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Abstract

Dueco, a final stage manufacture of utility trucks, was awarded a congressionally directed cost shared contract to develop, test, validate, and deploy several PHEV utility trucks. Odyne will be the primary subcontractor responsible for all aspects of the hybrid system including its design and installation on a truck chassis. Key objectives in this program include developing a better understanding of the storage device and system capability; improve aspects of the existing design, optimization of system and power train components, and prototype evaluation. This two year project will culminate in the delivery of at least five vehicles for field evaluation.

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Introduction

This final report describes the progress realized in the design, development, and demonstration of the Dueco Plug-In Hybrid Engine project.

This project culminated in the deployment of a new plug-in hybrid system for medium and heavy duty trucks mounted with equipment for utility, telecommunications, and other markets. This PHEV system incorporated a novel approach to connect the hybrid engine to the vehicle offering idle reduction, regenerative braking, launch assist, climate control, and exportable power.

This contract was awarded to Dueco/Odyne on October 1, 2009 and was a two year congressionally directed project, which was administered by the Department of Energy, and focused on the development of a hybrid technology for large utility trucks. Advancements in the technology included the design, development, and demonstration of an advanced PHEV system. The deliverables consisted of at least five vehicles equipped with the latest advancements in the Odyne PHEV systems. All of the utility trucks included a Navistar chassis, an Allison transmission, and were fitted with the GEN 2 hybrid system, which contain two lithium battery packs with a combined energy capacity of 28 kWh.

Odyne had developed and demonstrated several class 5-8 trucks equipped with proof of concept hybrid systems. At the onset of the contract, field performance of the proof of concept units was reviewed, and weaknesses were identified in the existing hybrid system. In general, the hybrid system performed well but issues surfaced relating to durability, serviceability, and the weight of the batteries. A clean sheet design was initiated using automotive grade components, manufactured by Tier 1 and Tier 2 suppliers, in an effort to improve reliability and reduce component costs. Functionally, the new design (GEN 2) incorporates many of the same features as the proof-of-concept system, yet has the ability to be modified to meet the diverse duty cycles that are typical of utility trucks.

Overall, most of the new components were engineering prototypes or early production versions of hybrid components that were slated to become commercially available. The lithium ion based battery packs were an interim solution while a Tier 1 supplier was conducting validation tests on a turn-key battery system. Initially the contract had a six month window to evaluate the performance of the next generation product (GEN 2) but delivery dates slipped as a result of supplier issues, prototype components, and driveline related concerns. This resulted in a several month delay in the delivery of the vehicles as they underwent a variety of component replacements and updates to improve the durability of the system. Ultimately, all five vehicles were delivered to the customers and are being field tested.

Executive Summary

Dueco/Odyne was awarded a cost shared contract to develop, test, validate, and deploy advanced plug-in hybrid electric utility vehicles equipped with truck mounted equipment for the utility and/or telecommunications markets. This demonstration intensive contract was awarded October 1, 2009 and scheduled for completion within a two year time frame. The first phase of the program focused on the collection of field data from proof-of-concept plug-in hybrid vehicles (PHEV's), development of the next generation system specifications, and system improvements and enhancements

The overall strategy, which influenced the direction of the hybrid program, was to leverage automotive suppliers that were developing hybrid products for the automotive market. These suppliers offered a limited range of validated products, so in some cases, Odyne incorporated preproduction or engineering prototypes into the demonstration vehicles. When plausible, Odyne was required to engineer, fabricate, and integrate alternative solutions while the desired components were undergoing validation tests. As a result, a number of modifications and upgrades occurred on several components prolonging the installation activity.

While new components were being secured and evaluated, field tests were continuing on a variety of proof-of-concept units which consisted of sales demos and units purchased by early technology adopters. These tests provided insight into usage profiles, reliability, and serviceability concerns. As a result of these field tests, it was understood that the hybrid system needed to adapt to the variability in the duty cycle which ranged from a hybrid electric vehicle (drive mode only) to an idle-off mode (stationary mode). New components were incorporated into the next generation product culminating in a "clean sheet" design of both the hardware and software.

