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# Introducing a 150 kW (200 hp) Permanent Magnet Propulsion System Achieving 1 hp/lb

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UQM Technologies, a developer and manufacturer of electric propulsion systems, has recently introduced a 150 kW (200 hp) system for use in high performance applications, achieving 1 hp/lb power density. This system is an upgrade of a 100 kW system that has been available for the last ten years. The upgrade was driven by both customer requests for higher power systems and the development of new technologies. The additional 50% output is being made available without any additional size or weight to the system. The key enabling technologies are the armature winding and commutation method, the combination of which has created the majority of the torque and power improvement. Other features have been introduced with this system, including control mode versatility (torque/speed/voltage control on-the-fly), improved safety features and failure modes, and a new graphical user interface (GUI). Extensive performance testing was completed during the spring and summer of 2007, with the results published for all electrified vehicle manufacturers to evaluate against their needs. UQM's next steps are to complete the acquisition and installation of production equipment and tooling to bring down the price of this system (and other UQM systems) as volumes increase.

**Keywords:** Electric Drive, Permanent Magnet Motor, Drive System, Propulsion

## 1. BACKGROUND

UQM Technologies introduced a 100 kW (134 hp) propulsion system in 1997, originally targeting wheel hub drives for series hybrid electric buses. Subsequent to this original application, these motors went on to be applied within hybrid electric Humvees for the military, the Spinner and Crusher unmanned military vehicles, and most recently, the Phoenix Motorcars sport utility trucks and sport utility vehicles. During this period over the last ten years, customers requested higher output and technologies emerged to support this request. The primary items that enabled higher output consist of the following:

- o Development of motor/generator commutation methods that created higher power across the speed range (UQM proprietary)
- o Development of armature winding techniques that reduce the AC resistance for fewer losses (UQM proprietary)
- o Better power electronics (IGBTs and capacitors) to support higher voltage and current limits
- o Higher temperature NdFeB permanent magnets

These items came together to create a new system that UQM calls the PowerPhase™ 150. The system is capable of 150 kW peak output, 100 kW continuous output, 650 N-m peak torque, and 5,000 RPM top speed. The torque and speed range of this machine have been selected to allow for straightforward electric vehicle integration (connect directly to the differential) and also for heavy duty parallel hybrid vehicles. The specifications and test results are detailed in the next section.

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## 2. SPECIFICATIONS AND TEST RESULTS

The performance of the PowerPhase™ 150 drive system was characterized on UQM's dynamometer test stand, which consists of calibrated equipment to measure input power (voltage and current) and output power (torque and speed). Peak output, continuous output, and efficiency were measured for this system both in motoring and generating modes. The results of this testing were summarized in performance maps that are shown in the following figures. In all of these graphs, the solid black line represents peak output, the dashed black line represents continuous output, and the efficiency contours represent measured system efficiency (machine and controller). Data was taken using a 360 VDC bus and 55 degrees C coolant input to the controller.

The duration of peak output depends upon starting conditions (primarily temperature), and is generally available for 30 to 90 seconds if the motor temperature begins the peak power event at a temperature of less than 100 degrees C.

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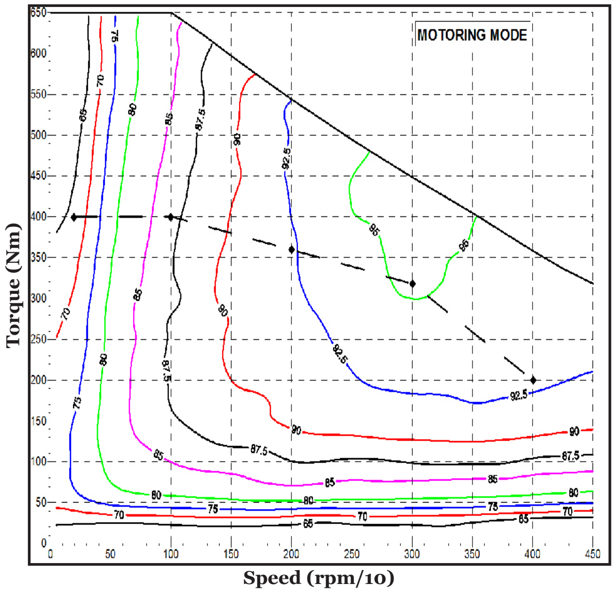


