

Artificial Intelligence Based Direct Torque Control of Induction Motor Drive System

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Abstract : In this project, a three-phase Induction motor (IM) under the direct torque control (DTC) technique is studied. IM is known for its simple engines and its self-starter feature but it always suffered a setback in the area of torque and speed control as it is a highly coupled nonlinear plant and proves to be most complex and expensive speed drive. The application of direct torque control (DTC) is beneficial for fast torque reaction in IM but provide high torque and ripples due to harmonic effects. Thus, the speed control of induction motor is important to achieve maximum torque and efficiency. The aim of this study is to improve tracking performance of the induction motor drive using artificial intelligence control system. A method for controlling induction motor drive is presented with Proportional-Integral (PI) controller and Artificial Neural Networks (ANNs) for performance comparison. MATLAB/SIMULINK software is used to develop a three-phase 2 pole-cage type induction motor model. Also the performances of the two controllers have been verified in terms of its speed and torque responses. The ANN is trained so that the speed of the drive tracks the reference speed. This study proved that the performance and dynamics of the induction motor are enhanced using ANN controller as compared with PI controller.

Keywords: Neural Network , PI controller, Direct Torque Control

1. Introduction

Induction motors have much application in the industry because of their low maintenance and robustness. In recent years, the control of the induction motor drive is an active research area and the technology has further advances in this field and one of it is can be controlled with the help of PI controller or artificial intelligence based system such as Neural Network and Fuzzy with the use of direct control technique.

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1.1 Direct Torque Control

DTC controls directly both the stator flux linkage and electromagnetic torque of the machine simultaneously by the selection of optimum inverter switching modes. The use of a switching table for voltage vector selection provides fast torque response, low inverter switching frequency and low harmonic losses without the complex field orientation by restricting the flux and torque errors within respective flux and torque hysteresis bands with the optimum selection being made. The DTC controller abandons the stator current control philosophy by directly controls the flux itself and it consists of two hysteresis comparators (flux and torque) to select the switching voltage vector in order to maintain flux and torque between upper and lower limits. DTC has fast dynamic performance but provides high ripples in torque due to the harmonics effect. Potential problems during start or low-speed operation and during changes in torque command [1]. The DTC control technique is shown in Figure 1.

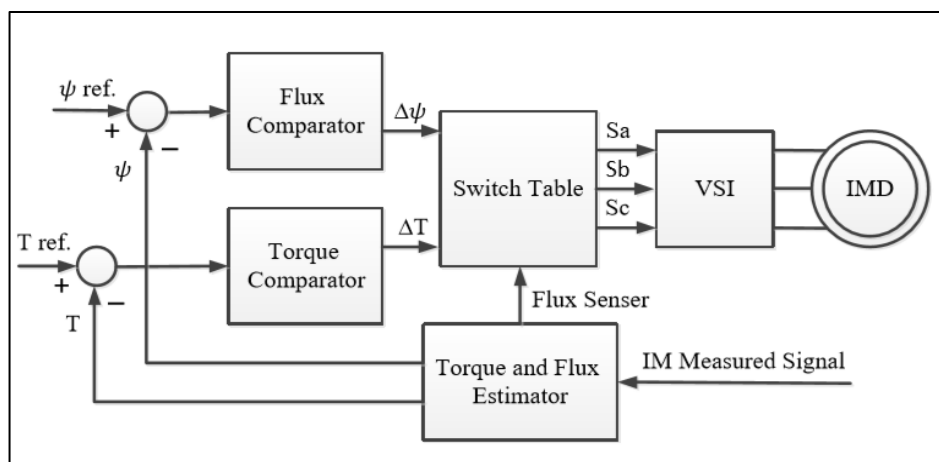


Figure 1: DTC Technique [1]

1.2 Proportional Integral Controller

The proportional integral (PI) controller is a feedback controller that drives the plant which is to be controlled with a weighted sum of error and the integral of that value. Known to increase the order and the type of the system by one. It also causes the steady state error to reduce to the zero, which is not the case for proportional only control in general. Somehow, PI controller can never achieve perfect control, that is, keep the speed of induction motor continuously at a desired set point value in the presence of disturbance or set point change [2]. The basic block for PI controller is shown in Figure 2.

