Motor Drive Design for a Battery Electric Vehicle (BEV)

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Abstract

This poster describes a novel BEV motor drive which accommodates fluctuations found in normal driving conditions. A BEV is in testing phase at the University of Arkansas – Fort Smith (UAFS) using a Baldor H2[1] drive and a 5-speed transmission. This H2 drive is designed for conveyor belts and air handling applications. The H2 drive disables when speed/torque demands abruptly change due to acceleration, hill climbing, and shifting gears. These abrupt increases in load current and rapid decreases in speed disable the H2 drive for 90 s.

The process of designing/constructing a drive to replace the H2 started Fall 2012; this drive will operate with a 380 V bus voltage while supplying 160 A for 20 s and 220 A for 3 s. Currently, a 1st generation BEV motor drive has been successfully tested with a 100 V bus. Tests conducted at a 380 V bus voltage have shown limited success; unexpected heating has occurred, leading to thermal runaway. Plans have been made to address this issue with a new 380 to 18 V DC/DC converter needed for IGBT drivers and adding liquid cooling.

This project built a bridge between local business and UAFS in motor development and specialized powertrain parts as ABB Baldor has donated an H2 drive and designed/built a customized BEV motor. ADKO and REEM/RUUD have also contributed machine shop services. It has connected students with practicing engineers to share knowledge/experience.

Battery Electric Vehicle (BEV) Background Information

A 2008 Pontiac G5 has been converted to a BEV using an 8 Hp induction motor, 21 kW LI battery, and 5-speed transmission. Figure 1 shows the BEV. Figure 2 shows dynamometer testing of battery voltage for various loads; a 6.2% voltage sag occurs at 145 Nm; this sag is acceptable and will not disable the drive.

BEV Drive Design and Construction

The H2 drive has been tested under dynamic driving conditions with limited success; as shown in Figure 3 below, the drive will disable when 117 A exceeds 3 s. This limits the BEV's acceleration to an unacceptable level. A drive to replace the H2 is under development. Connecting an untested drive to a LI battery is unwise and necessitates the use of a plug-in unit that simulates a LI battery. Figure 4 shows the schematic of the boost circuit used in the LI battery simulator. The DC/DC boost circuit is based on a PWM feedback control and includes a 12 Ω soft start resistor. Figure 5 shows the output voltage of the boost circuit under differing loads. Notice the output voltage is stable with loads greater than 2 kΩ. Figure 6 shows the prototype drive board; the drive board's microprocessor controls the IGBT switches producing 3-phase current.

Figure 1: This photograph shows the 2008 Pontiac G5 used in BEV conversion. The 5-speed transmission was left in the vehicle to better match driving demands.

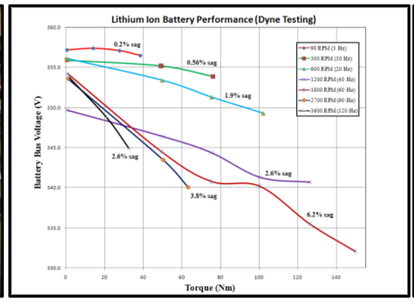

Figure 2: These curves show battery voltage sag at various loads. The battery was tested using an ABB Baldor H2 drive and 8 Hp motor as mounted in the BEV using a 50 Hp dynamometer.

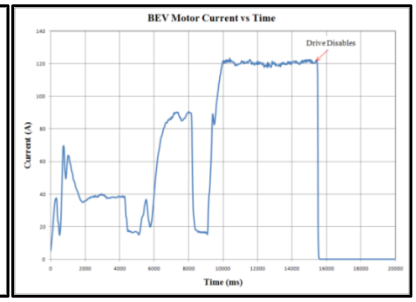

Figure 3: The H2 drive will disable when the load current exceeds 117 A for more than 3 s.

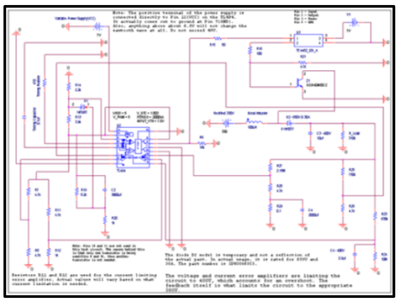

Figure 4: This figure shows the PWM feedback circuit used to boost 120 Vrms to 380 V DC

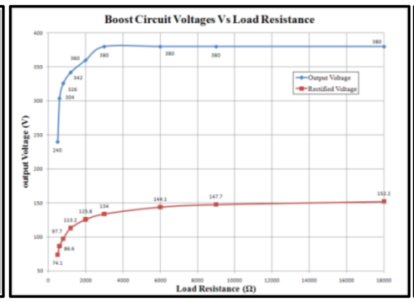

Figure 5: This figure shows the rectified 120 Vrms voltage and the boosted 380 V DC boosted voltage as a function of load resistance.

