A. Title Page

Final Report for Study of Advanced Control Techniques Applied to Electric Motors

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B. Restatement of problem researched or creative activity

In the last decade, major car manufacturers such as Toyota, Honda, Ford and Hyundai are engaged in researching, developing and manufacturing of Hybrid Electric Vehicles (HEV) and Plug-in Electric Vehicles (PEV) in order to promote fuel efficient and environmentally friendly cars. Electric motor is one of the major energy consuming parts in an electric vehicle. Other than the requirement to have high efficiency irrespective of driving conditions, the electric motor must also have high torque density and compact design. Some of the approaches followed to improve the efficiency of the electric motors used for (HEV) and PEV are based in the application of advanced control techniques like Robust Control or Model Predictive Control. The main purpose of this research activity is to study the application of advanced control techniques to the type of electric motors used in HEV.

C. Brief review of the research procedure utilized

In this proposal, a test stand for DC Brushed motors was built to compare Classical Control techniques and Model Predictive Control techniques. It was necessary to obtain the model of the DC brushed motor used in the test stand to be able to implement the control algorithms.

Using National Instruments hardware and software, a series of experiments were implemented to obtain the data needed for the system identification process. Once, the model was obtained the control algorithms were designed using MATLAB/Simulink. The implementation was carried out using the rapid system prototyping xPC Toolbox.

D. Summary of findings

Figure 1 shows the test stand for the DC motor used in this study. This test stand consists of a Pololu MC33926 Motor Driver Carrier, a small protoboard, a quad 2-input NAND gate IC 74LS00, a National Instrument Low-Cost M Series Multifunction Data Acquisition PCI-6229 card. The DC motor shown in Figure 1 has an Optical Quadrature Encoder with 300 PPR (pulses per revolution) and a gear ratio of 30:1, 200RPM, 12 V. In order to apply these techniques, it was necessary to obtain a model of the motor under study. A LabVIEW vi have been developed to record the speed response when the duty cycle of the H-Bridge connected to the motor is randomly varied. The PWM signal has a frequency of 20 KHz. The duty cycle was allowed to vary from about 10% to 100%. Figure 2 presents the Front Panel of the LabVIEW vi. Figure 3 presents the Block Diagram of the LabVIEW vi.

