A Comparative Control Study of a Separately Excited DC Motor Using Intelligent Controllers

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Abstract: In this study, a three-phase bridge controlled rectifier is used to drive and control a Separately Excited DC Motor (SEDCM) at desired values depending on different intelligent controllers, which are trained to get the desired values of firing angles to trig thyristors. The Fuzzy Logic (FL), FL with bacterial foraging algorithm (FL-BFA), BFA with PI (PI-BFA), artificial neural network with PI (ANN-PI), PI and Neurofuzzy (NFC) controllers are used and adopted to control speed of the SEDCM. Responses of the DC motor speed and torque are estimated using its transfer function characteristics and instantaneous output voltage and current of the controlled converter. The AC/DC drive circuit with intelligent controllers is adopted and modeled under different values of speed and torque conditions in stable and dynamic conditions. Model results explained success of the designed controller system. Also, it showed that during reducing speed, the FL, FL-BFA and NFC techniques caused the SEDCM to run out of working range. Therefore, PI-BFA, ANN-PI and PI techniques are dependable controllers and gave almost the same speed and torque responses. But the PI-BFA is considered the best. The speed and torque responses have acceptable agreement between the actual, estimated and desired values with fast dynamic response.

Key words: Sensorless speed/torque control, DC separately excited motor drive, artificial neural network, PI, bacterial foraging algorithm, dynamic response

INTRODUCTION

A Separately Excited DC Motor (SEDCM) is needed in different industrial applications due to its high efficiency and flexibility control over a wide range. High performance of a SEDCM drive circuit is very necessary to be developed. This development can be done through tracking a good dynamic speed and load regulation responses. Usually, closed loop operation with proper PI or PID controllers are employed to control speed of a DC motor. PID controllers have advantages to get steady-state error around zero to a step reference speed change. But the undesirable speed overshoot and slow response because of system disturbance are disadvantages (Hameed and Mohamad, 2012). Therefore, adaptive intelligent control techniques are applied to control speed of DC motors to obtain high-speed response and parameter insensitivity. Speed data is commonly provided using feedback speed sensors. Stability of the closed loop system can be influenced with speed sensor characteristics. Therefore, speed and torque of a DC motor is estimated. Bacteria Foraging Algorithm (BFA) can be used to search for the optimal parameters of PI.

By Bhushan and Singh (2011), BFA and genetic algorithm were used to control speed of SEDCM. The designed BFA gives faster dynamic performance than GA. By Rahar *et al.* (2012), Neuro Fuzzy Controller (NFC), PID and fuzzy logic controller were used to control speed of SEDCM. The study proves that NFC gives better response than other controllers. By Bansal and Narvey (2013), self-tuning of PID controller based on Fuzzy Logic (FL) was done. The FL is trained to adjust gains of a PID controller and the designed controller gives better results than conventional PID controller. By Antar and Allu (2014), sensorless speed control of a SEDCM was performed using Artificial Neural Network (ANN) with instantaneous armature current and reconstructed output voltage as inputs of the ANN. While the estimated speed and torque of a SEDCM in the four quadrant operation modes based on the ANN with instantaneous armature current and voltage as inputs was done by Antar and Allu, (2016).

In this study, three-phase bridge controlled rectifier is used to control speed of the SEDCM as illustrated in Fig. 1. Different intelligent controllers such as FL, FL with BFA (FL-BFA), PI with BFA (PI-BFA), PI controller, ANN with PI (ANN-PI) and NFC as controllers are trained,

