

Experimental Motor Controller

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ABSTRACT

The objective of this study is to conduct a low-cost and low-scale experiment for creating an ideal model for an ultra-high-speed switched reluctance motor (SRM) generator for automotive turbocharger assistance and energy recovery. For this purpose, a switched reluctance motor is selected for a controlled experiment. The experiment was implemented that consists of an 800 W, 35,000 rpm SRM coupled with a secondary SRM and a heat gun to exemplify the turbine load. The second major component is the controller and drive. Two controllers were selected for the experiment, which consist of a general low-cost solution and an optimized development board for prototyping optimization. The low-cost control solution is implemented with an Arduino uno and an assortment of relays configured into an asymmetrical half bridge. The second controller is the Digilent ZedBoard Zynq-7000 ARM/FPGA SoC Development Board (Zedboard). The Zedboard was selected due to its wide range of functions and its ease of programming using MatLab/Simulink. The Zedboard can control the gate driver signals, monitoring of phase current and voltage waveforms, display of the motor/generator states, observe and display the charge percentage, input encoder readings, control the optical sensor, and track rotor position. These various I/O functions will be implemented with Xilinx's onboard analog digital converter (XADC) and five peripheral modules (Pmods). Pmods are expansion headers that can be utilized for a wide range of I/O functions. Debugging can be done with JTAG, UART, and Hardware-in-the-Loop testing can also be utilized.

Keywords: analog digital converter, controller, drive, MatLab/Simulink, switched reluctance motor generator, Zedboard

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INTRODUCTION

The hybrid/electric sector within automotive industry in the particular real-world implementation can be seen in various research and development projects involving diesel engines in the farming and agriculture industry [1–3]. The ultra-high-speed switched reluctance motor (SRM) generator is designed and constructed that can harvest energy coupled with a turbocharger to increase the

performance and fuel efficiency of any combustion engine. Various control systems are analyzed to achieve the maximum torque and speed with optimized switching angles. In addition, investigation toward developing an energy recovery system is highlighted. All experiments would progress toward implementation on an automotive turbocharger. The overall design of a turbocharger consists of a compressor and

turbine on a mutual shaft with the goal of utilizing exhaust gas energy to spin the shaft which actuates the compressor. It utilizes the exhaust gases that are dispelled after the combustion process. By including an electric motor, not only will the turbocharger utilize the exhaust energy for the compress, but also store the energy into a battery, supercapacitor, and or flywheel for further energy harvesting. The implementations require high torque in a harsh environment. There are also applications that can achieve high horsepower and rpm [1, 2, 4–6].

EXPERIMENTAL MOTOR CONTROLLER

The provided motor controller in Figure 1 was designed for a Chinese outlet. So, a transformer and frequency converter were needed to set up the voltage from 120 to 220 V and convert the frequency from 60 to 50 Hz. The motor came with a shaft-mounted magnetic disc. Hall effect position sensor as shown in Figure 2 and bottom of hall sensor is shown in Figure 3 [7].

The Arduino-controlled motor is one of the main portions of this project; it has three Hall effect sensors located 120° apart around the top of the rotor shaft, and attached on that shaft is a magnet that rotates with the rotor, and with those elements, the position of the rotor poles is to be determined. The 5 V pulses from the active Hall effect sensor go back to the Arduino which is running a constant, if else case. If the rotor has reached the end of A phase, then turn on B phase and also the other way around.

The asymmetrical H bridge controls the flow of current; so during the demagnetization state, it will be directed back toward the rechargeable batteries. To use this, two motors are used: one will be controlled by our Arduino and the H bridge, while the other will simply be attached at the shaft and spinning freely.

Upon the start of the program, both motors start rotating to a desired speed, and next, the Arduino is given a signal to switch into



Fig. 1. The motor controller.

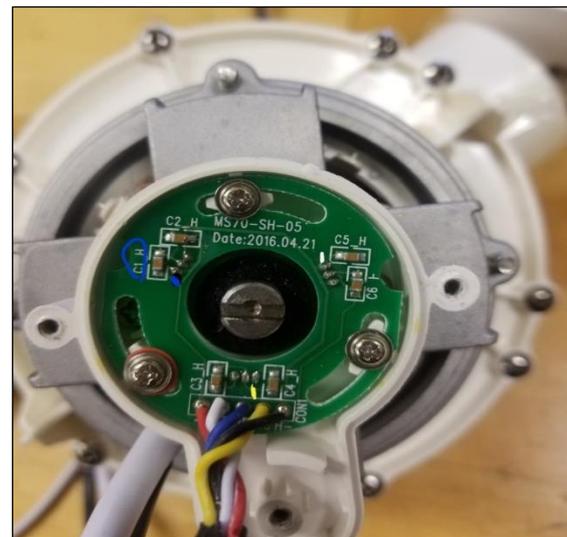


Fig. 2. The hall sensor.