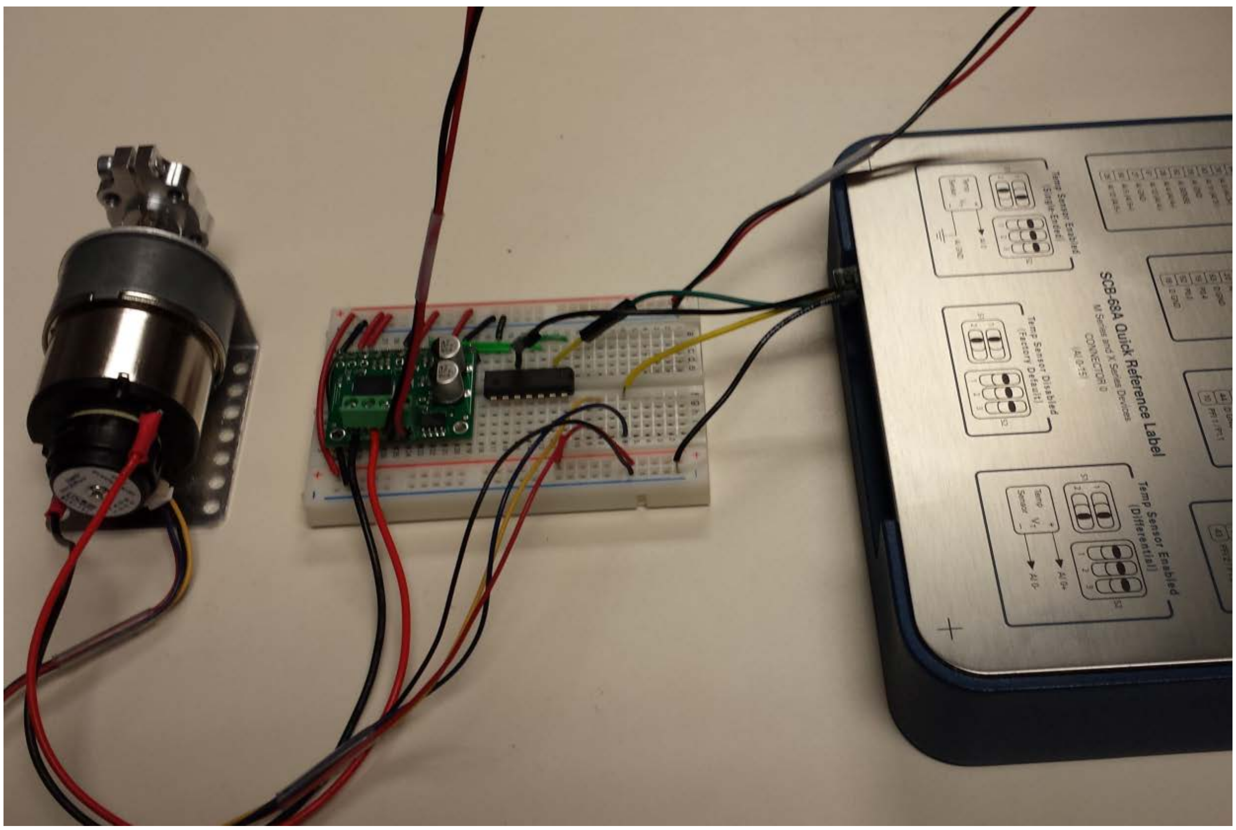


Figure 1. Test Stand for DC Brushed Motors.

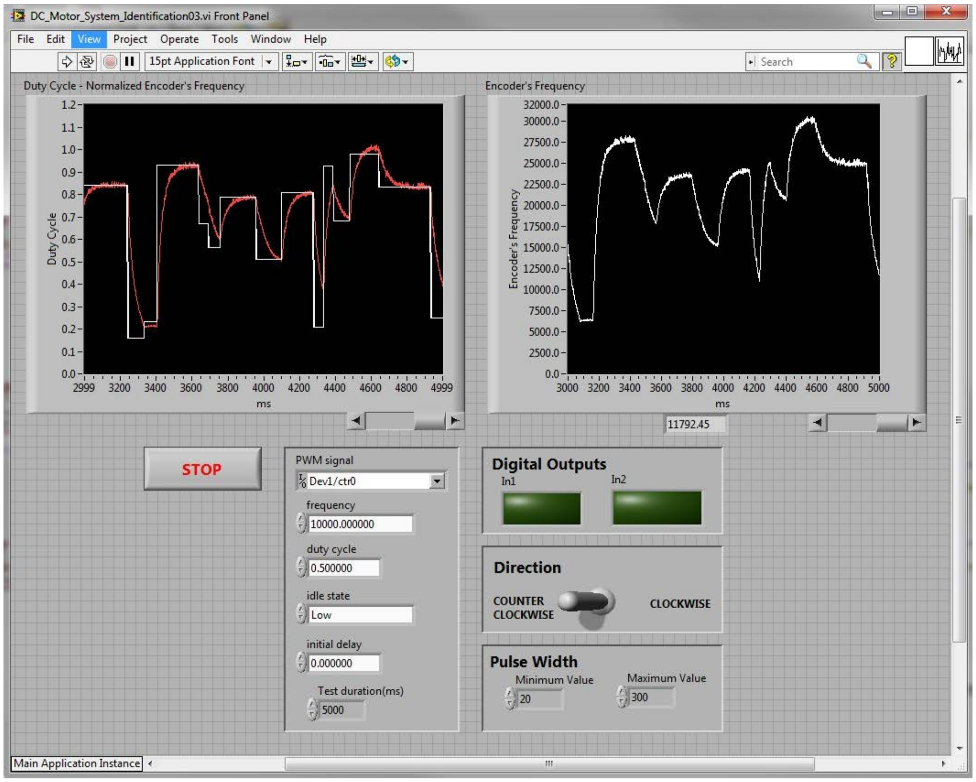


Figure 2. Front Panel of the LabVIEW vi.