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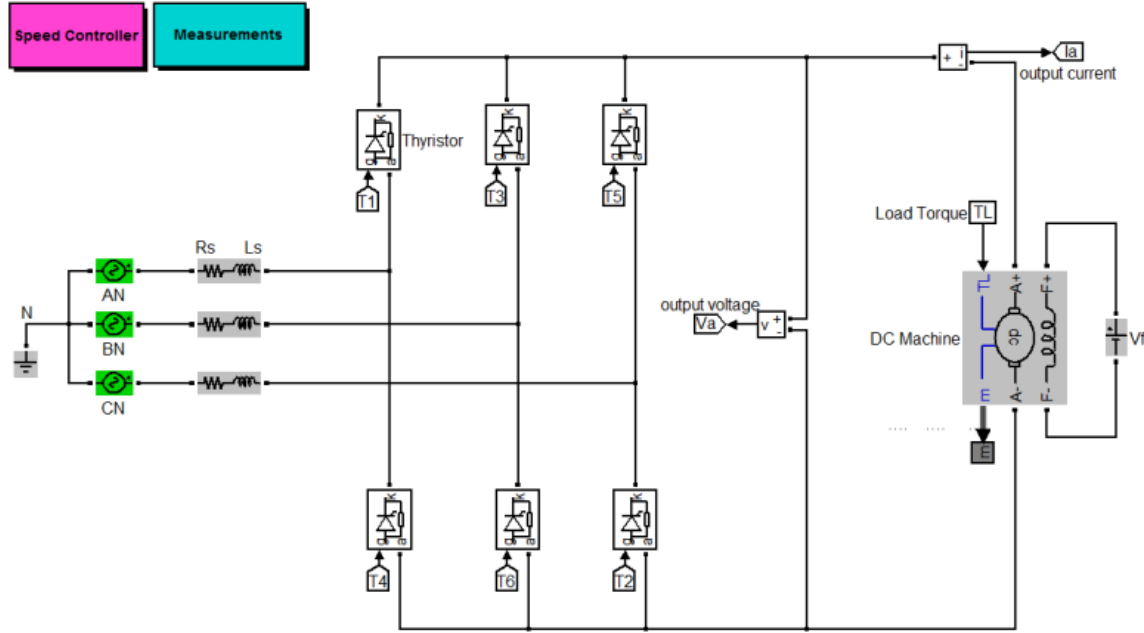
Fig. 1: Circuit model of the three-phase H-bridge controlled rectifier
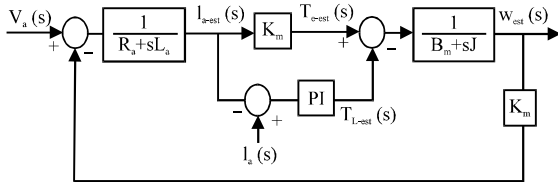

Fig. 2: Estimation circuit of the SEDCM

modeled and applied to control speed of the SEDCM by selecting the optimal value of firing angle (α) to trig thyristors of the AC/DC converter. These controllers are used to find out the proper controller that produce the best speed responses under different speed and torque values and operation conditions. Speed and torque of a SEDCM is estimated using transfer function characteristics depending on instantaneous output voltage and current as shows in Fig. 2.

MATERIALS AND METHODS

Converter configuration: Many researchers analyzed DC drive systems to obtain mathematical and programmable form for the variation of torque, speed and line current with firing angle variations. In this study, three-phase bridge controlled rectifier, shows in Fig. 1 is used to control speed of the SEDCM under different load torque conditions in order to obtain best speed responses. The DC drive system is controlled using different adaptive

controller. A closed loop system is used to find optimal value of (α) in order to improve the step response performance as illustrates in Fig. 3.

Modeling of speed/torque estimation circuit: Speed of the SEDCM is regulated by adjusting the terminal output voltage of the controlled converter. Torque and speed of the SEDCM is estimated depending on the DC motor transfer function characteristics as illustrated in Fig. 2. By using the laplace transform, the estimated speed (West) and torque (test) can be written as:

$$I_{a\text{-est}}(s) = \frac{V_a(s) - K_m * w_{est}(s)}{(R_a + sL_a)} \qquad (1)$$

$$T_{e\text{-ests}}(s) = K_m * I_{a\text{-est}}(s) \qquad (2)$$

$$w_{est}(s) = \frac{T_{e\text{-est}}(s) - T_{L\text{-est}}(s)}{(B_m + sJ)} \qquad (3)$$