Figure 1: Motoring Performance Map (Torque versus Speed)

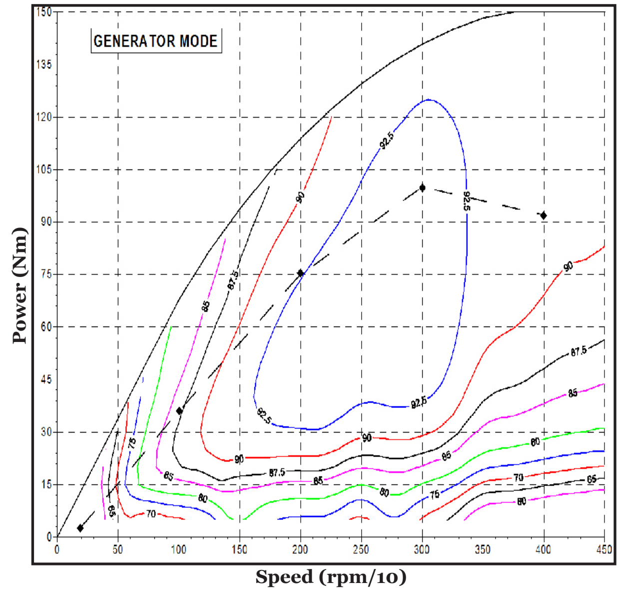


Figure 3: Generating Performance Map (Power versus Speed)

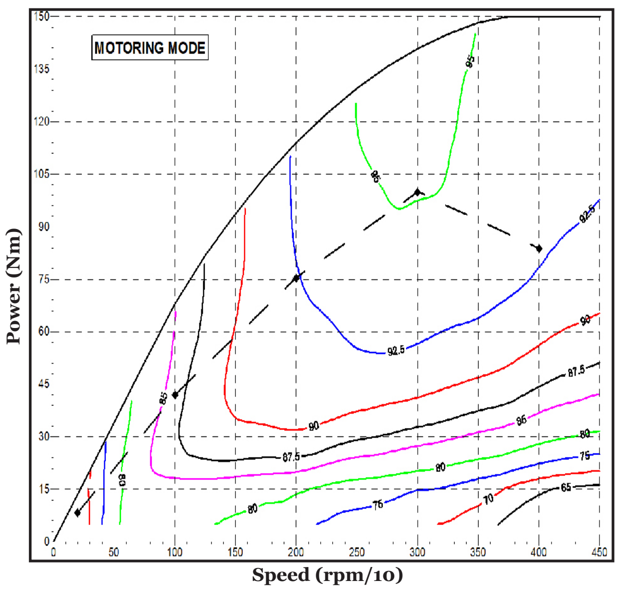


Figure 2: Motoring Performance Map (Power versus Speed)

## 3. SYSTEM FEATURES

In addition to increased output, the system now has other improvements for users. To start with, there are three control modes to choose from: torque, speed, and voltage control. Torque control is most often used for propulsion, controlling the degree of acceleration and deceleration based on a throttle input command (analog or CAN). Speed control is used for cruise control or in parallel hybrids to speed match the engine and transmission during gear change events. Voltage control is used in generating mode to aid in battery charge management. All three of these modes may be used for different reasons depending on the vehicle architecture and chosen vehicle control strategies. The control modes can be switched between “on-the-fly” to allow the user to change between modes as often as needed. In addition to control mode versatility, response times in each of these modes have improved dramatically. Customers who are developing more demanding parallel hybrid vehicles required this improvement.

The controller processor also has features to improve the safety and durability of the system. First, the controller includes provisions to accept a dual accelerator input to prevent undesired acceleration. Second, the system automatically switches into voltage control in the event the DC bus is disconnected from the drive system (contactor or fuse). Voltage control prevents damage from occurring to the motor inverter, even if the system is generating power into the battery at the moment of disconnection. Third, the system can detect the loss of a wire in any of the phase or bus current sensors (supply wire, signal wire, or ground wire). Fourth, the software will also determine if a driver or module is damaged. Finally, if the rotor position sensor moves, the software will detect this, and in most cases, the software will allow a “limp home” mode in such an event.

