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Testing of a Retrofit Hybrid Drive System and Biodiesel Blends in a Recycling Truck

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Objective

The objective of this project was to demonstrate the advantages of using a new retrofit hybrid drive system on a recycling truck and to show how combining this new technology with biodiesel can be beneficial from both a cost savings and an environmental standpoint of reducing regulated emissions. A secondary objective was to compare the performance of running B5 to running B20 with the hybrid system both on and off.

Description of Work

There are several electric and hydraulic hybrid drive systems available for trucks and buses. They are usually installed between the engine and the transmission and are an integral part of the vehicle and must be installed at the time the vehicle is manufactured. Hybrid drive systems are most effective in driving situations where there are numerous stops per mile. Therefore they are most effective on shuttle buses, urban school buses and delivery trucks.

We selected the VTM electric hybrid system because it can be fitted at any time to almost any front engine rear drive truck or bus with a GVW of less than 33,000 lbs. The motor/generator is installed between the output side of the transmission and the rear differential. The motor generator is 32.5 inches long yoke to yoke and is 14 inches in diameter and weighs 340 lbs and has a maximum torque output of 400 lb-ft.

During deceleration the motor generator stores energy in ultra capacitors. The truck was fitted with a double capacitor that has 126 lbs of capacitors that can provide 400 lb/ft of torque for 32 seconds. The hybrid can be turned off or if the hybrid system fails, power just goes straight through. Total weight of the complete system is 580 lbs. The hybrid system is connected to the truck's 12 volt circuit, the brake line via a pressure sensor and the accelerator pedal with a throttle position sensor.

The hybrid drive system was purchased from Variable Torque Motors LLC, (VTM), Fort Wayne, Indiana. The City of Minneapolis selected a Crane Carrier, CAT powered recycling truck for the platform for the retrofit; see Figure 1.

Figure 1. Recycling Truck with Trailer

The truck has a GVW of 33,000 lbs and always pulls a multi-compartment trailer with a GVW of 4,500 lbs. The empty weight of the truck is 19,940 lbs plus trailer empty weight of 2,900 lbs for a total of 22,940 lbs. The trailer never carries more than 1,000 lbs of recyclables.

The memorandum of understanding to conduct the testing of the hybrid system was signed by the City of Minneapolis and the University of Minnesota on April 12, 2010.

The truck was modified and the system installed by Midwest Diesel Service of Minneapolis.

The hybrid drive system with double ultra capacitor control system and cooling system cost $29,000 and the installation kit cost $1,850. The modifications to the truck and installation cost $11,019.

The installation included removing the carrier bearing and two driveshafts, removing the old oil tank, and moving some air and hydraulic hoses. Midwest installed the motor/generator, purchased two new correct length drive shafts and connected them between the transmission and the motor/generator and between the motor/generator and the rear differential as shown in Figure 2.