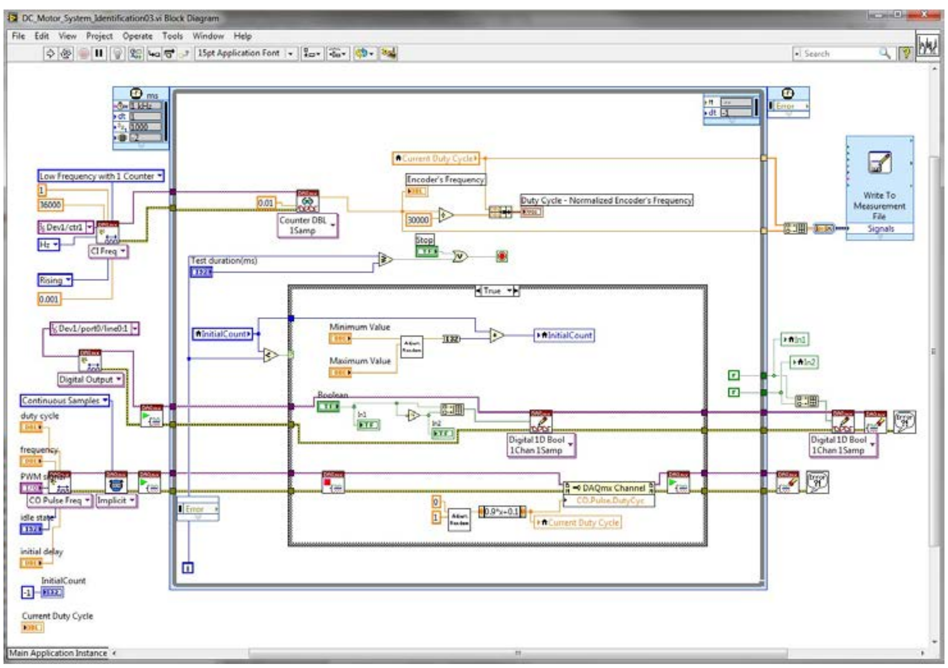
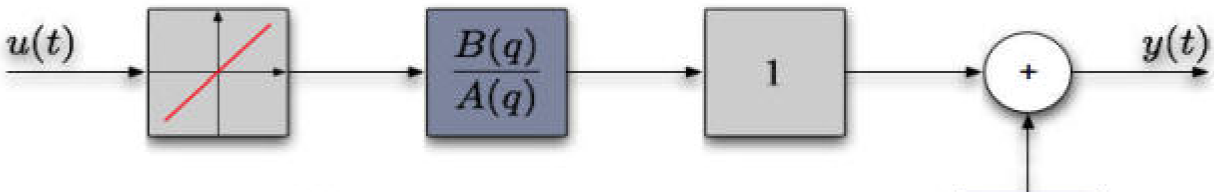


Figure 3. Block Diagram of the LabVIEW vi.

The random duty cycle signal generated and the output response (encoder's frequency) were saved to a file. After this, the data was imported to MATLAB and processed using the free available University of Newcastle Identification Toolbox (UNIT). The discrete-time DC Motor Speed model obtained with the UNIT is an ARX (Autoregressive Exogenous) with the structure shown in Figure 4.



$$A(q)y(t) = \sum_{i=1}^{m} B_i(q)u_i(t) + e(t)$$

Figure 4. Autoregressive Exogenous (ARX) model's structure

Next, some of the analysis plots displayed by UNIT during the system identification process are presented in Figure 5, Figure 6, and Figure 7 ,