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UQM has also developed a new graphical user interface (GUI) that provides users with simpler and more versatile configuration capability. The GUI can also be used to capture information about events that fall outside expected operation; for example, the system can be set up to capture under voltage or over voltage events. A few snapshots of the GUI screens are shown in the following figures.

Figure 4 shows the main display page with the data broken into different panels: Status, Physical, Electrical, Critical, Control, Logging, and Data Acquisition.

Figure 5 shows the General tab of the System Configuration menu where the user can select the Desired Control Mode, choose their Battery Parameters, or set up the Generator Settings.

Figure 6 shows the Torque/Analog tab of the System Configuration menu where the user can add in positive or negative Creep torques, put in speed limits in the Forward and Reverse direction and set up the accelerator and brake pedal valid inputs.

Figure 7 shows the Digital/CAN tab of the System Configuration Menu and allows the user to configure the CAN as desired.

Figure 8 show the Data Acquisition menu and allows the user to set up different triggers, the location of the trigger, and the desired data collection rates.

Figure 9 shows the Trigger Thresholds Menu for the triggers.

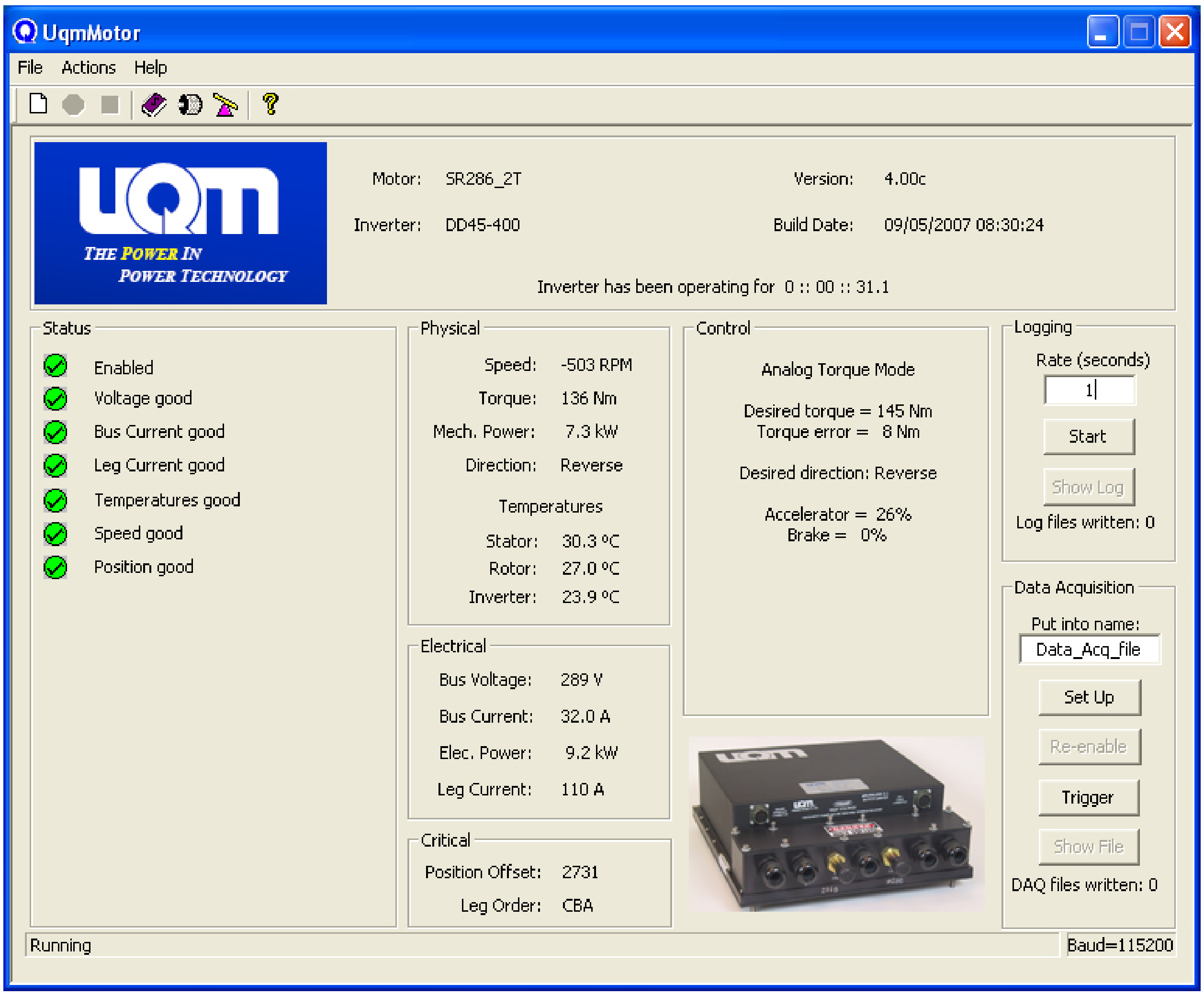


Figure 4: Graphical User Interface Main Screen

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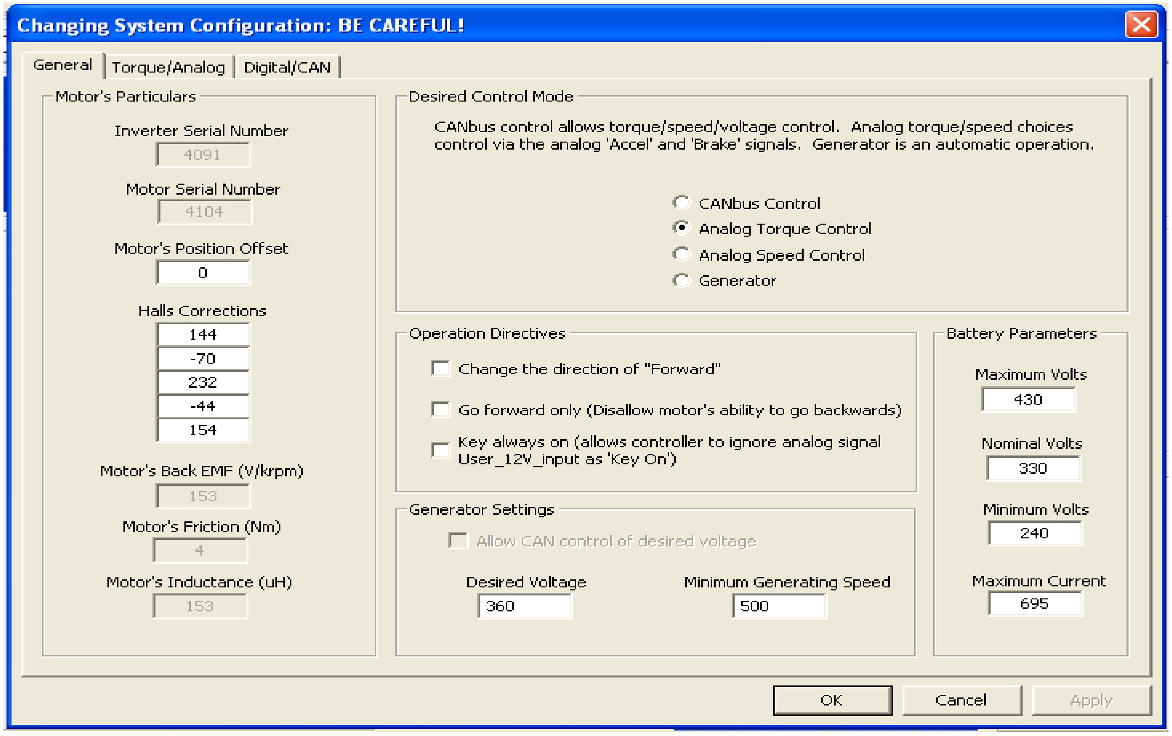