Despite a variety of delays stemming from supplier related issues and drive train NVH (noise, vibration, and harshness), the hybrid systems were successfully installed on five customer purchased utility trucks. Most of the trucks were delivered with a fully functional hybrid system. The two compressor trucks were delivered with the drive mode disable due to clutch bearing failure. This issue has been resolved and the last truck is scheduled for updates in late May, 2012. Meanwhile, vehicle and hybrid data are being collected from all of the vehicles.

Results and Discussion

This segment of the report will discuss some of the key component features and technical evaluations realized in this program. Since all of the control software and components are new, emphasis will be placed on the improvement in these components and integration activities. Additionally some systems and subsystem evaluations will be discussed as well.

Component Development

Motor

The motor configuration has undergone significant modifications since its selection. While the initial stator/rotor design has not been changed, a variety of improvements have been incorporated to improve the durability of this component. Initially, this motor used transmission oil for cooling and it was determined, early in the program, that cooling in series/parallel, with the Allison transmission, was not viable due to the excessive parasitic losses that would occur while the vehicle was in the stationary mode. Consequently a water/glycol cooling jacket was developed, for a through shaft motor, which provided adequate cooling for most applications. An illustration of the motor and bracket configuration is displayed in Figure 1.

Figure 1: New Motor Configuration (new coupler design and mounting)

Additionally, an IP67 rated high voltage connection, splined shaft design, and sealed bearings were incorporated to improve reliability and durability of this component.

Initial prototypes experienced failures that were attributed to higher than expected torque spikes observed on the drive shaft which was connected between the motor and PTO.

The influence of these spikes was reduced as a result of increased motor shaft diameter, stronger spline design, new shaft material, and through a reduction of shaft stress concentration points. Furthermore, a dampened drive shaft was also evaluated to determine the impact on peak torque reduction.

Inverter

Minimal modifications were required of the inverter. Some adjustments in the design were made as a result of high voltage connectors and mounting location. Validation tests identified some minor issues but the units were able to be exchanged and updated. Matching motors to inverters continues to be a challenge and efforts are underway to correct this issue via software or a more convenient setup procedure. While the inverter is oversized for this application, its durability and reliability make it a good candidate for the hybrid truck environment (see Figure 2).

Figure 2: Hybrid Inverter Design

Rechargeable Energy Storage System

Efforts to select a battery pack have been challenging and two technologies were considered for evaluation on these five deliverables. The first technology option under consideration was the AGM lead acid battery technology which consisted of fifty 12 volt battery modules (62 Ah) connected in series. While the lead acid technology is a mature and a relatively safe chemistry, the size and weight of this system does impact the load capacity of some vehicles. Additionally, the absence of a lead acid BMS (Battery Management System), a compact soft start contactor assembly, limited life, and leakage currents are all issues that have forced Odyne to consider lithium ion as the primary option for powering the hybrid system. Experience, which has been gathered as a result of testing approximately 30 hybrid units in the field, suggests that lead acid batteries are not the most cost effective solution to store energy. Therefore, activities to incorporate an AGM lead acid battery system, into the next generation hybrid product, were suspended.

The absence of validated lithium ion battery packs forced Odyne to look at other solutions. The most cost effective and near term solution was to identify lithium ion

battery modules that could be packaged in a configuration similar to the proof-of-concept prototypes. This enabled Odyne to leverage an existing lead acid battery pack design, which has been field tested for the past two years. A model of the lithium ion pack is displayed in Figure 3. In addition to a common battery module size (U1); this product also has a BMS in which all of the cells and modules in the battery pack can be monitored. This revised design was configured so that the BMS, contactors, connectors/disconnects, and fuses are all co-located in the battery box.