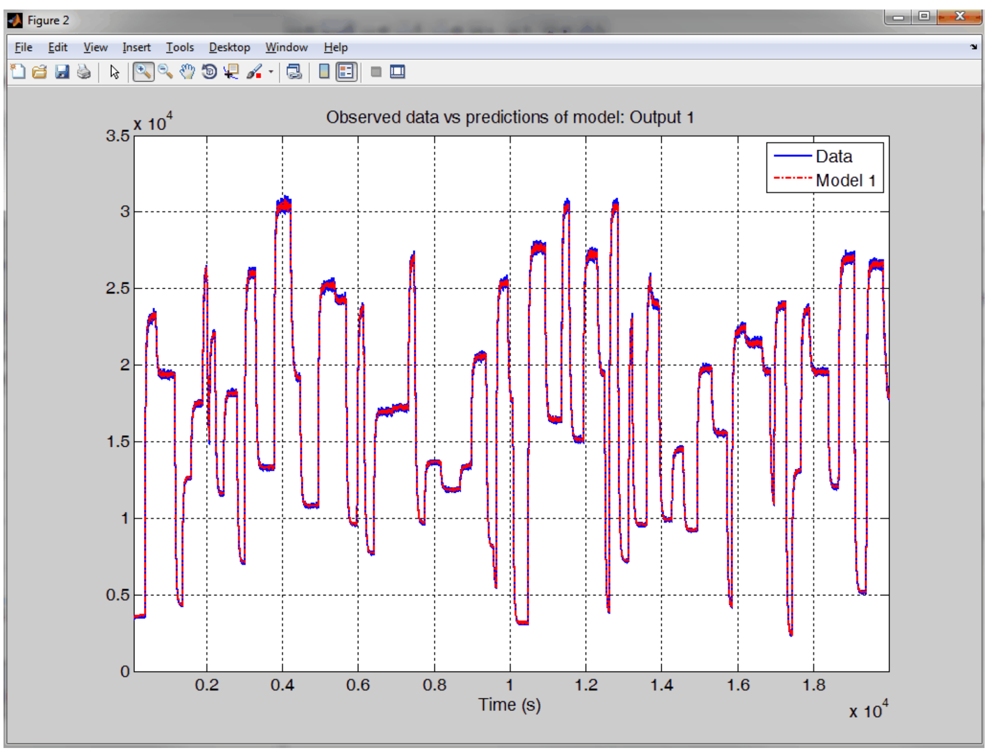


Figure 5. Observed and Predicted Output Data of the Model

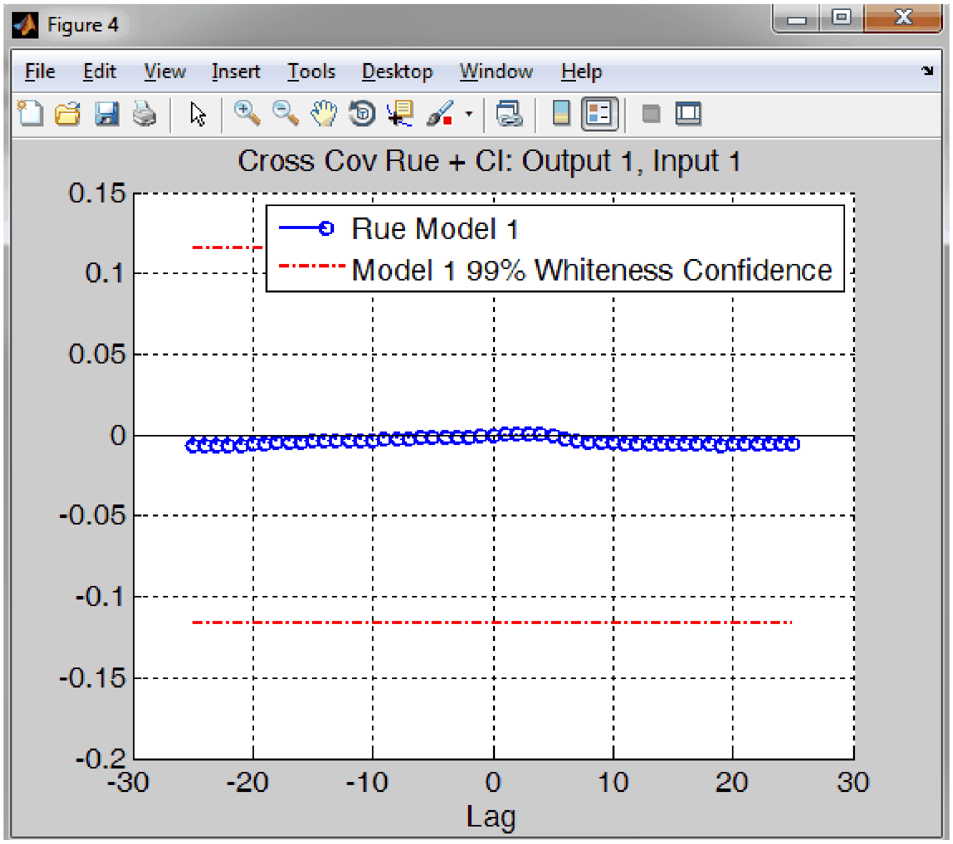


Figure 6. Cross-correlation between the Prediction Error and the Input

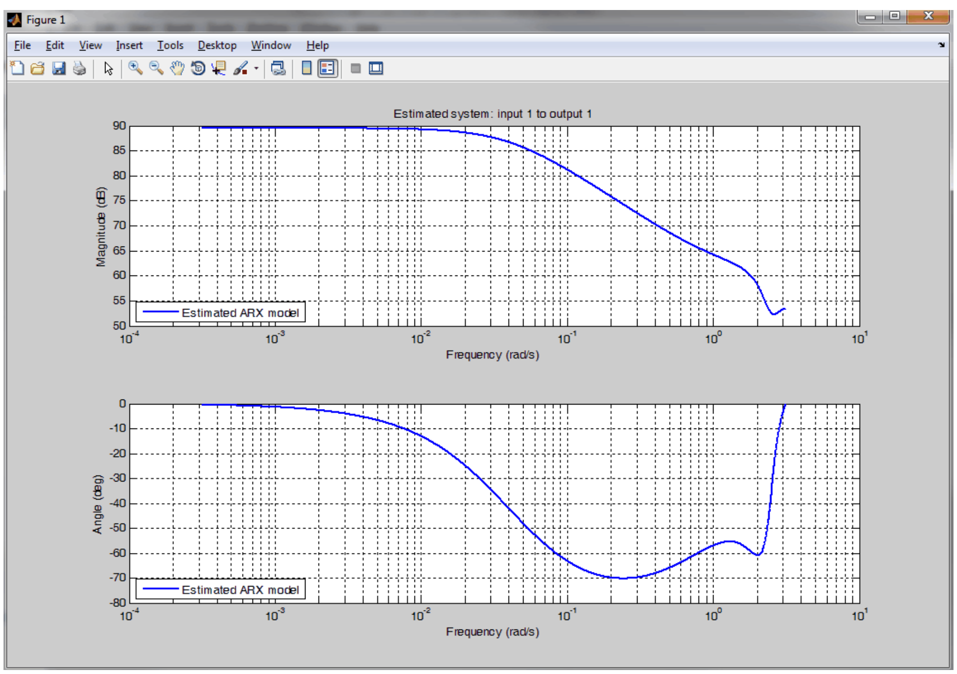


Figure 7. Frequency response of the model obtained.

The discrete-time model obtained is shown by (1)

$$H(\mathrm{z}) = \frac{1300.1907}{1-0.9583z^{-1}} \; Hz / Duty\,cycle \tag{1}$$

After the model was obtained, a DC Motor Position Control System was implemented using Classical Control Techniques and Model Predictive Control techniques. Figure 8 shows a DC motor position control system using a Proportional controller. Figure 9 shows a DC motor position control system using a Model Predictive Controller (MPC).