Figure 5: Graphical User Interface System Configuration Menu

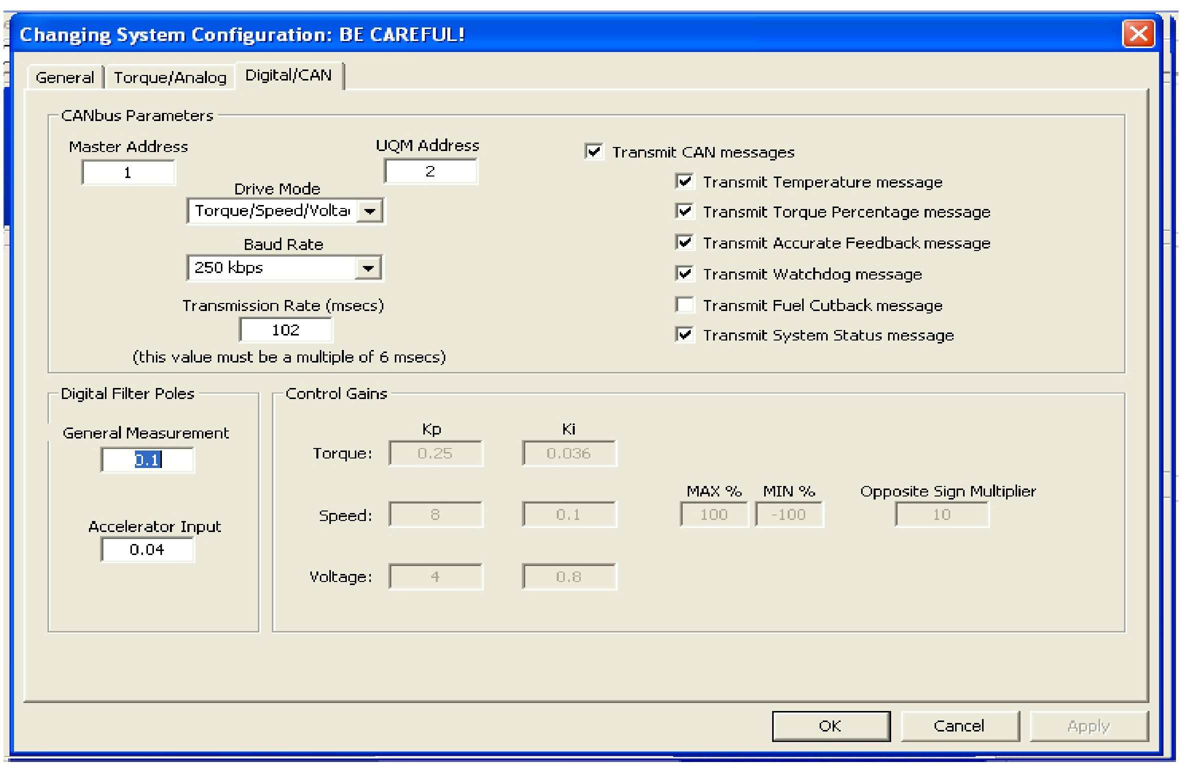


Figure 6: Graphical User Interface Output Configuration Menu

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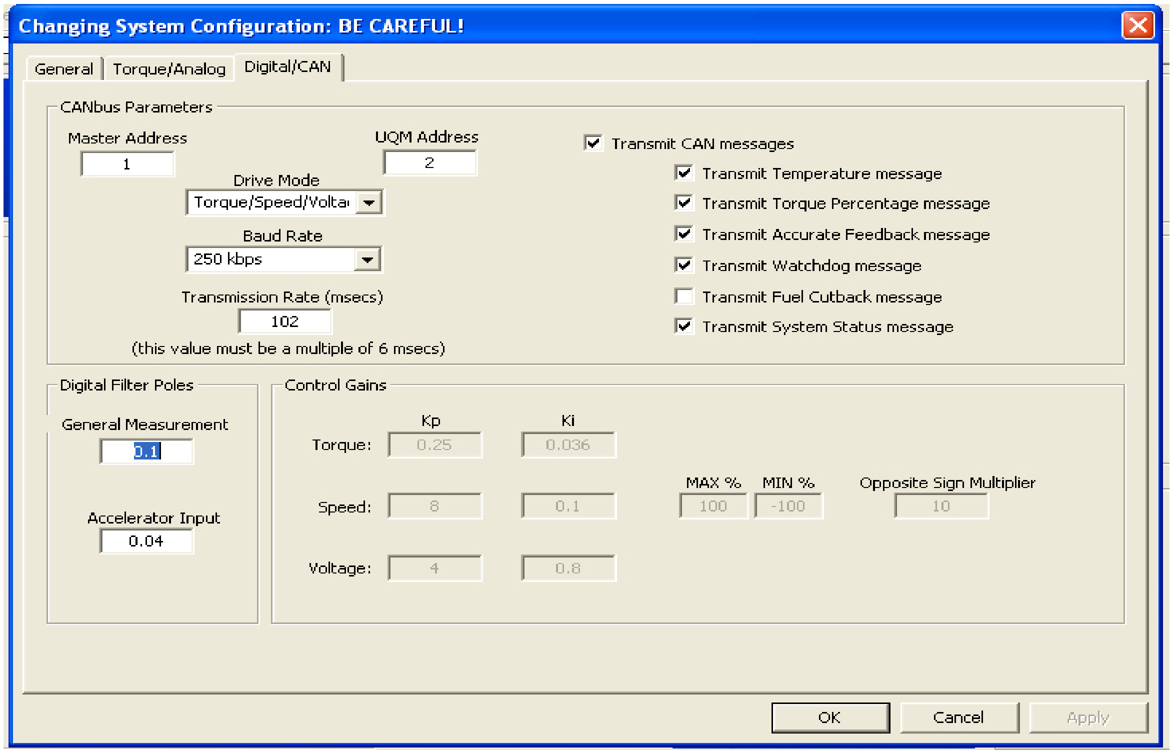


