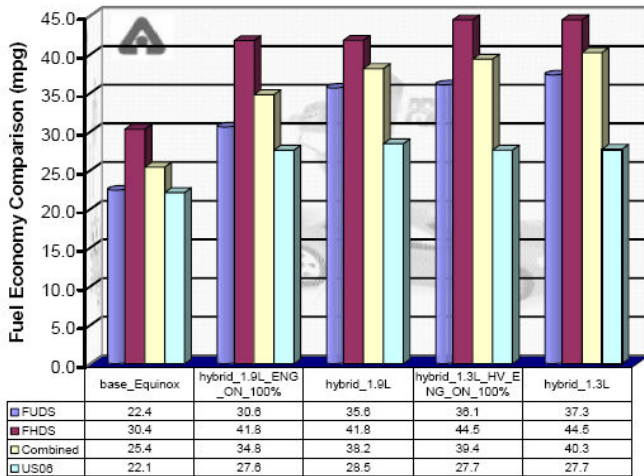


Figure 3 Vehicle comparison of the 1.3L and the 1.9L diesel engines using engine on and engine off strategies

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.

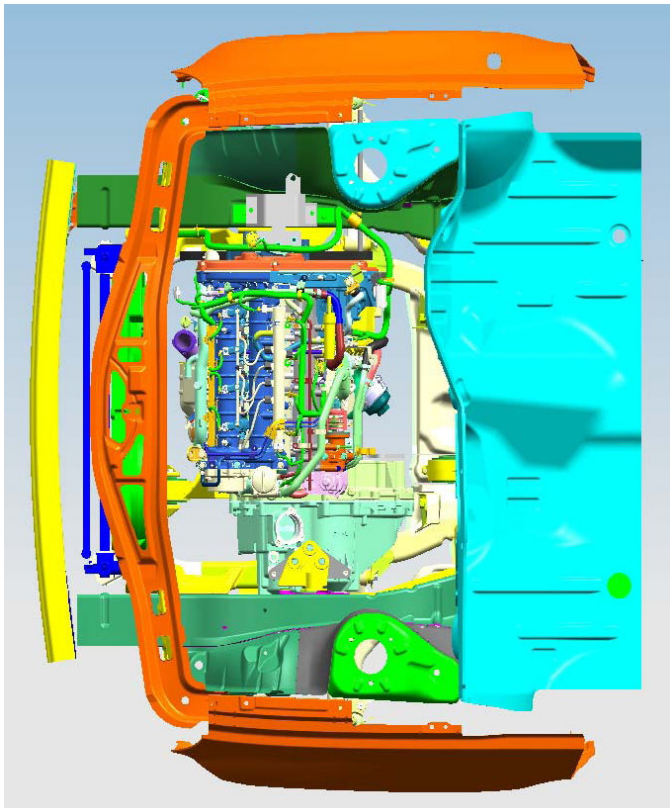


Figure 4 - 1.9 L GM diesel integration model

INTEGRATED POWERTRAIN

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 accounts 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. 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 parts to be interchangeable with the rest of the suspension components.



Figure 5-Rear sub-frame assembly

HIGH VOLTAGE ENERGY STORAGE DEVICE (BATTERY)

Three (3) locations for the Cobasys 288 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.

The final option was to orient the pack coinciding with the geometry of the rear drive shaft location as shown in Figure 6. 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.

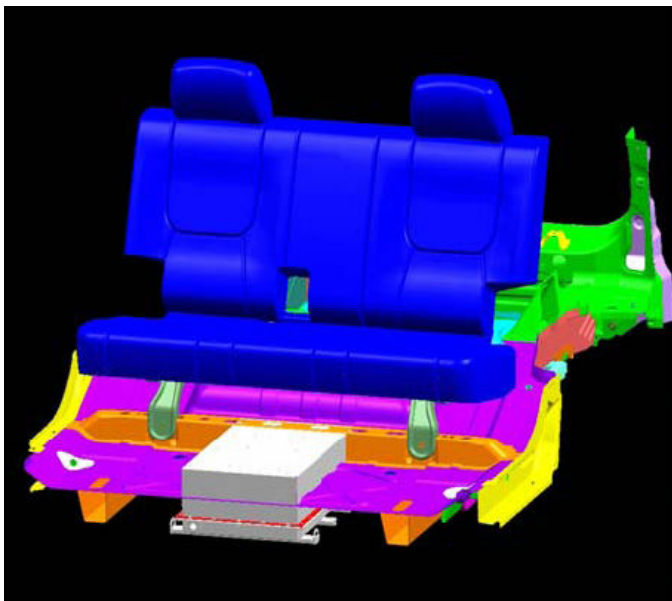


Figure 6 - Battery pack installation

Locating the pack in this area required cutting the front cross member to which the rear seat is secured. 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 sides of the pack are suspended from the restructured cross members. Additional supports were also added to increase structural integrity of the floor area.

