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Development of a control algorithm for a hybrid drive system with three sources of power

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Abstract

A small vehicle prototype is under construction to evaluate the performance of three driving sources. The driving sources comprise an electric motor, a hydraulic pump-motor and a small IC engine as a range extender. All three drive sources are connected in a parallel drive. This paper presents the initial results of simulation using the MATLAB Simulink commercial software package. The simulation model predicts that using the hydraulic-electric hybrid drive versus a conventional electric vehicle will reduce both the peak current draw and the average current by approximately 50% in the Artemis Urban Cycle. These reductions are attributed to the launch-assist capability and improved regenerative braking of the hydraulic-electric hybrid. The next steps planned include laboratory and field experimentation to validate the parameters of the simulation model for the hydraulic-electric hybrid.

Keywords: hydraulic -electric hybrid;

1. Introduction

The small vehicle prototype consists of a tri-power source driveline where each drive can be tested in various combinations. The tri-power source consists of hydraulic, electric and IC engines. The tri-power sources are all connected in parallel. A second-hand VW Polo was selected for prototype build. The vehicle's engine and all peripheries (air-conditioner, radiator etc) were removed, leaving the gearbox in place. The modified vehicle is shown in Figure 1.

The hybrid drive system introduced consists of a 25kW electric motor, an 18cc open-loop over-centre hydraulic pump/motor and a 330 bar 15l accumulator coupled with a 600cc GPZ Kawasaki motor, rated at 55kW at sea level. The battery pack consists of six 12V, 1.99 kWh cells connected in series, to yield a total rating of 72V and 12 kWh. The gearbox was retained to enable physical tests relating to whether it would be better to change gears or leave the vehicle locked into a fixed gear. Similarly, the Kawasaki gearbox was retained to select a gear that matched the speed of the electric motor and the hydraulic unit. The Kawasaki engine is rated at 12 000rpm. The electric motor is rated at 5 000rpm. The hydraulic motor is rated at 3 600rpm. These speed differences were matched by changing the number of teeth on the timing belt that acted as the mechanical connection.

All three drives are connected in parallel using a toothed belt rated for the speeds and torques. Any combination can be tested by changing to a suitable toothed belt fitted onto the relevant pulleys. Similarly, ratios can be changed by changing the number of teeth in each pulley.

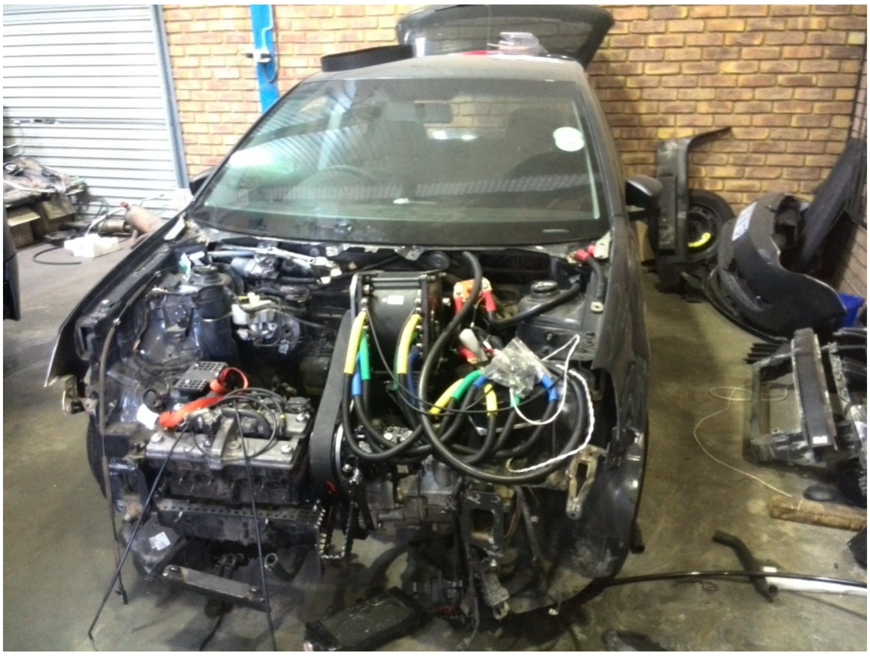

Figure 1: The modified Polo 1400 small vehicle consisting of three drivetrains.