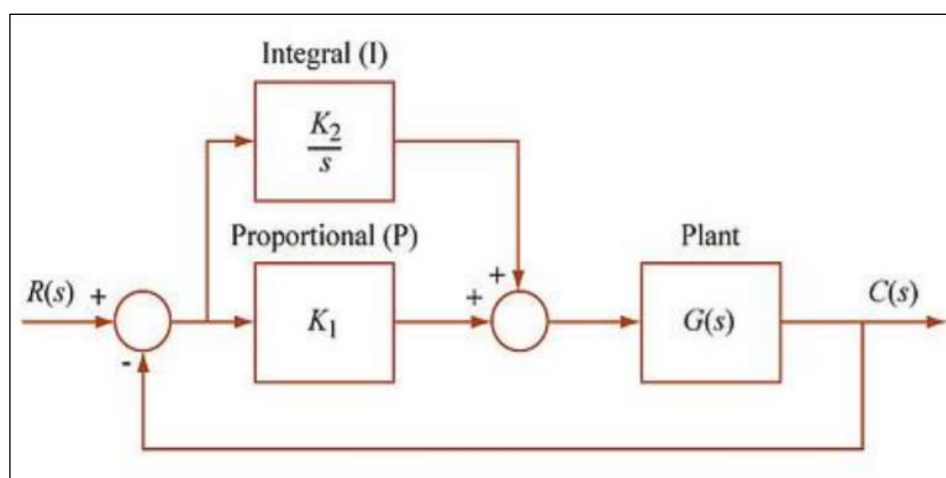


Figure 2: Basic PI system [4]

1.3 Artificial Neural Network (NN) Controller

NN is a mathematical model inspired by biological neural networks. It consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. The control system for this drive is very similar to that of traditional control systems with a reference input which is desired speed in, feedback (measured speed), the controller and the plant [10-11]. The Controller is made of the artificial neurons connected in a network of 1 input layer, 3 hidden layers and 1 output layer connected as a feed forward network and trained using the algorithm/coding. A sketch of the neural network is shown in Figure 3. It has the special ability of learning which implies that it can estimate the output of a system based on its experience on a set of previously trained data. Figure 4 shows the configuration topology used for the project known as an indirect scheme.

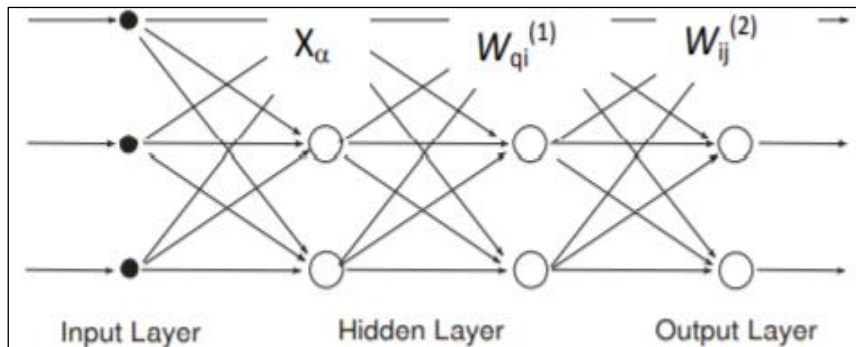


Figure 3: Neural Network Structure [5]

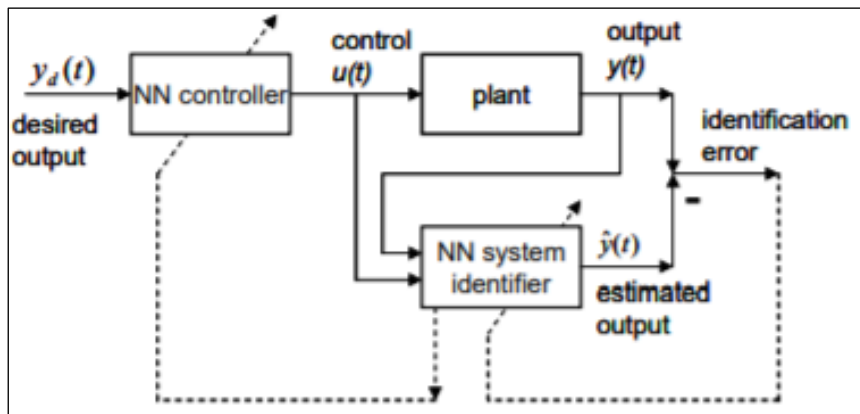


Figure 4: ANN Indirect scheme [9]

2. Research Methodology

This section will explain the methods used in developing and achieving the goals of this project. This study is fully based on a mathematical block diagram built into Simulink MATLAB where readings, graph and tabulation are taken and analyzed.