99% BUYOFF

NOISE, VIBRATION AND HARSHNESS (NVH) REDUCTION

Compared to the stock Equinox, Team Tennessee's hybrid initially experienced more noise and vibration, which primarily came from two sources: the diesel engine and the electric motor. Testing was done to analyze the existing NVH status, which were also used later to document the improvement. The goals were to find the largest contributor of noise inside and outside of the Equinox, the sound pressure level (SPL) in dB for those sources, and the frequency range in which they are operating.

The noise from the motor reaches peaks near 60 dB. The frequency area below 3500 Hz, in particular 3000 Hz to 2000 Hz, seems to be where the majority of the noise is. The goal was to keep all of the motor noise below 40 dB to the passengers.

The noise from the engine has peaks upwards of 70 dB. Most of the noise stays between 45 dB and 55dB. The majority of noise is below 500 Hz and is especially condensed in the area of 250 Hz. The goal was to reduce the noise below 35 dB with the hood closed inside the passenger cabin.

The most common way to reduce noise and vibration is to add insulation material to the vehicle. This is usually done by applying asphalt mats to deaden sound. Team Tennessee's NVH group chose to use a different material called QuietCar®.

Team Tennessee's NVH group decided that QuietCar® had many advantages over traditional mat sound dampeners. The total weight of the car is one factor that is regulated by Team Tennessee's VTS goals. When using traditional sound dampening mats, a significant weight would be added to the vehicle. Additionally, the underside of the engine cover was coated.

To improve the NVH condition in the rear motor bay, a new removable cargo compartment floor was fabricated. QuietCar® and a foam gasket were added to dampen vibration between the removable floor panel and the existing body-frame integral (BFI). This also allowed isolation of motor noise from the passenger compartment.

Through this implementation, a minimum decrease of 10 dB inside the passenger cabin was attained across most frequencies. The noise levels of the Challenge X Equinox were measured before and after the UT NVH team executed their plan to reduce noise levels inside the vehicle. Through the use of common Matlab toolboxes and commands the audio data was analyzed. Spectrograms and Fast Fourier Transform (FFT) plots were generated at various conditions, including a range of RPMs, gears and during acceleration and deceleration to compare the before and after results. The

spectrograms were used to show the magnitude of individual frequencies versus the time they occurred. Figure 7 below corresponds to the color coding used in the spectrogram, thus sound intensity increases as you move from left to right or blue to red in terms of decibels. The overall results showed a significant reduction of noise levels inside the car after the NVH team implemented their plan.

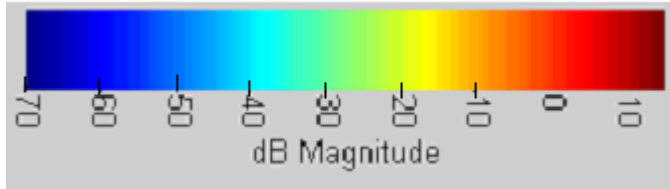


Figure 7 – Spectrogram Scale

Figures 8 and 9 show the spectrogram results under hard acceleration. The FFT and spectrogram for 2500 RPM in second gear are shown in Appendix A.