where, K_m is a machine constant. In order to evaluate speed of the SEDCM properly, load (T_L) and developed (T_e) torques are estimated to get high control reaction and suitable agreement between the estimated, desired and actual values. The estimator system is built and modeled by MATLAB/Simulink to evaluate and control torque and speed of the SEDCM as shown in Fig. 3. The estimation load torque and speed of the SEDCM is computed from
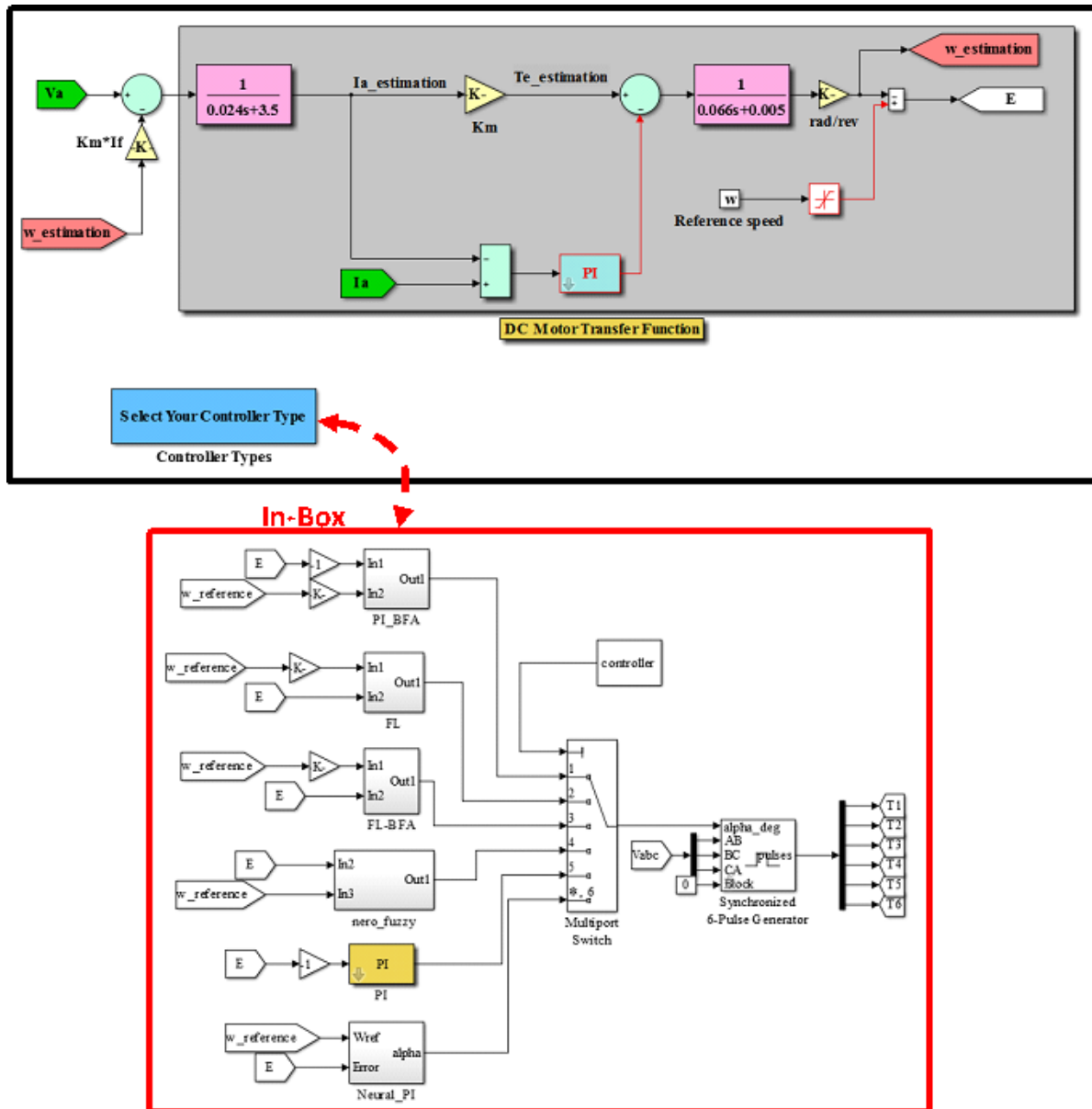
Fig. 3: MATLAB Model of the sensorless speed/torque and controller types

the instantaneous armature terminal voltage and current. Intelligent controllers such as FL, FL-BFA, PI-BFA, PI, ANN-PI and NFC are integrated together to get faster response and prevent excessive current to flow in the converter circuit. Thus, the suggested controllers have a quick dynamic response during load changing to reach stable as quick as possible.