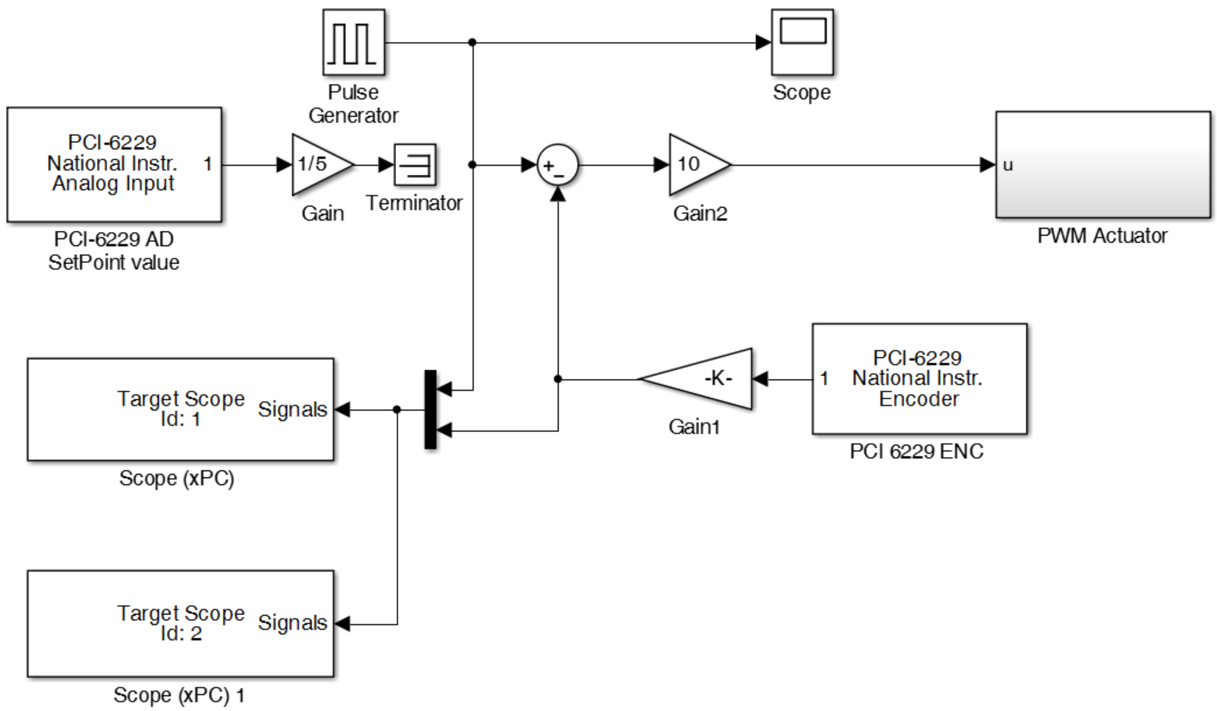


Figure 8. DC Motor Position Control System using a Proportional Controller.