Figure 3: Model of 14 kWh Lithium Battery Pack

This battery pack design was a short term solution as it provides similar energy, at the 1C rate, in comparison to the lead acid batteries. Dual pack (28 kWh) integration has been accomplished and implemented on all of the deliverables.

The long term solution was to obtain a validated battery pack which includes the BMS, contactors, and production intent RESS's (rechargeable energy storage systems) from JCS (Johnson Controls Saft). Several of these packs (see Figure 4) have been received late in the program and installed on an engineering development chassis.

While some modifications of the battery system have been requested, weekly management meetings with JCS have resulted in quicker progress towards production intent design. A JCS plant audit, performed in September, 2011, was conducted to review processes and procedures for the construction and testing of the RESS. PPAP documentation was reviewed and approved during an on site evaluation. The supplier is currently on schedule to meet their production launch date. These battery packs will be used for any future or replacement requirements.

Figure 4: JCS Battery Pack

Driveline

Preliminary driveline torque readings suggested that the u-joints and PTO drive shaft were undersized for the higher torque (compressor truck and digger/derrick) applications. Based on the torque loads, speed, and driveshaft angle, it was determined that the PTO driveshaft would not meet the durability objectives outlined at the beginning of the program, so a larger u-joint/driveshaft combination was used for the higher torque applications. Figure 5 depicts the typical torque limits for all of the driveline components.

Figure 5: Standard Hybrid Driveline Torque Limits for a Hydraulic System

For most bucket truck applications, the existing coupling/driveshaft configuration meets the durability requirements for hydraulic applications. An important aspect of the hydraulic application was the drive train alignment, selection of the couplings, and the ability to accommodate a variety of hydraulic pump shaft configurations. The input side of the hybrid motor was connected to the 1310 split drive shaft via a 14 tooth splined coupling. The output side of the motor also has a splined shaft which is connected to a love joy coupling. A bell housing provides the mechanical connection between the motor and hydraulic pump, while housing the coupling. The love joy coupling provides some relief for shaft misalignment, dampens torque spikes transmitted through the motor, and allows for multiple hydraulic pump connections (keyed, 14 tooth spline, or 15 tooth spline).

The configuration for a digger derrick or a compressor truck (see Figure 6) is unique in comparison to conventional applications. One popular configuration for the digger derrick is to connect two hydraulic pumps in tandem. This arrangement places a high cantilevered load on the bell housing requiring additional support for the pumps. Both of these pumps are placed in a bypass mode, during the drive cycle, to minimize parasitic hydraulic loads. The compressor truck has a similar issue relating to parasitic loads while in the driving mode. The compressor is disconnected from the drive train via an electromagnetic clutch that is placed in the driveline between the motor and compressor. The clutch remains disengaged until a demand signal is initiated thereby closing the clutch while the motor starts. Several design iterations were conducted with the supplier before an acceptable clutch solution was identified and implemented.

Figure 6: Selected Component Driveline Torque Values for a Compressor System

Air Conditioning

The air conditioning system is a split system in which the evaporator is mounted on the back wall (or under the seat) of the cab, and the condenser and compressor are mounted on the cooling subsystem. This compressor is powered directly from the hybrid battery and operates only in the stationary mode.

This split air conditioning system has been installed on four of the deliverables (one customer did not order this option) and pull-down tests were conducted on the NV truck (crew cab - compressor application) since it had the largest cabin volume. The a/c system was sized to maintain cabin temperature in hot ambient conditions during stationary operation. All components and control methodology have been evaluated and Figure 7 illustrates the results from multiple cabin thermocouples during the pull-down tests. While this auxiliary a/c system is not as effective as the vehicle a/c, it was capable of a 20°C temperature drop within an acceptable time frame. Hot ambient condition tests were completed and the results indicate suitable performance for pull-down and maintenance of temperature set points.