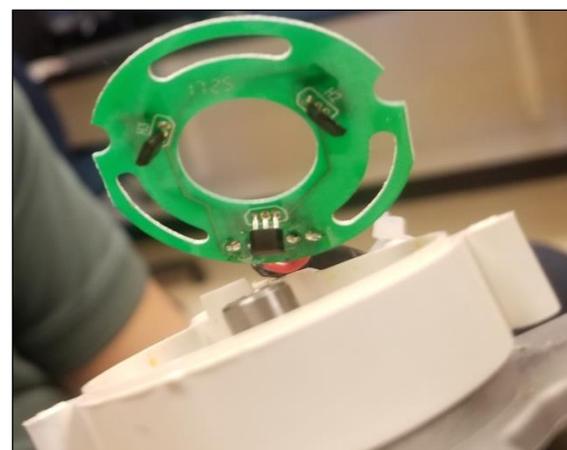


Fig. 3. The bottom of the hall sensor.

a generation state where the Arduino-controlled motor will begin acting as a brake. Here the Arduino will begin turning on the stator coils for a short duration after the rotor pole has passed, which will generate a negative torque and generate voltage to be sent back to the batteries.

The purpose of the free wheel motor is to simply keep momentum to turn the Arduino-controlled motor during the generation state.

The 24 V power supply is used to trigger the ice-cube relays during the motor process of the Arduino-controlled motor.

The motoring-only controller is the original method of motor control; however, it cannot be used to regenerate power back to the batteries. The working sequences are as follows:

Step 1: Power on all power supplies (24 V power supply, Arduino) and connect batteries.

Step 2: Run the Arduino program to get both motors up to speed.

Step 3: Give Arduino the signal to begin generation phase.

Step 4: Allow motor to completely stop before resetting Arduino and running through steps 2–4.

SRM CONTROLLER

The motor controller is integrated with the Zedboard. Eliminating provided shaft-mounted Hall sensors by duplicating the signals with the Zedboard Pmods. The shaft-mounted Hall sensor is magnetic with three channels. We believe that SA and SB are position sensors with SC being an index or reference signal to provide more precise monitoring of rotor position. Quadrature encoder is required.

MATLAB/SIMULINK-HDL AND EMBEDDED CODER

MatLab/Simulink has an SRM model that can be converted into HDL code. Within the HDL workflow as shown in Figure 4, the option to create IP cores for Vivado is available by designating the toolpath in the command window.