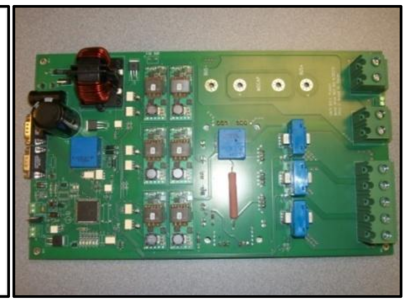

Figure 6: This photograph shows the completed motor drive board designed/ constructed by former student Christopher C. Arnold.

Conclusions

Testing indicated the H2 drive is inadequate for the dynamic loads experienced during driving. To resolve this issue, a novel motor drive has been designed and tested. Instead of using a LI battery for drive testing, a plug-in battery simulator has been designed/constructed. Figure 5 shows 120 Vrms boosted to a stable 380 V DC which powers the drive for testing. At this point in drive testing, we have noted three needed changes/corrections. These changes include redesigning the DC/DC converter used to regulate the 380 V bus to 18 V for IGBT switching, rerouting A/D traces, and including liquid cooling.

References

1. http://www.baldor.com/products/ac_motors.asp

Bibliographical information

Kirk D. Kimery will be receiving a BS in Electrical Engineering Fall 2013. Robert C. Murphree will graduate spring 2013 and Osman A. Martinez will graduate spring 2014. Kirk has worked on the BEV for the past 14 months; Osman joined the BEV team in December 2013 and Robert in May 2013. These students hope to find employment in fields related to BEVs. Kevin R. Lewelling received his PhD in 1997 and has been involved in higher education for the past 16 years. Emails: kkimer00@g.uafs.edu, rmurph00@g.uafs.edu, omarti00@g.uafs.edu, and Kevin.lewelling@uafs.edu.

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Abstract

The key component in designing an efficient Battery Electric Vehicle (BEV) is the motor drive. This efficiency issue can be further complicated by incorporation of a standard 5-speed transmission which is used to enhance the driving capabilities of the BEV. Currently, a BEV is in the testing phase at the University of Arkansas – Fort Smith using a standard Baldor H2 drive and a 5-speed transmission. This H2 drive is designed for an industrial application such as conveyor belts and air handling. This presents a real problem when using this standard H2 drive in a BEV as the speed/torque demands have abrupt changes due to acceleration, hill climbing, and shifting of the 5-speed transmission. These abrupt increases in load current disable the H2 drive for 90 seconds rendering the vehicle powerless. Rapid decreases in speed demand a drive that has full regeneration braking capabilities for proper operation as the current spikes can be shunted to the battery and not lost as heat.

The process of designing and constructing a new specialized motor drive to operate at a bus voltage of 380 V while supplying 160 A for 20 seconds and 220 A for 3 seconds started Fall 2012. Currently a first generation BEV motor drive has been successfully tested at a bus voltage of 100 V. Tests conducted at a bus voltage of 380 V have shown limited success. At 380 V unexpected breakdowns have occurred leading to thermal runaway; plans have been made to address this issue by incorporation of a new Buck converter design which provides an 18 V bus needed for the IGBT drivers; additional improvements include adding liquid cooling.

This project has built a bridge between local business, industry, and the University of Arkansas – Fort Smith in motor development and specialized parts needed in this powertrain as ABB Baldor has donated an H2 drive and designed/built a customized motor for BEV use. Other companies such as ADKO and REEM/RUUD have also contributed machine shop services. The project has been instrumental in connecting students with practicing engineers in these fields where knowledge and experience can be shared.

BEV Background Information

A 2008 Pontiac G5 has been converted to a BEV using a 360 V DC bus which is powered by a 21 kW GBS LiFeMnPO4 battery. This BEV uses an 8 Hp 3-phase induction motor and an H2 Baldor drive. Both the motor and drive were donated by ABB Baldor. Additionally, the BEV design incorporates the stock 2.2 L, 5-speed GM transmission to better match low speed high torque conditions. Figure 1 is a photograph of the BEV. Figure 2 shows the battery pack which is housed in the vehicle's trunk and weighs 550 lbs. Figure 3 shows the battery response to various loads as tested on an ABB Baldor dynamometer. The battery shows only a 6.2% voltage sag at a peak load of 145 Nm; this sag falls within acceptable limits and is not the source of drive shutdown.

Support

The Electric Vehicle Project (EVP) is being supported by ABB Baldor, Rheem/Ruud, Arkansas Space Grant Consortium (ASGC), Arkansas Student Undergraduate Research Fellowship (SURF), and the University of Arkansas - Fort Smith. This project has involved over 60 undergraduate students with contributions from 5 local companies. The authors would like to gratefully thank each organizations that contributed to this work.

Figure 1: This photograph shows the 2008 Pontiac G5 being converted to a BEV.