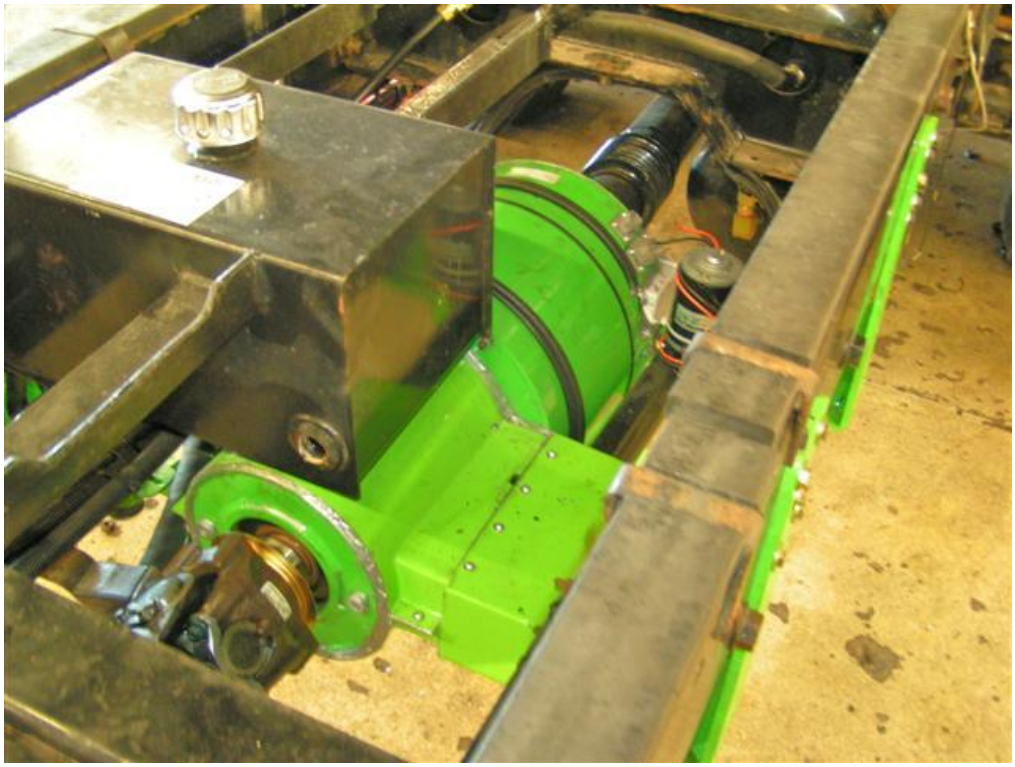

Figure 2. Motor/Generator Unit between Two New Drive Shafts.

A new hydraulic oil tank was fabricated and installed in front of the motor/generator as shown in Figure 3.

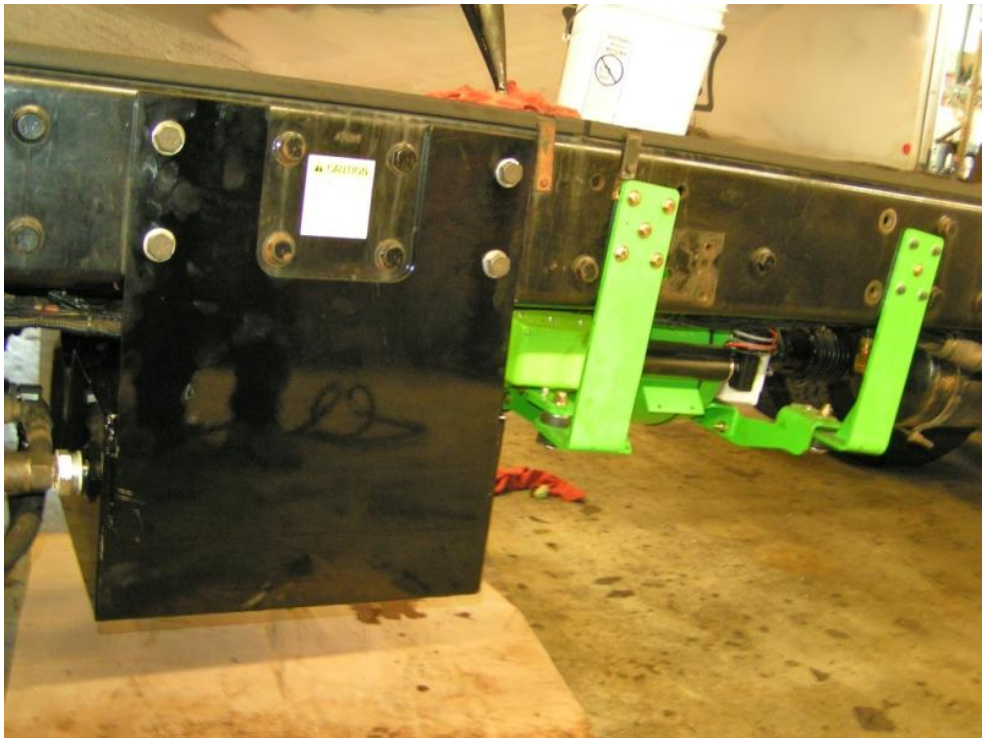

Figure 3. New Oil Tank

Because this truck has a dumping box and the compartments hang below the frame rails of the truck, there was no place for the capacitors and control boxes under the truck. A structure was fabricated behind the cab to hold the capacitors and control boxes and the cooling system as shown in Figure 4.