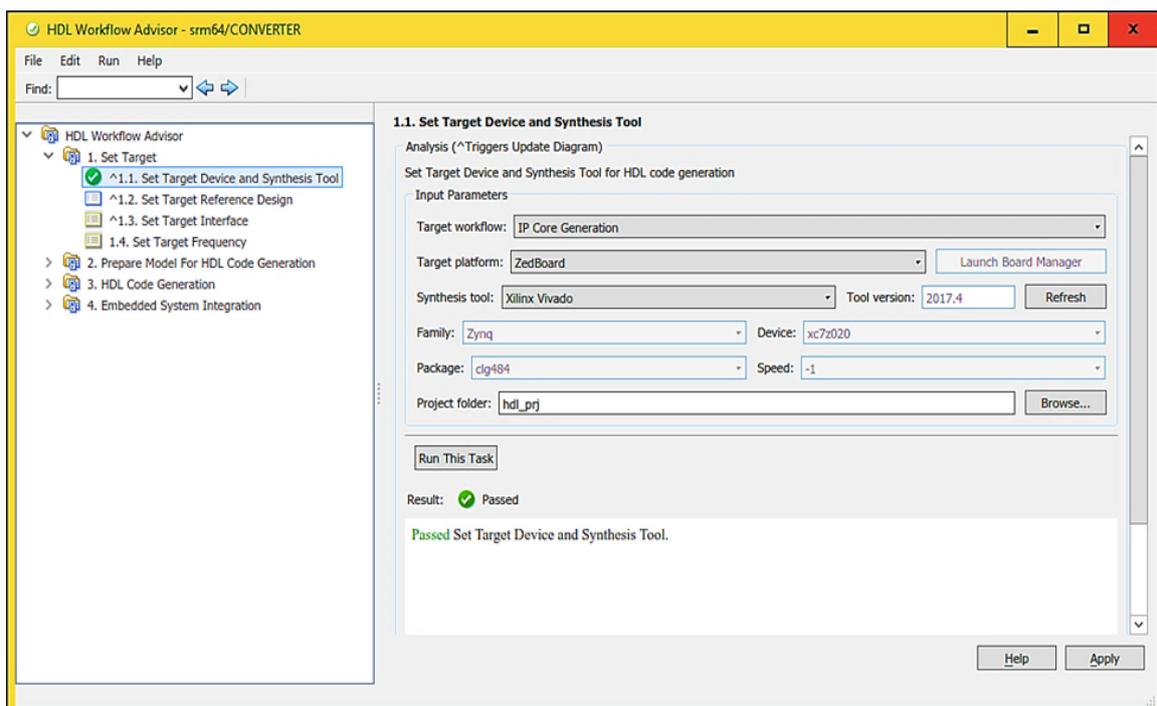


Fig. 4. HDL workflow.

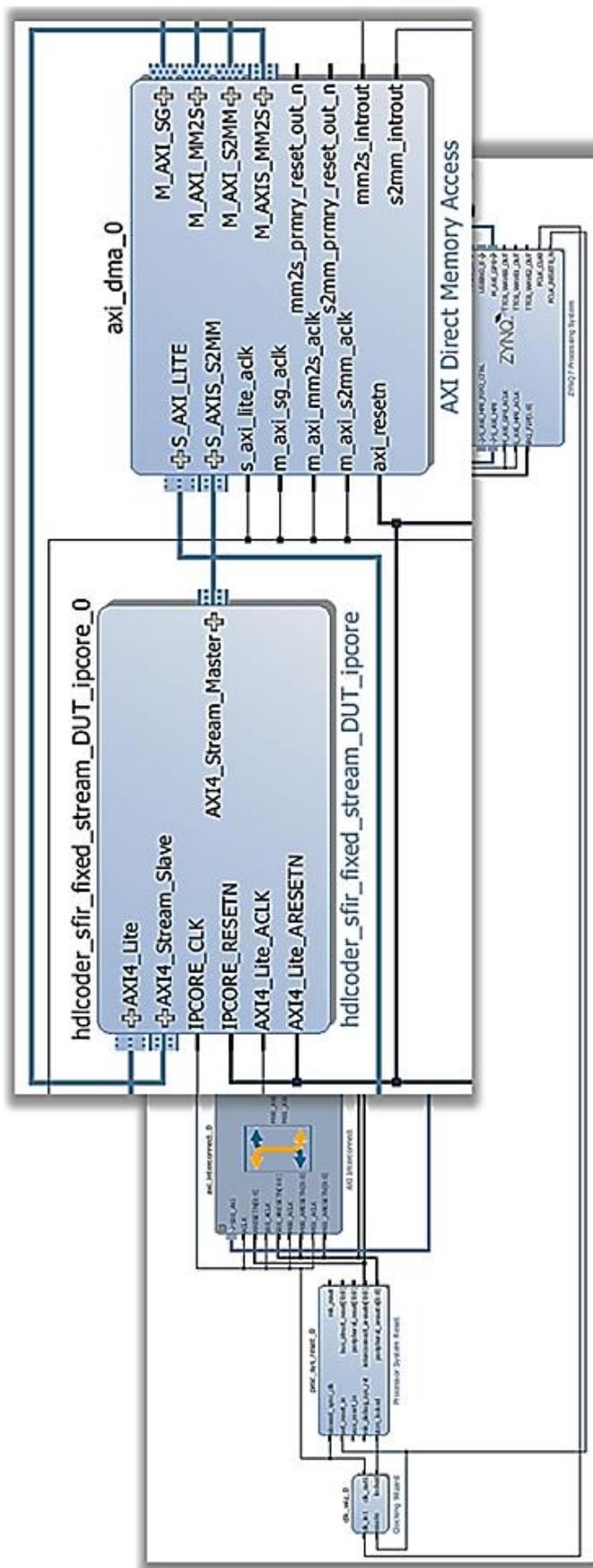


Fig. 5. The Vivado ip-core block design from Simulink-generated HDL.

This HDL code was translated into Vivado for synthesis for the Zedboard. Figure 5 displays a Vivado block diagram with Matlab/Simulink-generated IP-core.