RESULTS AND DISCUSSION

Estimation and control of load torque and speed of the SEDCM is done based on FL, FL-BFA, PI-BFA, ANN-PI, PI and NFC controllers. The intelligent controllers are trained to control speed of the SEDCM by choosing the optimum value of (α). The overall system is simulated and modeled by Matlab as shows in Fig. 1. Estimated speed response of the SEDCM using different intelligent controller techniques at load torque (TL = 7 Nm) is illustrated in Fig. 4. This Fig. 4 explained that PI and PI-BFA provide better responses than others. Also, techniques of FL, FL-BFA and NFC cause to run the DC motor out of working range during reducing speed. So, the PI-BFA, ANN-PI and PI techniques are depended to control speed and load torque.
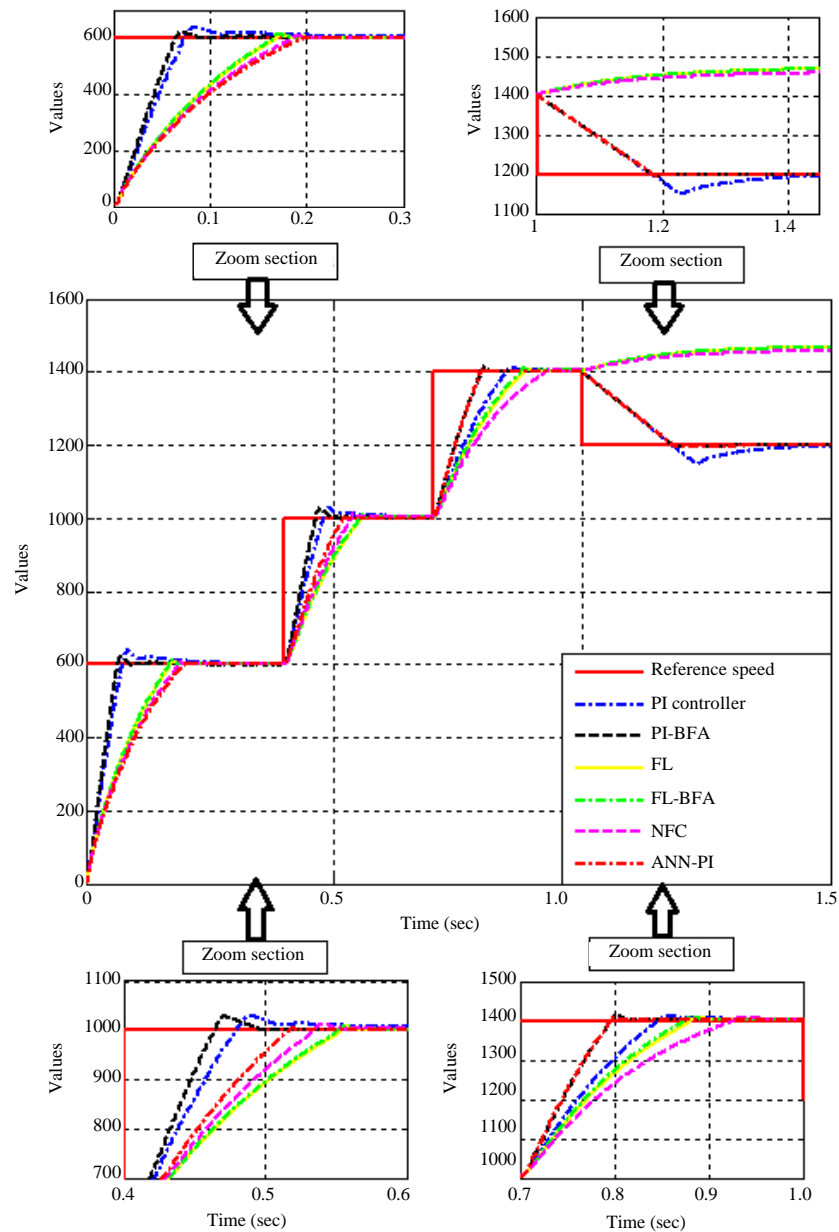
Fig. 4: Speed response of the SEDCM at constant load torque (7 Nm)