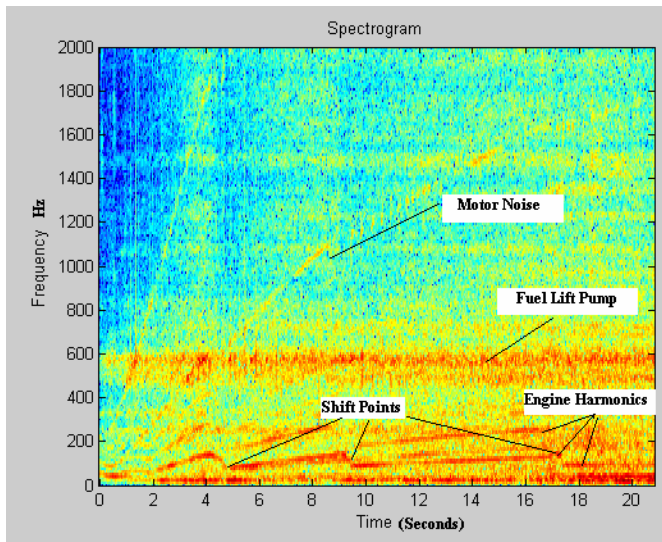


Figure 8 – Hard Acceleration Before NVH Treatments

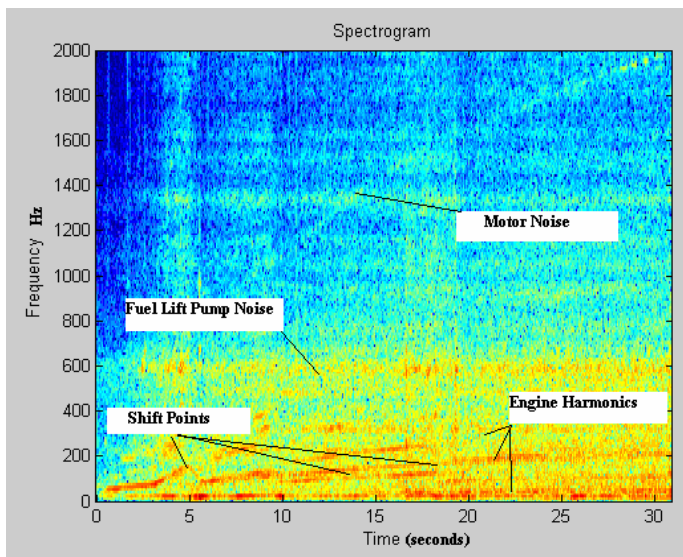


Figure 9 – Hard Acceleration After NVH Treatments

HIGH VOLTAGE COOLING SYSTEM

The high voltage cooling system will utilize an air-to-water style heat exchanger mounted behind the front grill. The coolant pump will also be relocated to the front of the vehicle. This will reduce the amount of noise inside the passenger compartment since the pump and fan will no longer be located below the cargo area in the rear. Hard tubing will be used beneath the vehicle for extra clearance and durability. Coolant will continue to be circulated through the battery, inverter and motor in a single series loop.

ELECTRIC MOTOR ISOLATION

Initially the motor was mounted solid to the rear subframe because it acted as a stressed member. This caused noise from the motor to resonate throughout the vehicle's chassis. To correct this, the motor was isolated using rubber mounts thus reducing vibrations without the need to severely change the geometry of the rear suspension and drive. By rubber mounting the motor, the previous feedback felt in the passenger cabin by the motor's vibrations was nearly eliminated. The design selected to complete this task involved the construction of two independent mounting brackets which utilized the existing bolt patterns located on either end of the Ballard motor, as can be seen in Figure 10.



Figure 10 - Mounting bracket for Ballard Motor

These mounting brackets are composed of custom fabricated rubber isolators on the top side of the motor with supplemental torque arm mounts on the bottom side, allowing the electric motor to float freely inside of the rear sub-frame.

After completing construction of the mounting brackets, it was necessary to reintroduce a lateral structural member to the rear sub-frame, as the motor was no longer serving as a load bearing member. A structural member was added between the control arm towers, protruding towards the front of the vehicle, to allow movement of the electric motor, as seen in Figure 5.

The structure was boxed in where the previous mounting brackets had been, to restore strength to the rear sub-

frame. In year two the cross-member had been re-enforced to allow clearance for the electric motor. The new design allows for greater movement of the motor therefore it was necessary to further modify the rear cross-member to allow for proper clearance. This was accomplished by removing a larger portion of the cross-member and then re-enclosing the structure. A completed assembly view of the electric motor and rear subframe can be seen in Figure 5.

YEAR 2 DRIVE QUALITY PROBLEMS AND SOLUTIONS

From the results from Year 2's drive quality event, it was noted, not only in the data but by the driver several significant issues, concerning shifting, pedal operation, start time, and fuel delivery system.