Figure 7: Pull Down Test for the Auxiliary Air Conditioning System

Cooling Subsystem

A cooling system was designed to address the heat load produced by all of the hybrid components. The glycol based system operates independently from the engine's system and is equipped with a brushless dc pump and fan enabling variable energy consumption based on cooling requirements. Components were connected in a variety of parallel and series configurations with minimal impact on the overall cooling results.

Preliminary tests suggest that the inverter and motor heat generation may not be as large as anticipated so a smaller cooling package may be suitable. Since the same fan was used for both the radiator and condenser, a more compact condenser, with similar heat transfer and refrigerant condensation, may be more suitable for this configuration. This may reduce the size needed for the thermal package yet provide similar performance. An illustration of the cooling package, including condenser and refrigerant compressor, is illustrated in Figure 8.

Figure 8: Illustration of the Cooling Package Including the A/C Condenser and Compressor

Electronics Bracket

The electronics bracket was designed so that one central location could be identified that would contain all, if not most, of the electronic components necessary to operate the hybrid system (see Figure 9). The components on this bracket are the central point for all of the low voltage wiring; are IP67 rated and include the power distribution module, vehicle control module, dc-dc converter, and battery charger. The bracket is located above the drive shaft and in between the frame rails. Locating all of the components in close proximity reduces the cost and complexity of the installation.

Figure 9: Electronics Bracket

Telematics

A Telematics system is being used to transmit high level J1939 CAN bus vehicle data, CAN bus data from the hybrid system, and analog data from sensors. These data are used to monitor the impact by hybrid system on the vehicle, and provides information on critical operation parameters of the hybrid system. Additionally, fault codes are broadcasted, as they occur, providing insight on potential component failure modes. A

list of some of the parameters measured, in the stationary mode, is depicted in Table 1. When the hybrid system is used in the conventional driving mode, a different data set is measure and transmitted via Telematics. Typically this data set includes a substantial amount of driving related information.

Table 1: Representative Hybrid system CAN Bus Information

Battery Maximum Temperature	°F
Battery Minimum Temperature	°F
Cell Voltage Maximum	mV
Cell Voltage Minimum	mV
Inverter Temperature	°F
Traction Motor Temperature	°F
Inverter Torque	lb-ft
Chassis Battery Voltage	Volts
Traction Motor Speed	Rpm
Composite SOC	%
Composite Voltage	Volts
Load Current	A
Battery Pack 2 SOC	%
Battery Pack 1 SOC	%
Pack 1 Voltage	Volts
Pack 2 Voltage	Volts
Compressor Temperature	°F
Receiver Pressure Sensor	PSI
Reservoir Pressure Sensor	PSI
Compressor Timer	Hours
Hybrid State	State
Vehicle State	State
BMS1 Contactor State	State
BMS2 Contactor State	State
ePTO Enable	Status
Air Conditioner Enable	Status
Exportable Power Enable	Status
Heater Enable	Status
Compressor Enable	Status
Charger Proximity Switch	Status
Hydraulic Pressure Request	Status
Compressor Airflow	cfm

It should be noted that this list includes several parameters related to the pneumatic system that is installed on the compressor trucks. The hybrid control unit (HCU) also monitors and controls the pneumatic system on these trucks and reports the system conditions via the Telematics unit. Due to the design of the supplier's compressor controller and the "on demand" feature required to conserve battery energy, Odyne's control system incorporates all of the control functions of the compressor system.

Bracket Design and Validation

The guideline for defining the structural performance of the various brackets is the SAE J1455, Joint SAE/TMC Recommended Environmental Practices for Electronic Equipment design for Heavy Duty Trucks. In general, this specification was intended for electronic component applications but the road vibration analysis serves as a worthwhile reference for the brackets. Once the finite model was created and all of the loads and restraints defined, the following analyses were conducted:

- 1) Modal analysis to determine natural frequencies
- 2) Random vibration analysis and associated fatigue analysis using power spectral density curves (Figure 10-12)
- 3) Operational shock analysis

These analyses will be conducted to determine displacements and stresses when the brackets were subjected to random vibration loads, and operational shock loads.