Figure 7: Graphical User Interface CAN Configuration Menu

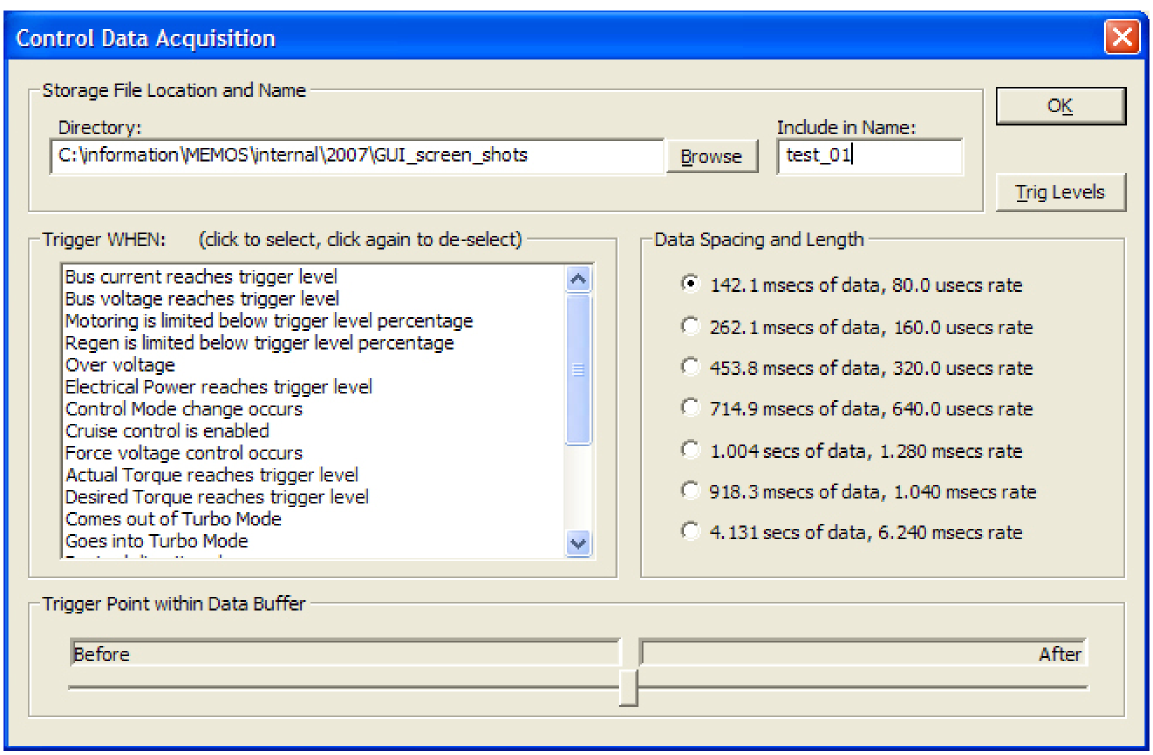


Figure 8: Data Acquisition Trigger Menu

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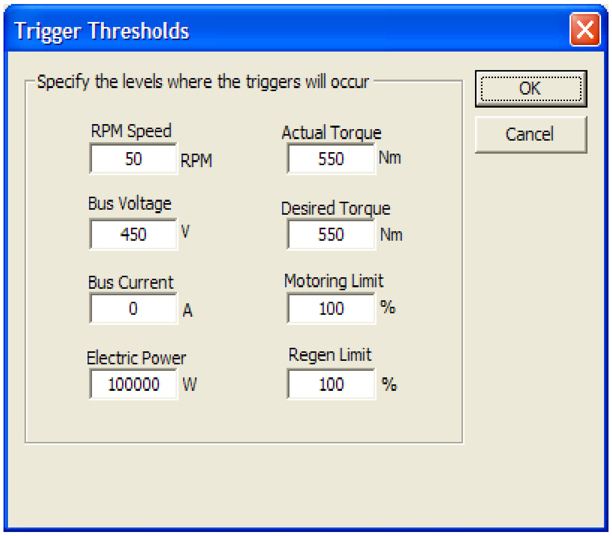


Figure 9: Data Acquisition Trigger Levels Menu

## 4. NEXT STEPS

The PowerPhase™ 150 drive system is now available for sale to all customers. It is considered to be a prototype system, although using technology that has been proven reliable over the last decade. The next steps for the system are to invest in production equipment and tooling, enabling higher volume and lower pricing. The most notable tooling items are high volume lamination punch dies and cast aluminum housing components. Production manufacturing equipment is being installed in UQM's production facility in parallel with the supplier tooling effort.

UQM has also developed a parking brake mechanism for battery electric vehicle applications. This parking brake consists of a pawl mechanism that is similar to that found in a conventional automobile. The parking brake is rated for a vehicle weight of approximately 2,500 kg.

## 5. CONCLUSIONS

UQM Technologies, a long-time leading supplier of electrified drive components for vehicles, is continuing to develop new and improved propulsion systems for vehicles, with the latest product release being the PowerPhase™ 150 system. This 150 kW (200 hp) propulsion unit is suitable for electric vehicles up to 3,000 kg as the sole propulsion motor, or much heavier vehicles in multiple drive or hybrid electric configurations. Prototype systems are being shipped to customers now, and UQM looks forward to additional orders that will allow further investment in manufacturing equipment and tooling. The benefits of this system, as compared to other available systems, include higher efficiency for longer range EVs or higher fuel economy hybrids, higher continuous power for heavy-duty applications, and improved user interface for performance optimization of a vehicle platform.

## AUTHORS

Jon Lutz is the Director of Engineering of UQM Technologies and has been with the company for nearly 15 years. Jon's background is electric machine design, specializing in electromagnetic principles as he earned his MSEE degree at the University of Colorado, Boulder. He now directs a staff of 20 employees focused on the development and application of electric machines and drives for electric transportation applications.

Carlo Kopf is the Software Engineering Manager of UQM Technologies and has been with the company for 15 years. Carlo's background is in control systems and earned his MSEE degree at UC Santa Barbara and his BSEE degree at Virginia Tech. Carlo led the development of UQM's advanced motor commutation and control algorithms. He has tested these algorithms on a wide variety of vehicle platforms from scooters to Humvees with power levels ranging from 1 kW to 150 kW. Phone: 303-215-3490.