2.1 Simulink Model

Figure 5 and 7 show the final design of the close-loop system based on the DTC scheme. Figure 5 is the PI control system where speed, torque and flux are controlled using the respective method. The PI controller is shown in Figure 6. Meanwhile Figure 7 is the improved version where speed controller of PI scheme is replaced by ANN controller. The PI controller for speed is replaced with ANN controller to use as the input of the feedback system to the torque controller. This means that both speed and torque controller has the ANN characteristic as input to the IM that made changes to the whole system response

with the neural network configuration. The IM has a rated speed of 1500 rpm which is 157.8 rad/s and a maximum load of 20 Nm. The estimator block diagram in this system is to compare the response of the system without a controller means inputs taken directly. Three inputs can be manually set which is the speed, flux and torque magnitudes to get the desired output.

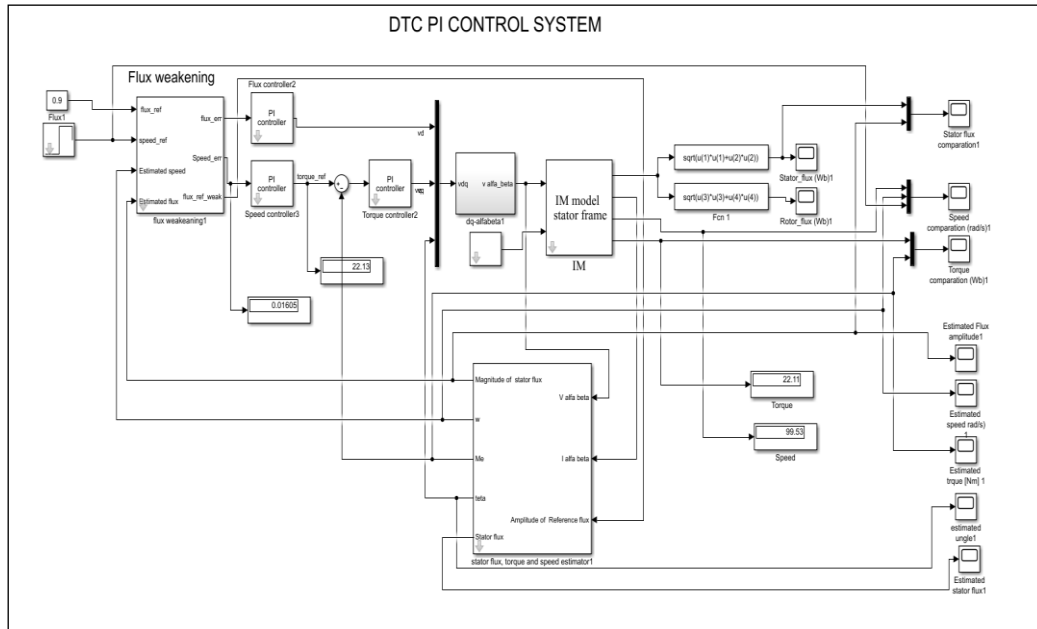


Figure 5: PI Control system

The PI system linear control strategy is given by Equation 1 below. Its output is the updating in PI controller gains (K_p and K_i) based on a set of rules to maintain excellent control performance even in the presence of parameter variation and drive nonlinearity.

$$T = K_p e + K_i \int e dt \quad \text{Eq.1}$$

The use of PI controllers for speed control of induction machine drives is characterized by an overshoot during tracking mode and a poor load disturbance rejection. This is mainly caused by the fact that the complexity of the system does not allow the gains of the PI controller to exceed a certain low value. At starting mode the high value of the error is amplified across the PI controller provoking high variations in the command torque[4]. The PI controller configuration of speed, flux and torque is shown in Figure 6.