Fatigue Analysis

Modal studies were performed to determine the natural frequencies of the brackets and frequency sweeps were performed to determine the transmissibility factor. The random vibration studies were conducted using the modal superposition method and the random vibration spectrums referenced in Figures 10-12. An example summary of the worst case rms stress and lowest cycle life contours for the vibration direction are summarized in Table 2.

Figure 10: Random Vibration Loads, Transverse (X) Direction

Figure 11: Random Vibration Loads, Vertical (Y) Direction

Figure 12: Random Vibration Loads, Longitudinal (Z) Direction

Table 2: Random Vibration Stress / Cycle Life Summary

	Loading Direction	Max Von Mises RMS Stress (psi)	Cycle Life	Location
Electronics Bracket	Transverse (X)	2,241	3,715,000	Support Flange
Electronics Bracket	Longitudinal (Y)	568	7,533,000	Flange Fillet
Electronics Bracket	Vertical (Z)	2,453	3,415,000	Corner Bend
Battery Bracket	Transverse (X)	3446	1,832,000	Support Point
Battery Bracket	Vertical (Y)	4374	1,148,000	Support Point
Battery Bracket	Longitudinal (Z)	2814	2,223,000	Bottom Plate Weld
Cooling Bracket	Transverse (X)	2,802	2,203,000	Pump Mount Bracket
Cooling Bracket	Vertical (Y)	2,978	2,051,000	Fan/Shroud/HE Mount Hole
Cooling Bracket	Longitudinal (Z)	3,228	1,892,000	Cooling Bracket Mounting Hole
Motor Bracket	Transverse (X)	8,700	315,500	Corner/Bend
Motor Bracket	Vertical (Y)	5,425	1,122,000	Frame Rail to Bracket Connection
Motor Bracket	Longitudinal (Z)	2,380	3,081,000	Corner/Bend

The results for the random vibration analysis suggest that most of the components can achieve over one million cycles in all vibration directions. The one component that did not achieve this level of random vibration is the motor bracket in the transverse (X) direction. Peak stresses were observed at bends, corner radii, or mounting flanges and are displayed in Figure 13. Adding more generous radii at these bends and corners along with adding gussets in the support flanges was expected to reduce stresses further.

Figure 13: Motor Bracket - RMS von Mises Stress, Random Vibration, Transverse (X) Direction

Operational Shock Analysis

Operational Shock analysis represents the shocks encountered during the life of the vehicle that are caused by curbs, potholes, etc., and vary widely in amplitude, duration, and occurrence. The shock profile is meant to represent a vertical shock load caused by a depression in the roadway. The vehicle would pass over the depression at 30 mph (48 kph) and would subsequently become airborne. The severe shock would be experienced when the vehicle returns to the roadway.

The operational shock analyses was accomplished by determining the transmissibility factors for a single degree of freedom system with the mass of the bracket and a variable spring stiffness that was subjected to the SAE J1455 shock load profile illustrated in Figure 14. The peak accelerations from this shock profile (-14 g's operation) was multiplied by the transmissibility factor, corresponding to the primary system natural frequency. The resulting acceleration is approximately -19 g's (see Table 3).

Figure 14: Operational Shock Load Profile

Table 3: Operational Shock Analysis Results

	Load (g's)		Max Disp (in)	Max von Mises Stress (psi)	Location	Allowable Stress (psi)
Component	Direction	Value				
Battery Bracket	Vertical (Y)	-19.74	0.500	104,000	Support Point	36,000
Electronics Bracket	Vertical (Z)	-19.46	0.506	45,150	Corner Bend	58,000
Cooling Bracket	Vertical (Y)	-19.46	0.164	67,600	Fan Mount	36,000
Motor Bracket	Vertical (Y)	-19.07	0.506	>58,000	Bracket	58,000

The vertical shock analysis of the Electronics bracket appears much better than the other brackets but there is still room for improvement.