2. Simulation Results

The MATLAB Simulink software package consists of mathematical modules that fully represent each of the three selected drivetrains. The modules are assembled with given initial conditions. The model for the conventional electric vehicle drivetrain is run and the drive cycle result is given in figure 2. Similarly, the model for the electric-hydraulic vehicle drivetrain is run and the drive cycle result is given in figure 3. Both drivetrain results show equivalence for the given initial conditions and is set as the reference for evaluation of the current drawn from the source. The current drawn from the source is given in figures 4 and 5 respectively for each of the two drivetrains. Visually, it can be seen that the current draw is significantly different. From the MATLAB toolbox, the maximum current drawn in the conventional EV is recorded as 432A and that for the hydraulic-electric hybrid model is recorded as 197A.

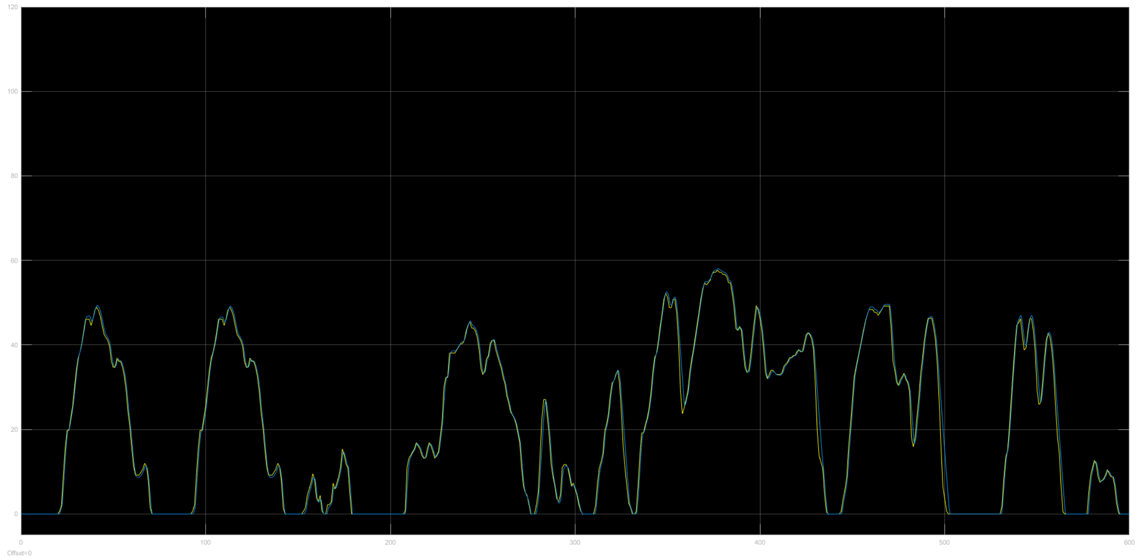

Figure 2: The conventional electric vehicle drive cycle

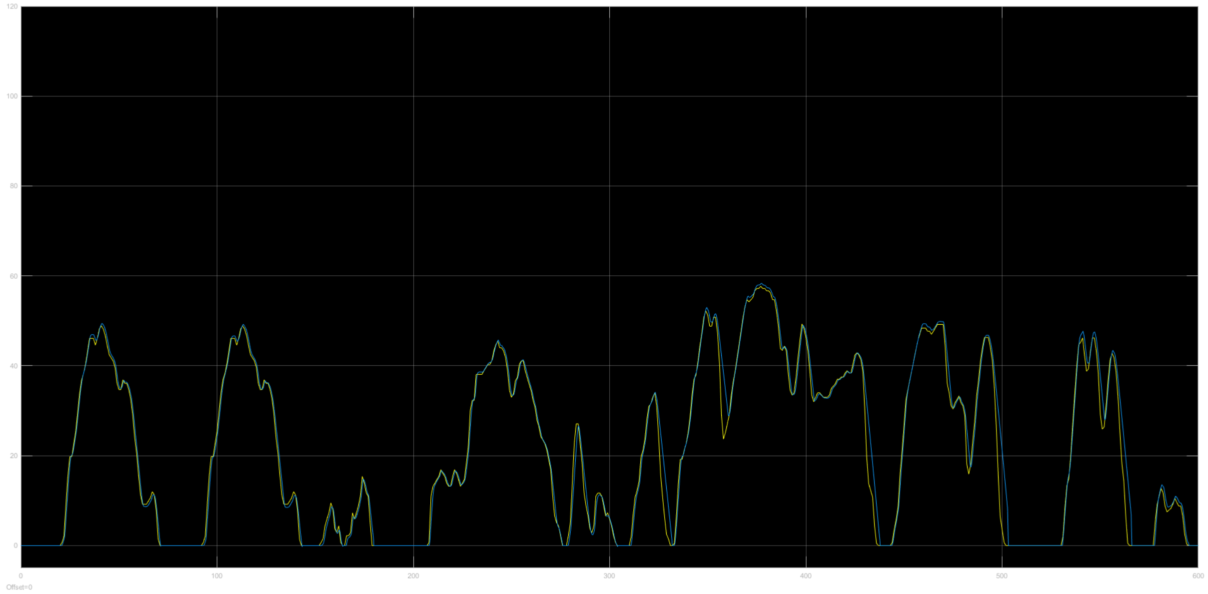

Figure 3: The electric-hydraulic hybrid vehicle drive cycle

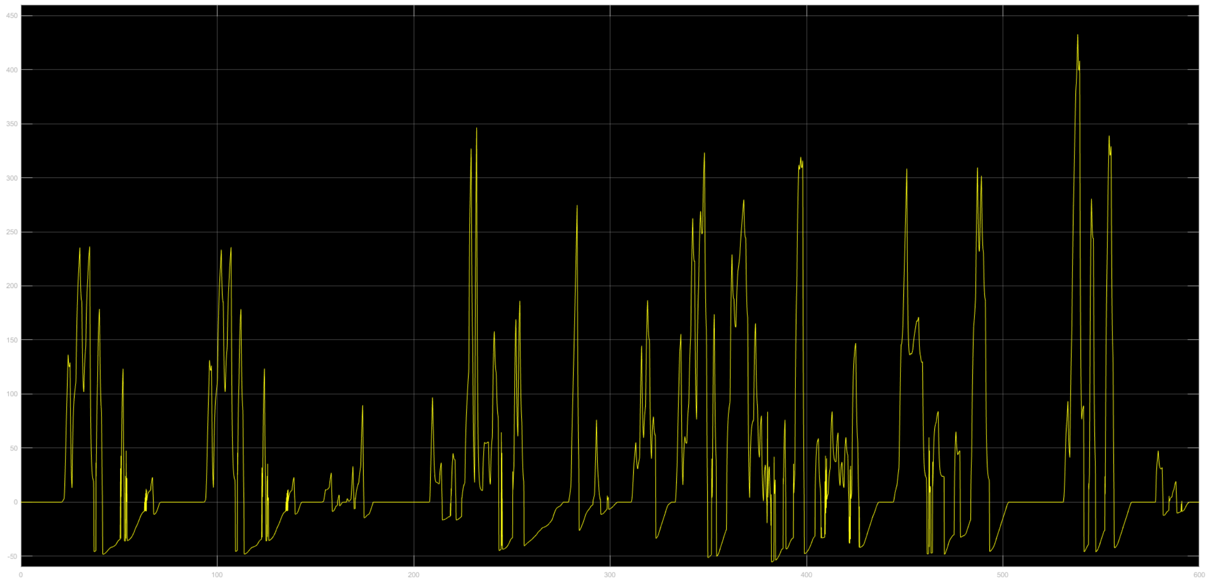

Figure 4: The current profile for the conventional electric vehicle drive cycle

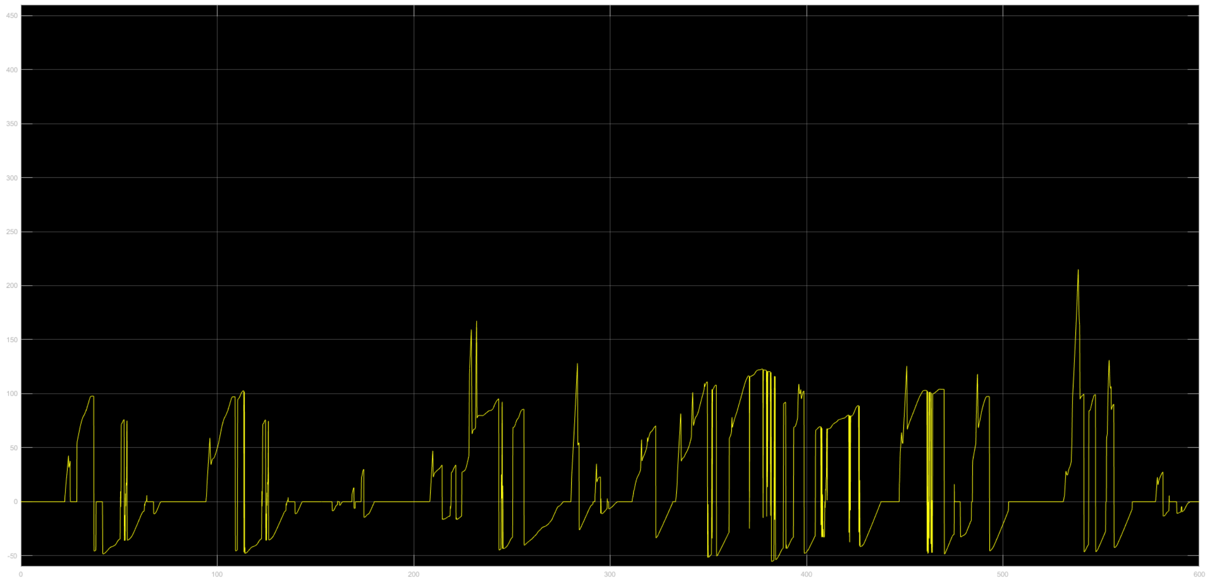

Figure 5: The current profile for the electric-hydraulic hybrid drive cycle

For completeness, the hydraulic motor pressure is given in fig 6 over the same drive cycle where the change in pressure indicates the contribution of the hydraulic system to both “launch-assist” and improved regenerative braking.

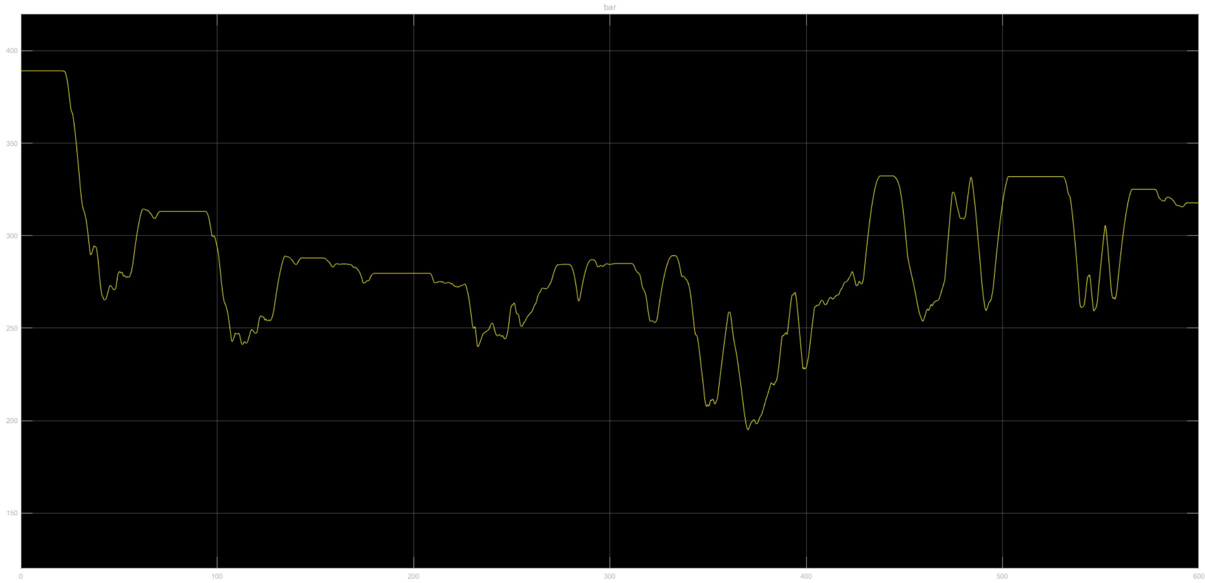

Figure 6: Hydraulic motor pressure for the electric-hydraulic drive cycle

3. Discussion of simulation results

3.1. Discussion of battery-life extension by reducing the Depth of Discharge

In a conventional electric drive, the depth of discharge is directly related to the drive cycle as this represents the energy required from the battery to complete the cycle. In a conventional electric drive, the maximum rate of regenerative braking is limited by the allowed charging rate for the battery and this is often lower than the required braking torque to meet a drive cycle, implying loss of regenerative-braking energy. Hydraulic accumulators do not have the same limitation. Hydraulic accumulators have higher power density and the ability to sustain high rates and high frequencies of charging and discharging. The high-power density of the hydraulic-hybrid concept is suited to all types of vehicles undergoing frequent stopping and starting phases – as in a typical urban driving cycle.