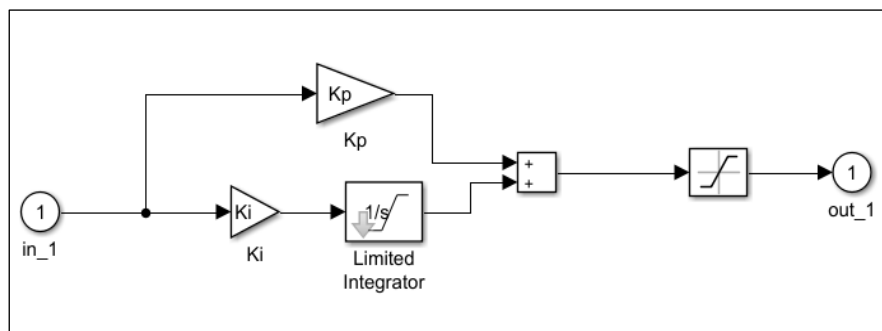


Figure 6: PI Model

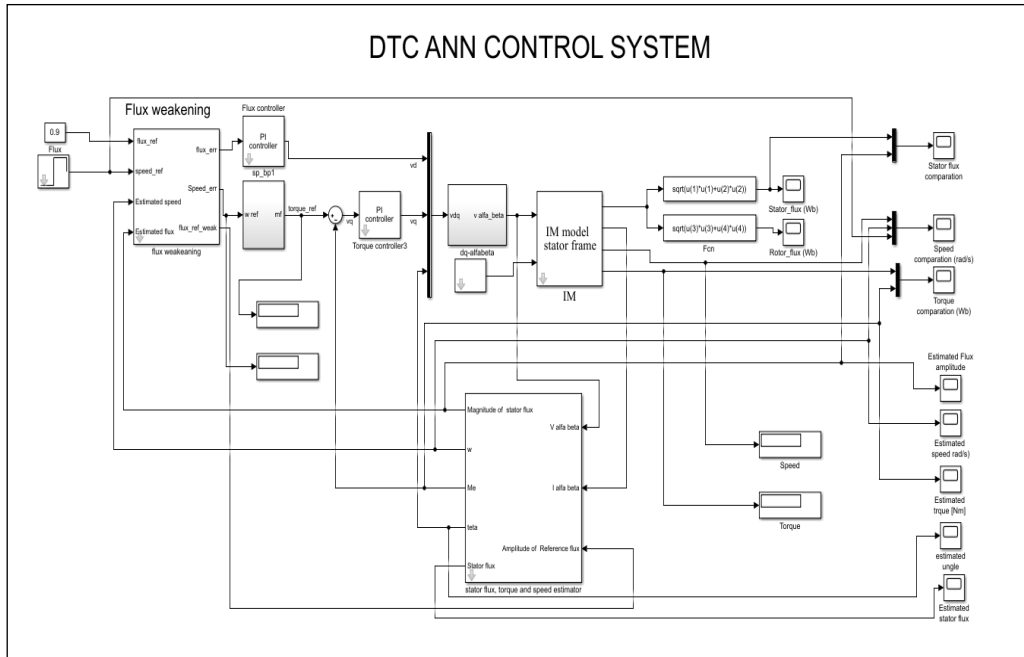


Figure 7: ANN Control system

Figure 8 shown the system configuration for the ANN controller. The ANN is trained by a learning algorithm through coding which performs the adaptation of weights of the network iteratively until the error between target vectors and the output of the ANN is less than an error goal. In this paper, the ANN with 1-3-1 structure has been implemented. Neural network has been devised having as inputs the speed error.

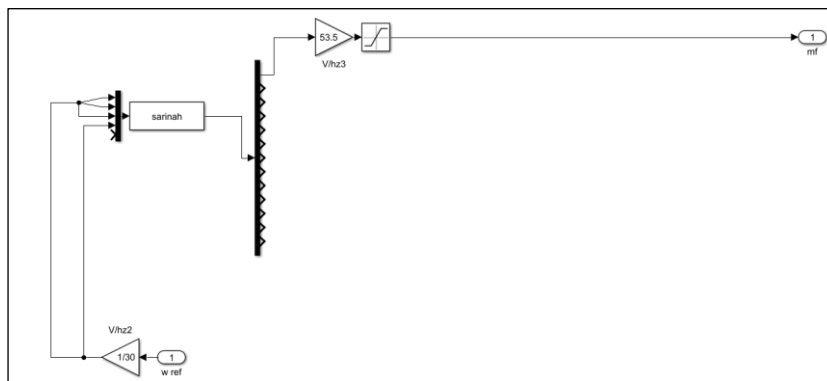


Figure 8: ANN model

2.2 Flow chart

Figure 9 summarize the process of developed feedback control system for both PI and ANN systems. For both systems, the flux controller is not updated to ANN system infact it sticks to PI system and has a fixed set value of 0.9 as the best input for the system. The feedback system detect error before entering the IM model this is to ensure that desired output will be at least error and system highly efficient.