Manual Transmission Shifter

The Year 2 shifter was improperly installed and therefore allowed selection of reverse without the use of the reverse lock out. Additionally, the 5th and 6th gear were not easily selected without significant force. To fix this problem the shifter was reinstalled and properly calibrated.

Pedals

One of the main goals for year three was to make the Equinox 99% ready for production. The pedals that were in the vehicle for year two did not meet these criteria because of clutch pedal interference with the steering assembly and lack of brake and accelerator pedal foot room. The pedals have been redesigned to increase foot room, reduce excess play in the clutch pedal as well as the steering shaft interference.

Start time

One of the downfalls of the control system developed for year two was the slow start time. This control system utilized a National Instruments Compact Rio with the software developed in LabView. For year three the goal is to reduce the start time to less than a second by changing the control system to a Mototron module that utilizes Matlab/Simulink software. The Mototron system is similar to what is implemented in production vehicles and thus makes Tennessee's Equinox closer to the 99% buy-off objective.

Fuel delivery system improvement

The final problem and possibly most detrimental was a poor fuel delivery system. Due to the lack of baffling and improperly located fuel pickups, not all of the fuel in the tank could be used. Not only was this inconvenient, it was partially to blame for less than ideal fuel consumption results. During hard deceleration and cornering, the pickup would starve for fuel, hence the engine would die. To make up for the lost time in

constantly restarting the vehicle, the driver was forced to drive more aggressively to meet the driving schedule.

EMISSION REDUCTION STRATEGY

The EPA Tier 2 Bin 5 standard is the 50 state light duty diesel standard for the US, as shown in Table 2. For compression ignition engines to NOx, THC and PM standards are the most difficult to meet. To perform better than the year two results, shown in Table 3, Team Tennessee implemented an aftertreatment to reduce the NOx emissions.

Table 2-EPA TIER 2 BIN 5 Standards

50,000 miles	NMHC	CO	NOx	PM	HCHO
	0.075	3.4	0.05	-	0.015
100,000 miles	NMHC	CO	NOx	PM	HCHO
	0.09	4.2	0.07	0.01	0.018

Table 3-ChallengeX Year Two Emission Results

CO	NOx	THC	MPG	Fuel
gm/mile	gm/mile	gm/mile	mpg	Type
0.116	2.392	0.003	20.39	B20

YEAR 2 EMISSIONS RESULTS

The only area of non-compliance was the NOx levels which were nearly 48 times the allowable limits. The high levels of NOx are a normal effect from compression ignition engines. The initial plan implemented a Lean NOx Trap (LNT) to reduce total NOx emissions. It was decided that the fuel penalty associated with the LNT and expense involved made an ammonia/urea Selective Catalytic Reduction (SCR) system better suited for the project.

In addition to the Urea SCR system the stock diesel oxidation catalyst and diesel particulate filters are also used.

SCR

Extengine LLC donated an ammonia Selective Catalytic Reduction (SCR) system. This system, known as the ADEC 1, shown in Figure 11, uses a controller to numerically predict the amount of ammonia to inject into the exhaust to reduce NOx over the SCR catalyst. This system was originally designed for large diesel trucks,

such as dump trucks, and has a proven NOx reduction rate of 80-95% [1].

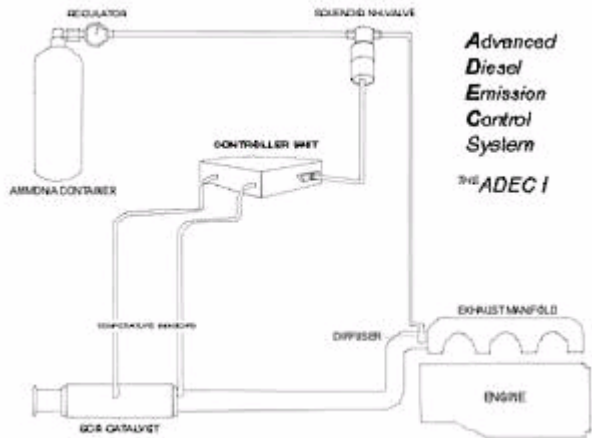


Figure 11- ADEC 1 SCR system diagram

EXHAUST SYSTEM REROUTE

A major problem with the year two competition was maintaining the 7.5 inch ground clearance limit. Due to the method of routing the exhaust pipe under the motor and rear subframe the clearance was not met. To remedy this, the exhaust pipe was redesigned by using a low clearance exhaust tubing routed in an alternate, less invasive location.