It should be mentioned that the method of determining the transmissibility factor and application in an equivalent static analysis, is a very conservative method for calculating the effects of a shock load. Further, specification SAE J1455 states that the operation shock curve, defined in Figure 14, is a very severe shock curve. With these considerations, the shock analysis results should be considered rather conservative.

System Performance

Overall system performance can vary substantially from truck to truck based on the aerial device, chassis selection, and duty cycle. While there appears to be a general acceptance of the CILCC (Combined International Local and Commuter Cycle) as the drive cycle for utility trucks, a representative duty cycle for the stationary mode has yet to gain similar acceptance. In an effort to elucidate the energy required while the truck is stationary with the PTO engaged, conventional work trucks were equipped with sensors (pressure and flow) and a Telematics system enabling measurements of the hydraulic horsepower to be recorded every 10 seconds. The trucks instrumented were identified as vehicles that would have a duty cycle similar to each deliverable.

The results depicted in Figure 15 illustrate engine rpm as a function of time and includes information on the drive cycle and duty cycle. The key item to note in this graph relates to the idle time and two speed engine operation while the PTO is engaged. When the PTO is rotating, the rpm increases slightly to override any idle limiting protocols that may exist. At this lower speed, the hydraulic pressure and/or flow rate is reduced, so the aerial device moves slower. There is a high speed step which increases the hydraulic horsepower allowing the hydraulic powered equipment to move faster. In this particular duty cycle, the rpm was increased and held at the higher rpm for approximately one hour.

Figure 15: Engine RPM vs. Time for a Conventional Utility Truck

In defining the system requirements, it was necessary to have a clear understanding of the breadth of applications that the hybrid system would have to power in the stationary

Figure 16: Digger/Derrick Battery Data in the Stationary and Driving Mode.

mode. A first generation hybrid system (GEN 1), equipped with a digger derrick, was outfitted with sensors so the battery voltage and current could be monitored during the drive cycle and for specific stationary operations as illustrated in Figure 16. This data illustrates the electrical demand based on typical digger/derrick device movements. The stationary data was used to determine the necessary battery capacity needed to run the aerial device, without the engine running, for a specific period of time. Limited data, in the driving mode, provides a sense of the peak currents for assisting in vehicle launch and regenerative braking. The stationary loads on the digger/derrick represent some of the highest loads measured on a utility vehicle.

Stationary mode data collection has also been completed on a medium duty utility truck equipped with a 55 foot aerial device (see Figure 17). The peak loads for the aerial device (10 kW) are substantially lower than for the digger/derrick (33 kW). These data identify the hydraulic loads realized for selected hydraulic functions. This data also contributed to the specification requirements for the second generation hybrid system (GEN 2).

Figure 17: Aerial Device Battery Data in the Stationary Mode

The hybrid system is expected to operate with a wide variety of equipment that has different rpm and torque requirements. In general, most of the aerial devices are installed with preset PTO speeds to obtain the desired output of the hydraulic or pneumatic units. Industry practice is to set the high idle speed and adjust pump (or compressor) flow rates to get the desired performance. Table 5 illustrates the speed and torque requirements for typical work truck equipment.

Table 4: Utility Truck Device Requirements

Unit Type [Continuous]	Speed (RPM)	Horse- power (HP)	Torque (Nm)
Small Aerial	1200	9	53
Medium Aerial	1200	13	77
Large Aerial	1200	24	142
Air Compressor	1675	47	200
Digger Derrick	1800	68	269

As a result of the delayed vehicle delivery, the quantity of system level performance data taken on the deliverables was minimal. However, a brief driving cycle was conducted to monitor CAN bus data from the hybrid controller and key vehicle J1939 CAN bus data as illustrated in Figure 18. The torque in and out of the inverter and vehicle speed were measured as a function of time on the GEN 2 hybrid. For this test, the peak torque of the inverter was limited to approximately 175 Nm and positive torque is measured during launch assist while negative torque is displayed during regenerative braking. One of the key capabilities of this hybrid control system is the adjustability of the level of torque and its duration in the drive cycle.