Chen [1] and Krishnamurthy et al [2] research demonstrated that energy stored in the accumulator can reduce the number of charging-discharging cycles of the battery over a given drive cycle. Hence, hydraulic-electric hybrids potentially can reduce the battery size and extend battery life. Additionally, braking can be done by both electric and hydraulic braking, which will further increase the ability to store energy.

In the hydraulic-electric hybrid model, power from the braking process is reused in the acceleration phase. Given that the hydraulic-electric hybrid regenerative braking system (HRBS) stores the vehicle's kinetic energy, benefits can be amplified with increased vehicle mass and with increased braking frequency. In addition, improved regenerative braking and with reduced charging current to the battery, the hydraulic-electric hybrid vehicle is expected to have improved battery life as compared to a standard electric vehicle

3.2. Discussion of the IC motor as more than just a range extender

Battery Electric vehicles rely on the battery charge in the vehicle to achieve any given range. This requires either a battery with sufficient charge or access to charging stations. This range limitation is one of the main challenges of electric vehicles and therefore one solution is to add an engine to charge the batteries. This project will explore the additional capability to charge both the hydraulic and electric storage with the on-board engine to determine the effect on battery range and life cycles. The proposed technology demonstrator that is being built has an internal IC engine that acts as a range extender, but additionally has the ability to directly drive the vehicle and charge both the hydraulic energy storage and electric storage and this will result in significant difference in application, including solving the “range anxiety” but also improving vehicle performance.

The Miser type design with the torque summing mode has the ability to run the IC engine far closer to the ideal BSFC (“Brake Specific Fuel Consumption”) line than a normal series hybrid as power can be diverted into and out of both the hydraulic and battery storage devices while still sending power to the conventional drive line as required. Previous work on a Miser equipped vehicle has shown this to be a viable method of operation. As an explanation, the IC engine has a “island’ of ideal operation relative to best BSFC this is a relatively fixed speed and power. This power generated (in a serial genset setup) can only be the sum of the power to charge the batteries at the max allowable rate PLUS the power sent directly to electric motor to power the vehicle. Typically, the power to charge the battery is relatively low as there is a maximum rate of absorption allowed into the batteries, therefore most must be directed to the motor to drive the vehicle. By inspection of drive cycles, there are many conditions where the load required to drive the vehicle is low and the internal IC engine simply cannot be held at the same power setting that equates to the best BSFC. So, while the manufacturers state the engine runs at best operating point, this is simply not feasible in any drive cycle, specifically an urban cycle.

There are numerous existing designs of electric vehicles with range extenders, such as the Chevrolet Volt, which has a small battery of 16kWh (versus this design of 12kWh) with an IC engine as a pure genset layout and GM reports that 60% of all distance in that vehicle in pure electric mode. The BMW i3 is similar and uses a 647cc engine as the range extender but report that the range extender is used over 60% at time of introduction but that it decreased significantly over time as drivers adjusted their driving style and expectations. This vehicle was typically not the primary vehicle in the household.

3.3. Discussion on battery life versus charge rate

Batteries cannot absorb energy at the rate required during a conventional drive cycle and the excess energy must be dumped into the service brakes. This technology demonstrator can combine both electric and hydraulic braking to store more of the energy available than either system on its own and can be designed to reduce the braking current to lower levels than other concepts.

4. Conclusion

The simulation model shows the designed vehicle will be capable of testing the various methods to improve battery life and vehicle performance and the data will be confirmed in the test phase. The technology demonstrator vehicle that is being built will have the ability to explore techniques to improve battery life and electric vehicle performance by reducing the DoD, improved regenerative-braking efficiencies and having an on-board IC engine that has abilities more than a typical range extension engine. The design of the technology demonstrator is flexible and can be modified to test each of the models.

References

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