CONTROL STRATEGY

Team Tennessee has applied the systems engineering approach to determine the appropriate advanced powertrain architecture for the entry into the Challenge X competition. Based on the 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 12. 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.

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 13. 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.

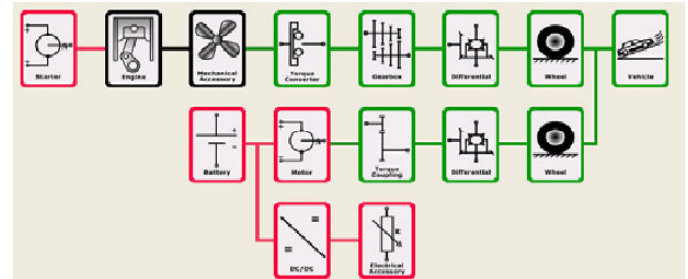


Figure 12 - PSAT TTR block diagram

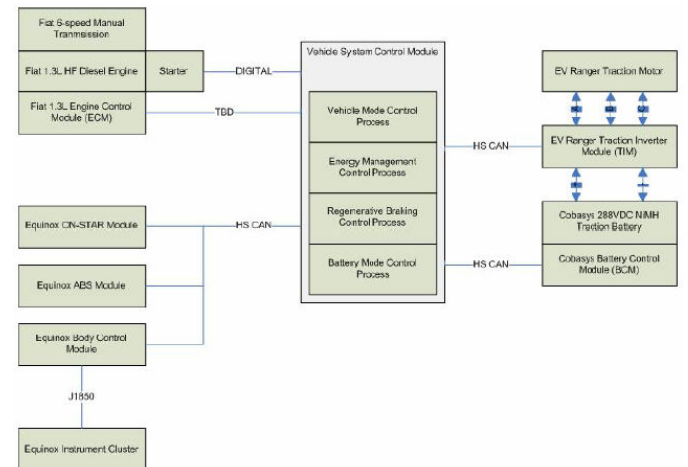


Figure 13 - Basic block diagram for UTK vehicle controller

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. The operation of the engine for this vehicle is very basic and due to the added complexity of implementing this strategy with a manual transmission it was not feasible. Additionally, compression ignition engines use less fuel when idling than spark ignition engines. Keeping the engine on while idling has the added benefit of keeping the catalyst hot which is necessary for proper emission control.

Idle charging of the high voltage battery pack is simply not possible with this configuration. The vehicle must be moving in order to charge the battery, which is control with the BMCP.

The 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 14. 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 14 is merely a baseline. An optimization involving the efficiencies of the battery pack and traction motor should be employed in such a 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 15 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).