Figure 18: PTO Torque and Engine Speed Monitored Over Time

Packaging

It is essential that the hybrid system minimizes the footprint on the chassis as there is considerable competition for space on the frame. Previous designs, used lead acid based chemistry, added considerable weight, and occupied valuable space throughout the chassis. The available space, illustrated in Figure 19, represents areas where the hybrid system could be installed and has a minimal impact on the body, aerial device, and other chassis mounted equipment. Odyne worked closely with the prime contractor (Dueco) in identify regions where hoses or wires were routed and where the sub-frame was tied into the chassis frame. Modifications to the body were also identified due to battery pack interference.

An illustration of a truck chassis equipped with the GEN 2 hybrid system is shown in Figure 20. The five main subassemblies have been designed for quick installation with minimal intrusion on body storage and tower position. This figure represents the final form of the product that is delivered to the final stage manufacturers.

Figure 19: Common Utility Vehicle Chassis and Body Configuration.

Figure 20: Location of Key GEN 2 Hybrid Components

Demonstration Units

A total of five trucks were delivered to utility customers equipped with a GEN 2 hybrid system. These deliverables included three bucket trucks and two compressor trucks, one of which was a retrofit. All of these trucks are International chassis equipped with an Allison transmission and Lithium ion battery modules manufactured by Valence. In general, these vehicles are located within Dueco's territory and will be serviced at regional facilities. Figures 21-25 are photos of the actual deliverables

Figure 21: Final hybrid deliverable to Choptank

Choptank Electric Cooperative, a Maryland based Touchstone Energy Cooperative, took delivery of a plug-in hybrid bucket truck with a Terex HR42M aerial device to be used in maintenance of electric lines. Choptank is the first electric cooperative to take delivery of the new Odyne advanced hybrid power system.

Figure 22: Final hybrid deliverable to NiSource

NiSource, a utility in Northern Indiana, took delivery of a plug-in hybrid bucket truck with a Terex TL41 aerial device for use in maintenance and construction of its electrical utility grid. This vehicle has a short wheelbase and had the cooling package mounted on the outrigger.

Figure 23: Final hybrid deliverable to PHI

Pepco Holdings Inc., one of the largest energy delivery companies in the Mid-Atlantic region, serving about 1.9 million customers in Delaware, the District of Columbia, Maryland and New Jersey, will be using a new plug-in hybrid underground utility vehicle with a Vanair under deck compressor for underground gas infrastructure maintenance. This compressor truck was for medium duty applications (100 psi, 125 cfm) and is equipped with a 7 kW quasi sine wave inverter that is powered from the hybrid battery.

Figure 24: Final hybrid deliverable to NV Energy

NV Energy will use its plug-in hybrid underground utility vehicle featuring a Vanair under deck compressor for maintenance of underground natural gas infrastructure in the Reno, Nevada area. This unit had been built for NV Energy as a conventional vehicle and Odyne retrofitted its advanced plug in hybrid system to enhance efficiency. The battery packs were mounted in the bed of the truck and replaced a 6.5 kW generator set. This truck represents the most severe application as it requires pneumatic pressure of 150 psi and flow rates of 160 cfm. This truck is also equipped with a 7 kW quasi sine wave inverter.

Figure 25: Final hybrid deliverable to Consumers

Consumers Energy, the principal subsidiary of CMS Energy (NYSE: CMS), providing natural gas and electricity to 6.8 million of Michigan's 10 million residents in all 68 Lower Peninsula counties, took delivery of a plug-in hybrid utility truck with a Terex 5FC55 55' aerial device. This truck is the first tandem axle vehicle equipped with the GEN 2 hybrid system.