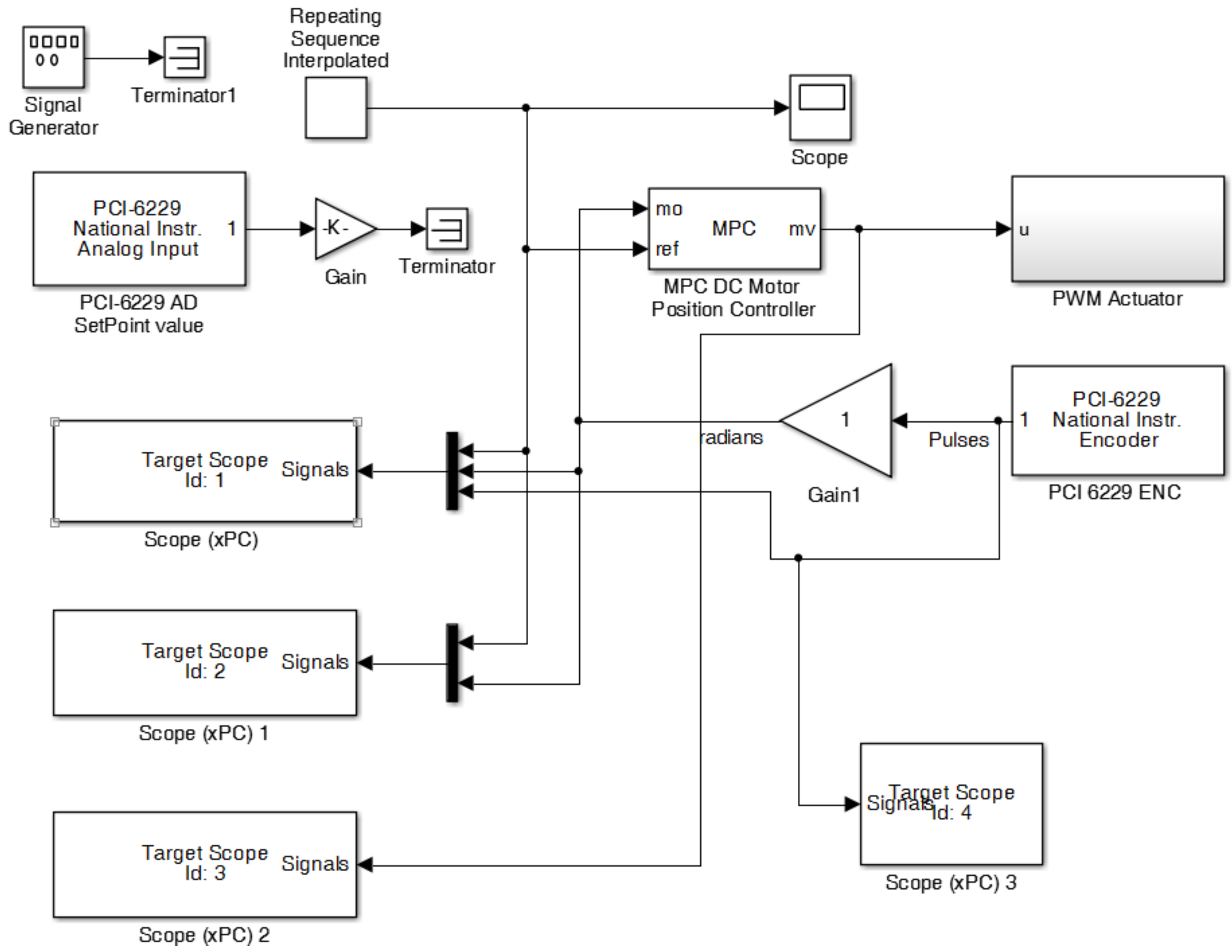


Figure 9. DC Motor Position Control System using a Model Predictive Controller (MPC).

Figure 10 shows the response of the DC motor position proportional controller to a square wave Set Point signal.