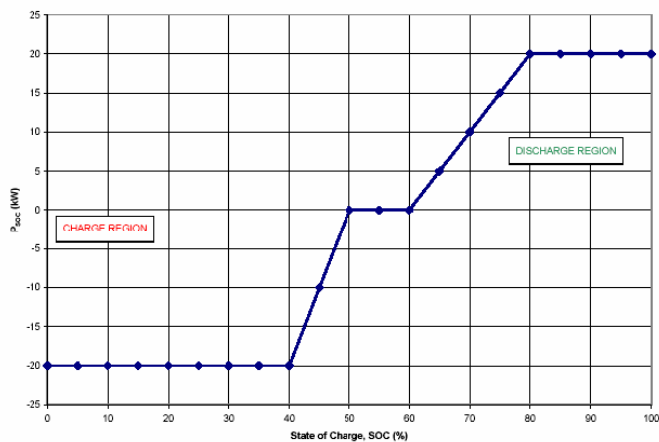


Figure 14 - Determination of battery SOC maintenance power for BMCP

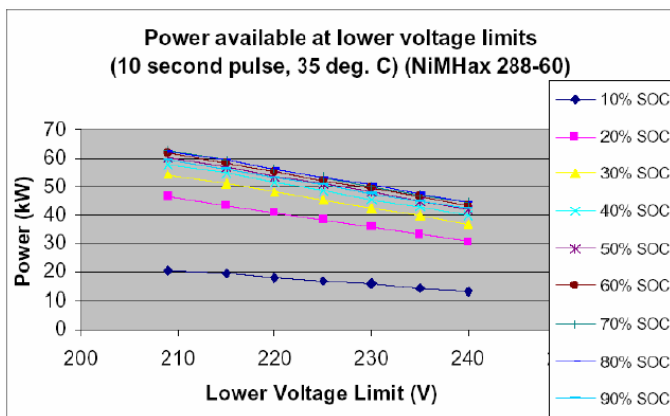


Figure 15 – Typical physical power limitations for Cobasys high voltage battery pack as a function of pack SOC

The 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 EMCP is the most critical process within the VSCM. It 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 16 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.

The general outputs from the flow diagram in Figure 16 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.

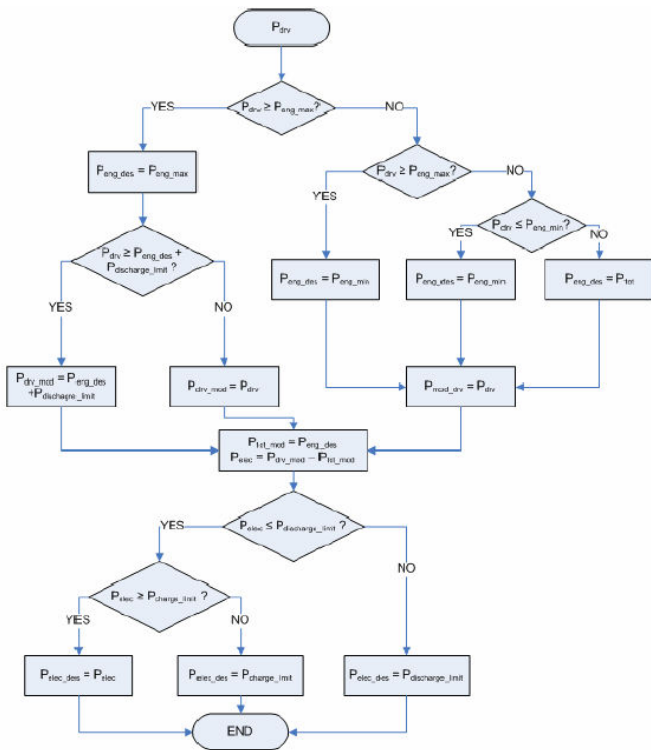


Figure 16 - Energy blending methodology for the EMCP

POWERTRAIN CONTROL AND OPERATION

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. 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 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 Team Tennessee, 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 vehicle 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.

CONCLUSION

The University of Tennessee's solution of a small efficient diesel engine, utilizing biodiesel, with a through-the-road hybrid is an effective way to reduce the well to wheel energy use, increase fuel economy and reduce emissions from a stock 2005 Equinox. The through-the-road architecture allowed a safe, simple and effective platform to implement a full hybrid system. The GM 1.9 L turbo diesel exceeded all of the teams expectations and with the appropriate exhaust aftertreatments makes an excellent powertrain for this application.