Conclusion

The overall objectives for the design, development, and demonstration of a hybrid system have been accomplished for the Dueco Plug-In Hybrid Engines project. In fact, many of the accomplishments in this program go beyond the original intent of this project. At the onset of the project a broad survey was initiated to identify validated automotive grade components in an attempt to improve the reliability and durability of the hybrid system. Unfortunately, many of the components were in the development phase yet some suppliers were willing to provide samples with the understanding that product iterations would occur. As a result of obtaining this state-of-the-art technology, modifications or up-dates were required of the supplier's software and hardware. Where necessary, Odyne has developed interim solutions due to the lack of mature hybrid components from the supplier base.

Tasks relating to component verification and optimization have been postponed or eliminated due to contract timing constraints. Bracket validation models were developed and consisted of random vibration and operational shock analysis referencing SAE 1455 vibration and shock load recommendations for heavy duty trucks. In general the electronics bracket, inverter/motor bracket, and battery bracket results looked acceptable with some minor improvements identified, which should improve cycle life.

In general, integrating the hybrid system for the hydraulic applications was straightforward with minimal complications. However, deviations from the original performance requirements have occurred on the retrofit compressor truck and modifications to the compressor control system were required to take advantage of the "on demand" feature of the hybrid system. The hybrid system controller software has been reconfigured to control the entire compressor subsystem for both compressor trucks. The control system also incorporates a dual pressure feature and an electromagnetic clutch that disengages the compressor during the drive mode.

Five vehicles have been delivered to program partners with prototype GEN 2 hybrid systems for field evaluation. Efforts are underway to complete a comprehensive test plan for the software, components, and subsystems. Additionally, the test plan will include: system level performance verification and validation (where feasible), third party verification, and customer validation tests. Telematics data will continue to be collected, on deliverables, for approximately twelve months.

Numerous ongoing improvements to the GEN 2 hybrid system have been planned and include; improved bracket design, OEM grade electrical components, more efficient control algorithms, better packaging, and refined assembly techniques. These improvements will be addressed in complementary demonstration efforts or as part of future investments in the technology.

References

No references in this document.

List of Acronyms and Abbreviations

AC Motor	Alternating Current Motor
AGM	Absorptive Glass Mat
Ah	Amp hour
BMS	Battery Management System
CAN bus	Controller Area Network bus
CILCC	Combined International Local Cycle and Commuter
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
DFMEA	Design Failure Mode Effect Analysis
DOE	Department of Energy
DV	Design Validation
EMI	Electro Magnetic Interference
ePTO	Electric Power Take Off
FEA	Finite Element Analysis
g's	Acceleration Constant
GEN 1	Generation 1 Hybrid System
GEN 2	Generation 2 Hybrid System
GPRS	General Packet Radio Service
GVWR	Gross Vehicle Weight Requirements
HC	Hydro Carbons
HCU	Hybrid Control Unit
HEV	Hybrid Electric Vehicle
HVAC	Heating, Ventilating, Air Conditioning
Hz	Hertz
J1939	Control protocol for trucks
kW	Kilowatt
kWh	Kilowatt-hours
MPG	Miles per Gallon

List of Acronyms and Abbreviations – continued

NO _x	Nitrogen Oxide
OEM	Original Equipment Manufacturer
PDM	Power Distribution Module
PHEV	Plug in Hybrid Electric Vehicle
PM	Particulate Matter
PPAP	Production Part Approval Process
PSD	Power Spectral Density
psi	Pounds per Square Inch
PTO	Power Take Off
PV	Production Validation
RESS	Rechargeable Energy Storage System
rpm	Revolutions per Minute
rms	Root Mean Square
SAT	Satellite
SOC	State of Charge
SRD	System Requirements Document
TCU	Telematics Control Unit
Tier 1	Company that makes products for OEM suppliers
Tier 2	Company that makes products for Tier 1 suppliers