LOAD/DYNAMOMETER MOTOR

The initial goal was to have a motor that would be coupled to an exhaust test rig. Unfortunately, our motor cannot handle the proximity to the harsh temperatures that can exceed 2000 F as well as make an effect on the induced torque generated from the turbine. A proposed solution can

simulate the torque and temperature relative to sufficient motor for testing. To inject torque, an impact wrench will be mated to motor shaft. To exemplify the dynamic states of a turbine, the motor will initially drive the shaft of the impact wrench. The rpm range of the initial conditions will be approximately 20% of the maximum rpm of 40,000. This state will simulate idle and the torque needed to drive a relatively heavy shaft of a compressor and turbine. After achieving the maximum rpm test, a separate test will

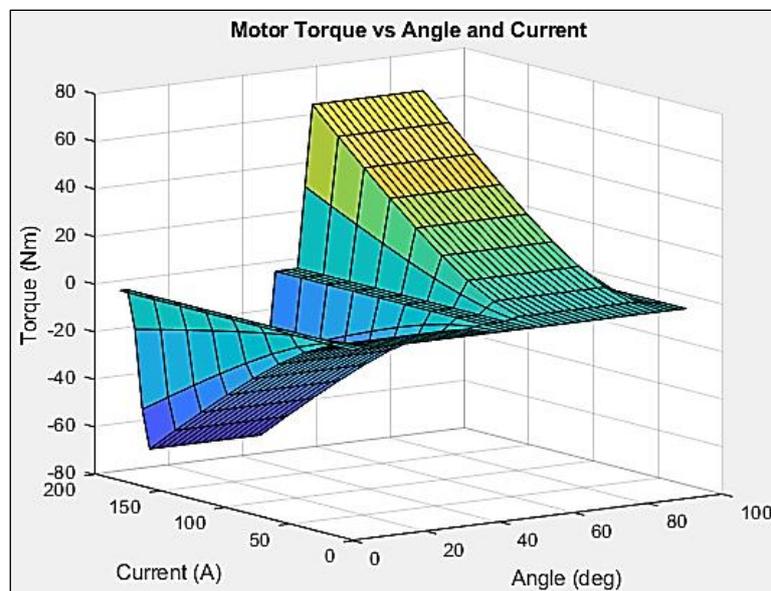


Fig. 6. The motors torque, current, and rotor position.

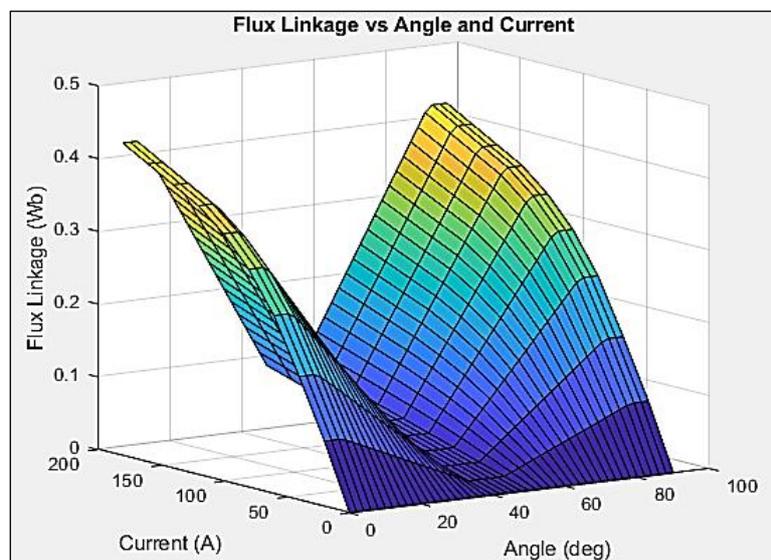


Fig. 7. The electrical steel's flux, current, and rotor position.

stimulate spool boost control with the generation state and harvest energy from the impact wrench as the prime mover.

Simulation of harsh temperatures must also be considered; so a temperature heat gun is selected to achieve temperatures above 1000 F. In order to achieve an optimal wide range of torque and speed, the stator and rotor material characteristics need to be known. Magnetic saturation, flux linkage, phase current and voltage, and rotor position need to be mapped to log the nonlinear characteristics of a switched reluctance motor. Figures 6 and 7 present the characteristics of motor, such as rotor position, torque, flux, and power.

CONCLUSION

In this article, a rotor is constructed for experimentation. In order to achieve an optimal wide range of torque and speed, the stator and rotor material characteristics are observed. Magnetic saturation, flux linkage, phase current and voltage, and rotor position are mapped to log the nonlinear characteristics of a switched reluctance motor.

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