Figure 4. Ultra Capacitors and Control Box

The truck was test driven and returned to the City of Minneapolis on June 4, 2010. It passed its annual DOT safety inspection on June 7 and was returned to service on June 8. Final wiring and calibration was completed on June 29-30 by VTM. A minor problem with the safety interlock system was corrected on July 5.

The testing of the truck began July 16, 2010 and continued to December 30, 2011.

The route is made up of 10 separate daily residential routes. Therefore the total route is 10 days. The pickups are made in residential alleys with a typical residential lot being 40 feet wide. The driver usually stops between every other house and collects the recyclables from two houses on each side of the alley each time he stops. Therefore the distance the truck travels between alley stops is 80 feet. Because the stops are so close together, the driver uses very little throttle to accelerate the truck to the next stop and the transmission does not shift out of first gear since the maximum speed is only a few mph. Also when the truck slows, the engine does most of the deceleration of the vehicle, therefore the brakes do very little work.

We found that this short and slow cycle leaves little for the hybrid to do in assisting the acceleration of the vehicle since the hybrid does not engage until 0.3 mph. It does not recover much energy during deceleration because the engine does most of the braking, and regeneration stops when the truck speed drops to 0.2 mph. Thus, in the alleys there is very little time that the hybrid system is active, and regeneration is compromised by the large amount of engine braking. The system appears to be effective when the truck is driving from the garage to the neighborhoods and returning to the garage.

Testing

The test conditions were with the system turned on and off and with B20 made with number 2 diesel fuel, and B5 made with number 1 and number 2 diesel fuel. The onboard engine computer provided overall mpg for each two-week test period and was also able to provide driving only mpg by segregating out idle and dumping time fuel consumption. The driver also filled out daily cab tickets on which he recorded the date, odometer reading and the amount of fuel he added each day.

No maintenance data was recorded because no maintenance was required on or related to the hybrid system.

Testing started on the original route July 16, 2010 and concluded April 22, 2011.
Testing began on the new route on May 8, 2011 and concluded December 30, 2011.
The new route was farther from the garage and the new neighborhoods did not have as many residents recycling. Therefore, there was more distance between some stops. It was hoped that this new route would allow the hybrid system to have more opportunities to regenerate and do more work.

In an effort to improve the hybrid's performance, we tried four different combinations of parameters on what speed the assist begins and at what minimum speed regeneration stops. We also installed a hardware upgrade that increased the motor torque output 20 percent to its full 400 lb-ft. None of these had any effect on the fuel economy.

Data Analysis and Summary

A comparison of the drivers cab tickets and the onboard computer fuel mileage showed an excellent close correlation. The average difference between the computer and cab tickets was 0.08 mpg with the greatest difference on a single two-week period being 0.20 mpg.
It was decided to use the engine computer data because sometimes the cab tickets were not complete for the two-week period or had some other mistake or ambiguity.

Summary driving mpg original route

- With hybrid turned on with B20 made with number 2 - average 3.8 mpg
- With hybrid turned off with B20 made with number 2 - average 3.7 mpg
- With hybrid turned on with B5 made with number 1 - average 3.5 mpg
- With hybrid turned off with B5 made with number 1 - average 3.6 mpg

Summary of original route overall mpg
With hybrid system turned on made with B20 - average 2.7 mpg
With hybrid system turned off made with B20 - average 2.5 mpg
With hybrid system turned on made with B5- average 2.6 mpg
With hybrid system turned off made with B5 - average 2.6 mpg

Summary of new route driving mpg
With system on with B5 made with number 2 - average 4.3 mpg
With system on with B20 made with number 2 - average 4.2 mpg
With system off with B20 made with number 2 - average 4.1 mpg

New route overall mpg
With system on with B5 made with number 2 - average 3.0 mpg
With system on and B20 made with number 2 - average 3.0 mpg
With system off with B20 made with number 2 - average 3.0 mpg

Although the testing continued until December 30, 2011, no usable fuel economy data was obtained after October 21, 2011 because the fuel distributor delivered a variety of fuels from the end of October thru December ranging from: straight number 1, blend of 1 and 2 with a small amount of biodiesel, a load of B10 made with number 2, and several loads of B5 made with number 2. Therefore, no conclusion could be made about fuel economy during this period.