Figure 2: This photograph shows the 21 kW LI battery as it is mounted in the vehicle's trunk.

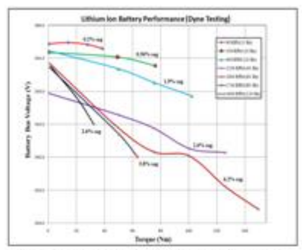

Figure 3: This figure shows how the LI battery performs under load testing. This test used the ABB Baldor H2 drive and 8 Hp induction motor that are currently mounted in the BEV. Notice that under a 145 Nm load the battery's voltage sags 6.2% which is an acceptable amount for BEV driving performance.

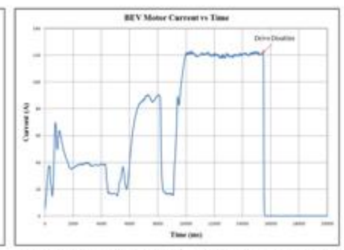

Figure 4: This figure shows data collected while driving the BEV up an approximate 5% grade. The drive disables when the motor current stays above 117 A for more than 3 seconds. When the drive disables, a 90 second timeout is experienced.

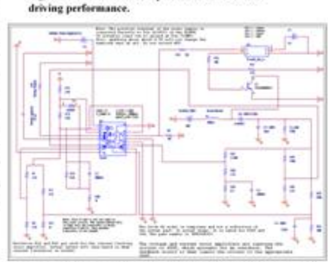

Figure 5: This figure shows the circuit used to boost 120 Vrms to 380 V DC. The 380 V DC is needed to power the motor drive bus during the testing phase. At the heart of this circuit is the TI TL494 PWM feedback control. This controller adjusts the feedback duty cycle and has two error amplifiers to protect the circuit from over current and voltage.

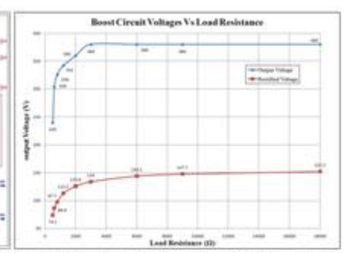

Figure 6: These curves show the performance of the boost circuit shown in Figure 5. A 12 Ω soft start resistor was used during all testing. The bottom (red) curve shows the voltage measured across the rectification capacitor as a function of load resistance. The top (blue) curve shows the output voltage as a function of load resistance. Notice as the load resistance increases, the voltage approaches the desired 380 V.

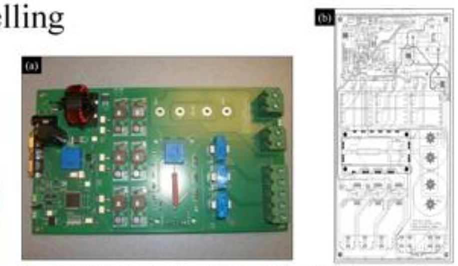

Figure 7: (a) This photograph shows the motor drive board under development. (b) shows the PCB layout. This PCB is a 4 layer board with 4 oz copper on each layer. This circuit was designed/constructed by former student Christopher C. Arnold

Future Work

Preliminary testing of the motor drive discussed on this poster indicated several corrections and improvements that need to be made. One correction that needs to be made is rerouting the analog to digital traces to the HC912 microprocessor. BEVs are usually controlled with an accelerator potentiometer and need 8 to 10 bits of accuracy. Due to a board design flaw, our BEV only receives 6 bits. A redesign of the Buck circuit is planned due to MOSFET overheating and improper inductor value. The Buck circuit's purpose is to reduce the 380 V bus to 50 V which is used to power the DC/DC isolator boards. These DC/DC isolator boards further reduce the voltage to 12 V and are used to turn on the IGBTs which produce the motor 3-phase voltage. If the redesign goes according to plans, the DC/DC isolator boards will be eliminated entirely; the new Buck circuit will reduce the 380 V bus to 18 V directly which is the optimal voltage for turning on the IGBTs. Heat sinking is another issue that is being addressed; our BEV application demands peak currents of over 200 A requiring rapid removal of heat. In future revisions, a liquid cooling system will be pursued.

Educational Outreach

The Electric Vehicle Project (EVP) has involved over 60 UAFS students since its inception. The electric vehicle has been taken to three high schools and five middle/junior high schools for visits in the past three years. These visits included a presentation over energy generation and conservation with hands-on activities for the students. At each presentation, current electrical engineering students describe their experiences associated with university studies and work on the BEV. The aim of this outreach effort is to encourage young students to pursue STEM careers by letting them experience firsthand what it is like to design and build an electric vehicle.

Figure 8: (a) Shows students at Kimmons Junior High School looking at the BEV. This presentation discussed BEVs and energy conservation. Figure 8(b) shows students Chris Arnold, Kevin Tran, and Osman Martinez with the second generation BEV. They are decoding CAN messages which control BEV operation.