Figure 5 illustrated the estimation speed and load torque responses at 1200 rpm and different load torque values (8, 12 and 4 Nm). The speed responses are good. To clarify the success of these controller techniques, the system has run under different speed and load toque values as shows in Fig. 6. The waveforms explained that also the PI-BFA technique gives better responses. In order to prove these results, delay, peak overshoot and settling times with Steady-State Error (ESS) and Peak Overshoot (POV) values are calculated and drawn as illustrated in Fig. 7. These results prove that the PI-BFA

technique has better results. But the overall results of the three controllers are within acceptable performance. The estimated, reference and actual speed and load torque is shows in Fig. 8. The estimated speed and torque follow the reference point and remains stable during speed and load changing and stay around the reference points with almost zero steady state error. As a result, sensorless torque and speed responses of the SEDCM are good which verifies the value of the estimated system to follow the required torque and speed. The designed controllers offer excellent responses and gets steady state as quick as possible.
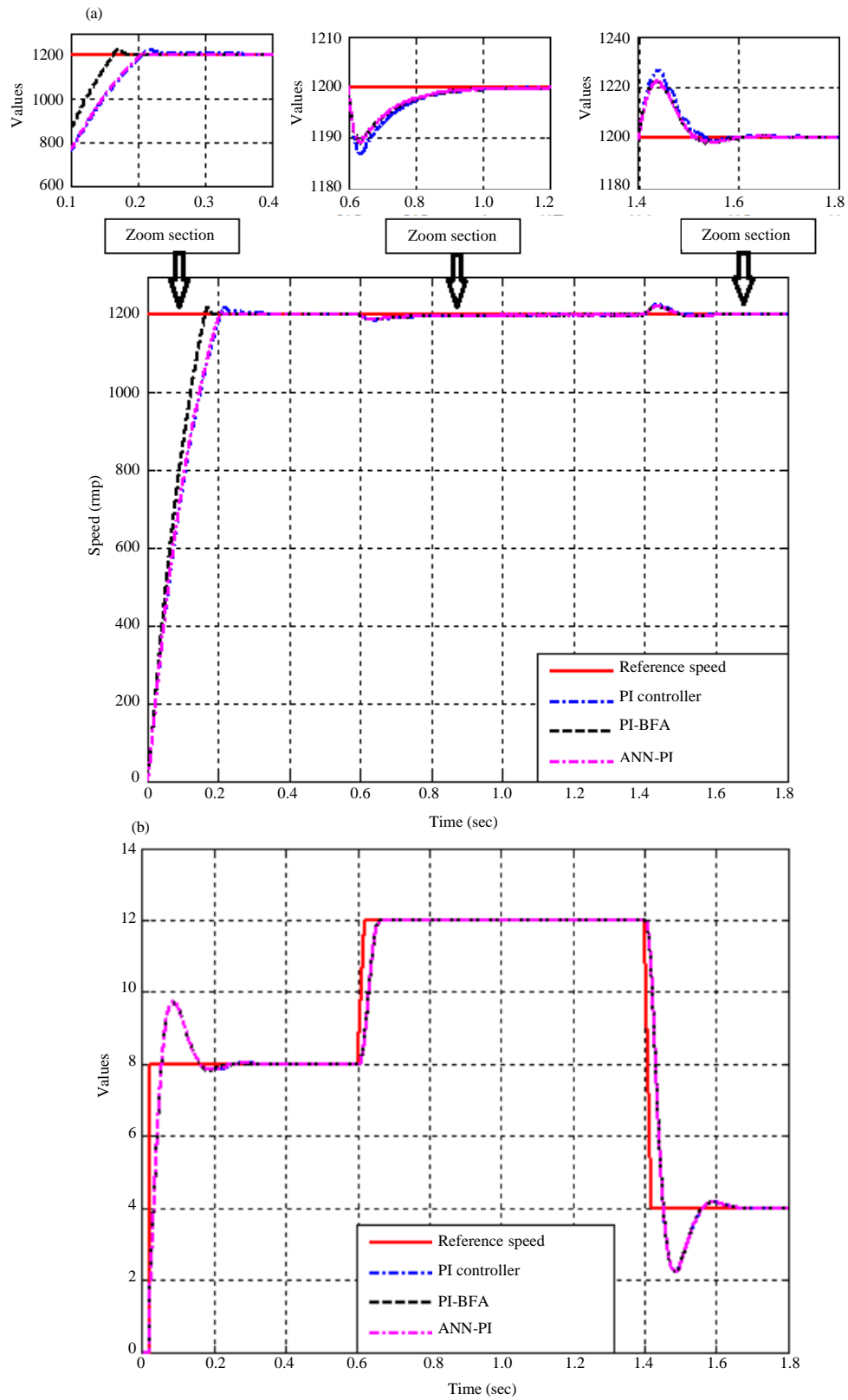
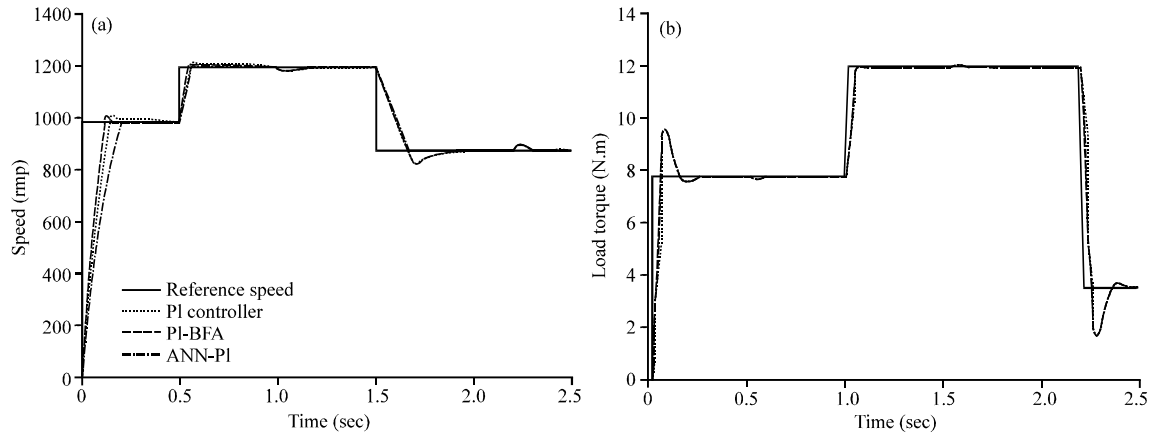Fig. 5: a) Speed and b) Load torque responses at 1200 rpm and different load torque