The fuel mileage and fuel energy content tracked correctly except for on the original route the B5 with system off is 102 percent of the mpg of B20 system off. However, the energy content of B5 made with number one is only 94 percent of B20 made with number 2.

Emissions Testing and Results

The exhaust gas of most interest in this project was NO_x. We wanted to see if the hybrid system when combined with B20 would have lower emissions than the base fuel without the hybrid.

The emissions were measured with a Greenline 8000 portable gaseous emission analyzer that was mounted behind the cab on emission test days. The exhaust sample was drawn from a sampling bung welded into the exhaust pipe between the engine and the muffler as shown in figure 5. Since the exhaust analyzer had to be located outside the cab, sampling could only be done on days when the temperature was above 32 °F and it did not rain.

On the days emissions were measured, the analyzer would be mounted on the truck, hooked to 12 V power from the truck and the sample line connected to the sampling port. The odometer reading was taken and the driver drove his route. All sampling was done on the eighth day of the two-week route so the data was comparable.

At the end of the day the analyzer was removed and the odometer reading recorded. The analyzer was taken back to the University and the data downloaded. Emissions data was logged on 10 different days during the project. Initial testing was conducted in the fall of 2010 on the first route. Testing then continued during the summer of 2011on the new route.

The NO_x emissions were averaged over the course of the day and varied from 250 to 310 ppm. The average NO_x emissions for all the days were 284 ppm with a coefficient of variation of 6%. This variation is not significant when compared to the many other changes that would affect the emissions and the drive cycle such as; changes in the ambient conditions, the changes in driving habits, the amount of recyclables placed at the curb, etc.

Figure 5. Greenline Emissions Sampler Mounted on Truck

Conclusions

There is no change in fuel economy with the hybrid system. The differences are only 0.1 mpg and are not consistent for driving only mpg and overall mpg and the two routes. Also, differences of 0.1 mpg are well within the experimental error of this type of testing.

There appeared to be a difference in driving mpg between B20 made with number 2 and B5 made with number 1, and these differences are the same as the change in the energy content of the fuel, but these differences are small and within the experimental error of the testing. The same applies to the limited data comparing B5 made with number 2 vs. B20 made with number 2.

There was no measurable difference in brake wear because these trucks have a very long brake life.

The average NO_x emissions during the days tested was 284 ppm with a COV of 6%. It is very difficult to accurately measure small changes in emissions during a demonstration program that has significant variable in other areas. We see essentially no change in the emissions beyond what would be expected due to variations in the route and the drive cycle. In order to more accurately assess the effect the hybrid unit would have on emissions, a much larger data set would be needed, but this is very difficult to do with the 10-day cycle the truck route consists of, along with weather issues.

The VTM hybrid system proved to be a trouble free, totally reliable system. No problems or repairs were required during the 17-month test period.

Recommendations

Since the recycling truck stops are too close together and the speeds in the alleys are too low for the system to operate efficiently, we recommend the hybrid system be reinstalled on a truck that travels greater distances between stops and achieves higher speeds.

The City of Minneapolis has Problem Materials (PM) trucks. These trucks are Freightliner Model 106 box trucks powered by CAT C7 250 HP engines, with a GVW of 31,300 lb. They are used to pick up things that cannot be handled by the refuse trucks or the recycling trucks. The materials they pick up are things like

furniture, appliances, tires, air conditioners, water heaters and electronics. Their pickups are scheduled in advance and the PM trucks therefore do not have regular repeating routes; the stops are blocks or miles apart. This type of route would allow the hybrid to regenerate and provide more assist during acceleration as the truck travels greater distances between stops and achieves higher speeds between stops. The cost of reinstalling the hybrid system on a PM truck would be minimal since we already have the complete hybrid system, and the installation on a PM truck would be much simpler than on the recycling truck.

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