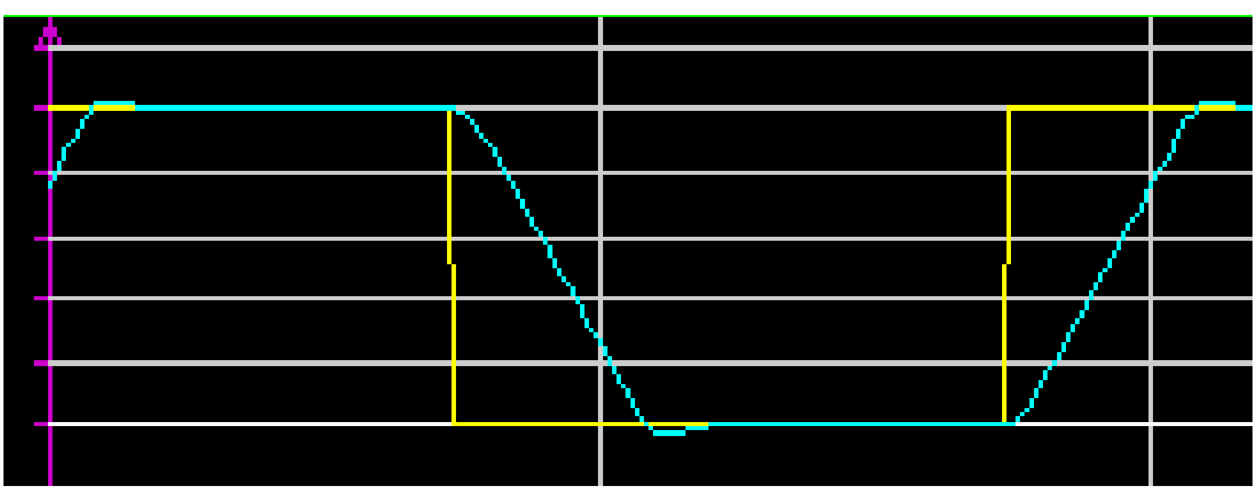


Figure 10. Response of the DC Motor Position Proportional Controller.

Figure 11 shows the response of the DC motor Model Predictive Controller to a square wave Set Point signal.

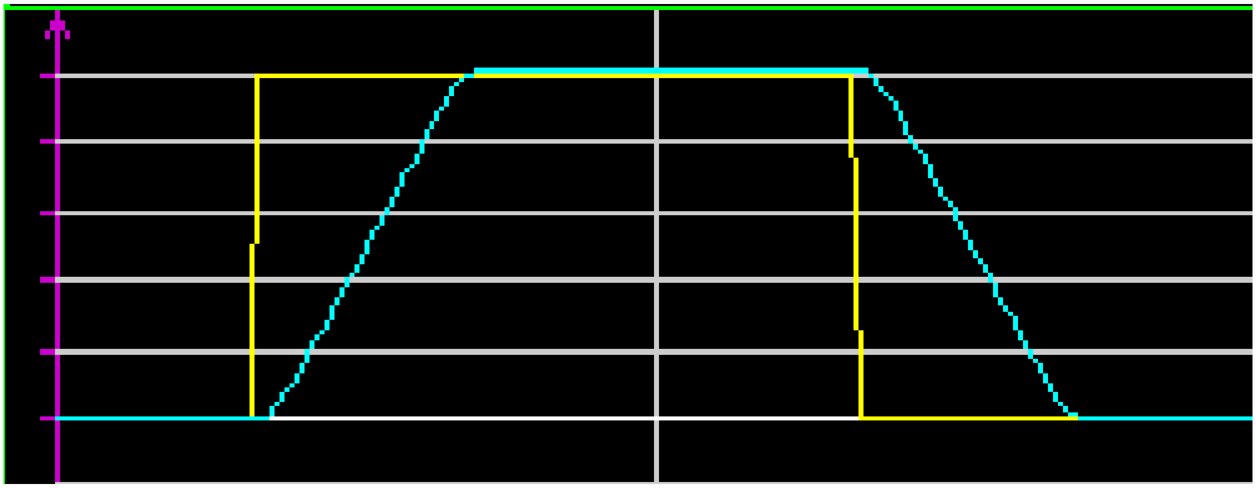


Figure 11. Zoom out of the Response of the DC Motor Position Model Predictive Controller.

It can be observed from Figure 10 and Figure 11 that the MPC does not have any overshoot but the Proportional Controller presents overshoot.

E. Conclusions and recommendations

In conclusion, the Model Predictive Controller provides a smoother control of the position of the DC motor. This smoother response makes MPC a more appropriate control technique for applications that require precision position control. Further study is needed using additional control techniques like H_∞ Robust Control and Nonlinear Control techniques. DC Brushless Motors and Permanent Magnet Synchronous Motor should also be included in future research.