Fig. 6: a) Speed and b) Load torque responses at different torque and speed operation conditions
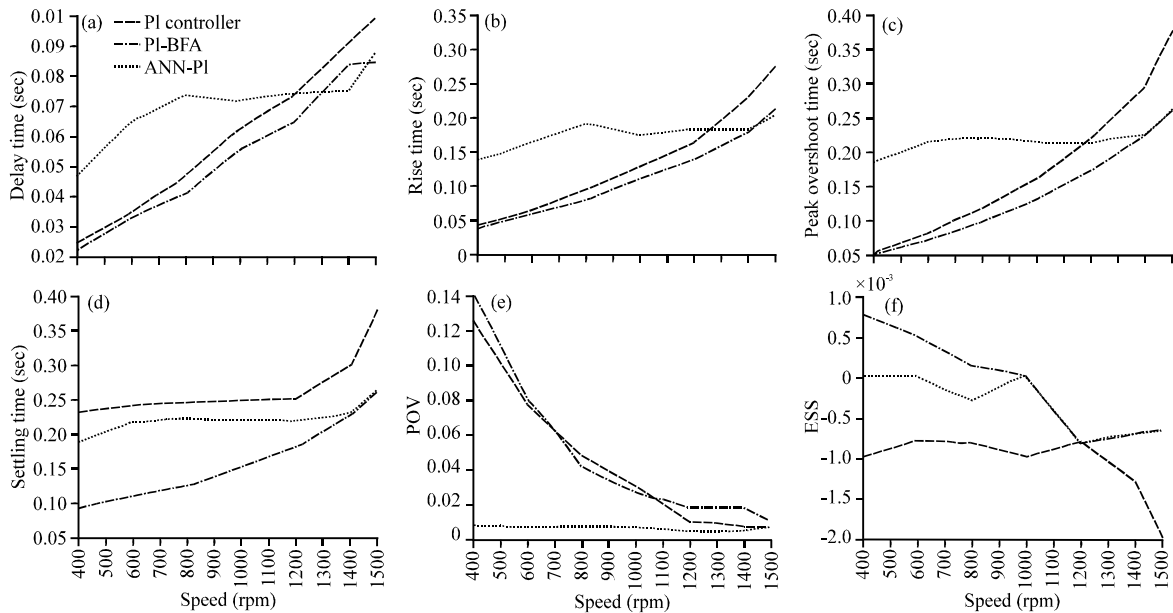

Fig. 7: Speed response characteristics based on: a) Delay time; b) Rise time; c) Peak overshoot time; d) Settling time; e)
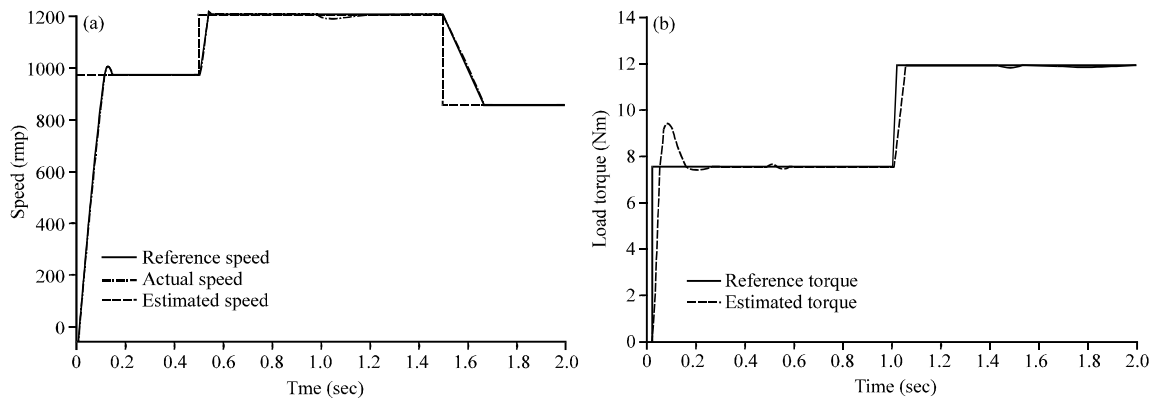Peak overshoot and f) Steady-state error responses

Fig. 8: Waveforms of the reference, actual and estimated: a) Speed and b) Torque of the SEDCM

CONCLUSION

Speed and torque estimation of a SEDCM using transfer function characteristics based on instantaneous output voltage and current of the three-phase bridge controlled rectifier has been done in this study. The FL, FL-BFA, PI-BFA, ANN-PI, PI and NFC controllers have been built to achieve smooth starting and acceleration. A wide range speed variations of a SEDCM is obtained at different mechanical load. Simulation results illustrated that during reducing speed, the FL, FL-BFA and NFC techniques cause the DC motor to run out of working range. Therefore, PI-BFA, ANN-PI and PI techniques have been taken into account to control speed and load torque and given acceptable performance. The PI-BFA technique provides better results than others. The overall results prove the strength of the designed controller to the variation in the torque and speed.

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