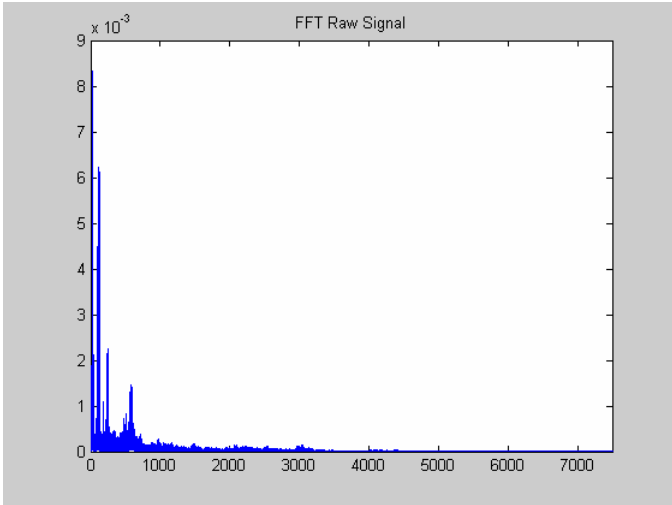
ACKNOWLEDGMENTS

Cowboy Butch, & Scooter

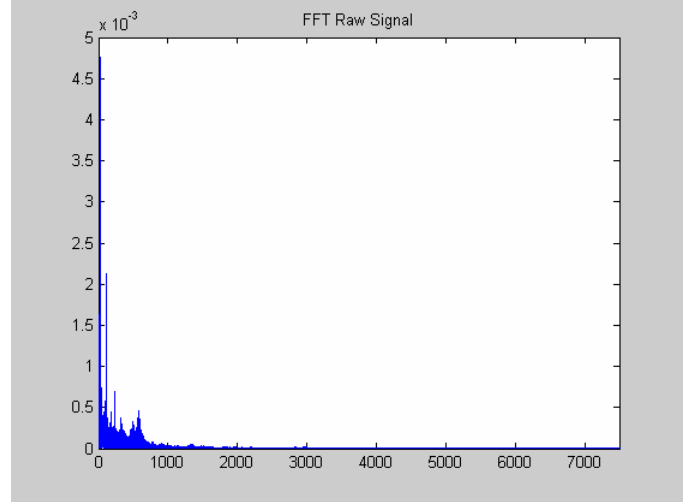
REFERENCES

1. <http://www.extengine.com/adec.htm>

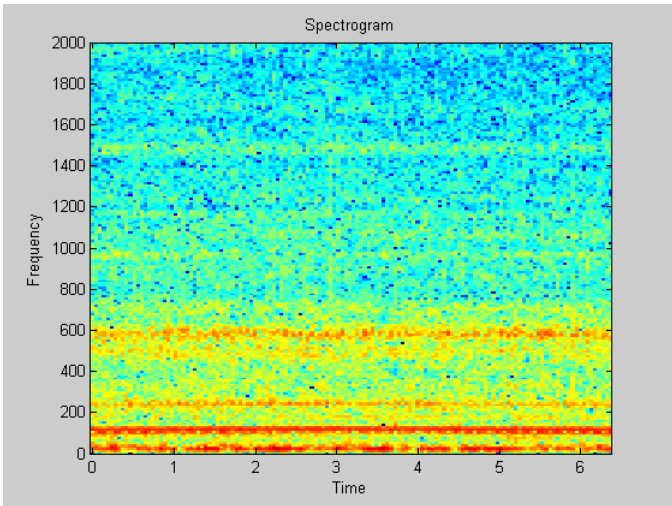
APPENDIX



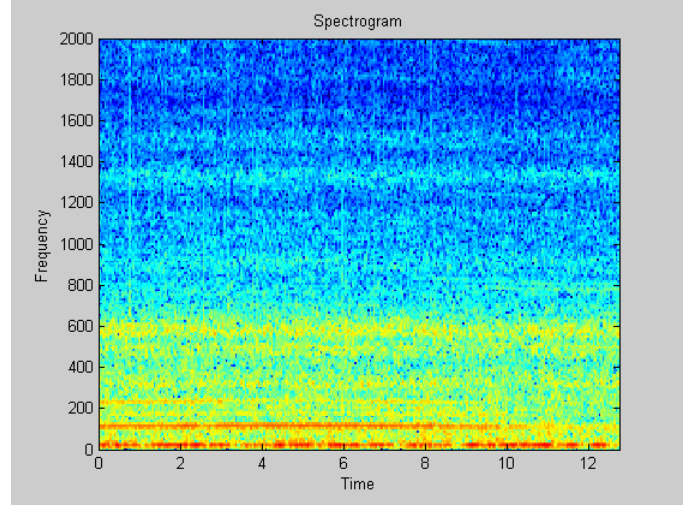
**Figure A1. FFT Before NVH Treatment –
2nd gear 3500 RPM**
Note high value for engine harmonics at 20Hz 100Hz
220Hz and 600 Hz



**Figure A3. FFT After NVH Treatment -
2nd gear 3500 RPM**
Notice reduction in amplitude of harmonics



**Figure A2. Spectrogram Before NVH Treatment -
2nd gear 3500 RPM**
Note high frequency noise in light blue above 600 Hz



**Figure A4. Spectrogram After NVH Treatment
2nd gear 3500 RPM**
The reduction in high frequency noise is obvious
with much more dark blue above 600 Hz