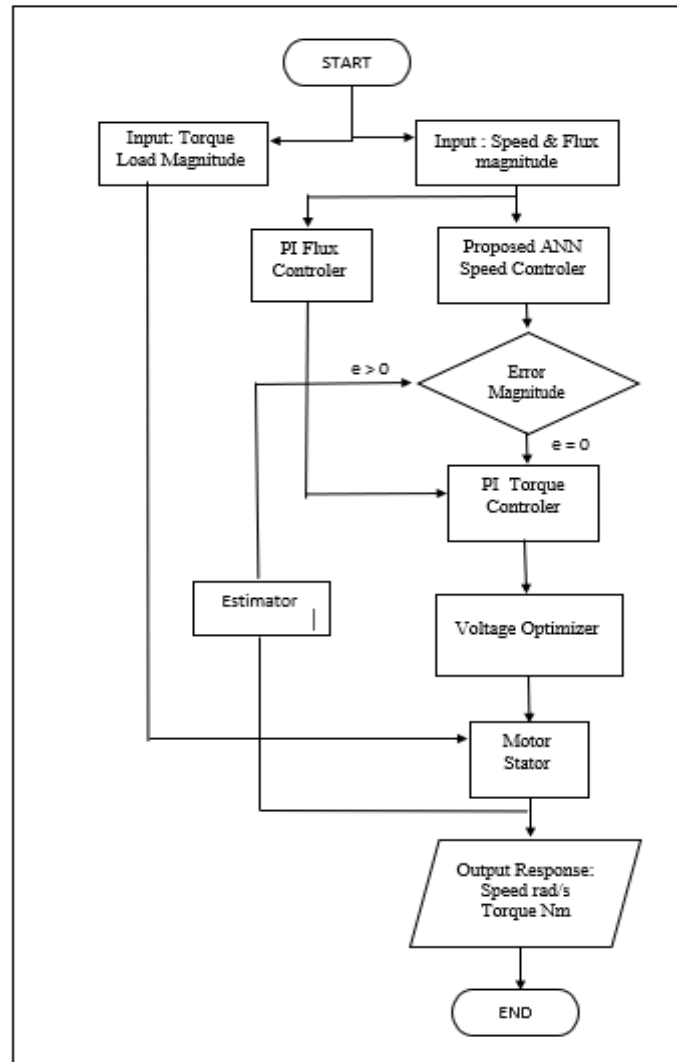


Figure 9: ANN system flow chart

3. Results and Discussion

The results of the both PI and ANN controlled systems will be presented. Results are taken from the model scope as well as the magnitude value of desired parameters. The output response from both PI and ANN controller were tested and gathered for three condition which are constant speed with constant load, constant speed with variance load, lastly variance speed with constant load. Performance characteristic for both controllers are compared. Outputs represent by Torque (Nm) vs time (second) graph characteristic as well as speed (rad/s) Vs time (second) graph.

3.1. Constant speed constant load

For this testing, the IM speed is set to fixed value which is 50 rad/s while load is set to 20 Nm. This condition is run simultaneously for both PI and ANN and the output responses of speed and torque performance are shown from Figure 10 to Figure 13. It can be seen that during constant load the responses of the ANN system are stable and smoother without spark/oscillation at the start of operation and it took about 0.25 s to run at desired speed, meanwhile PI speed response in Figure 10 shown there is overshoot up to 70 rad/s at the start up operation. Also, the starting torque of ANN system reaches to 70 Nm only compare to 150Nm starting torque of PI system which is quite high and even though high starting torque is desirable, it causes an increase in losses and can reduce efficiency during normal

condition. This is because during high starting torque, high rotor resistance is produced that cause high slip.

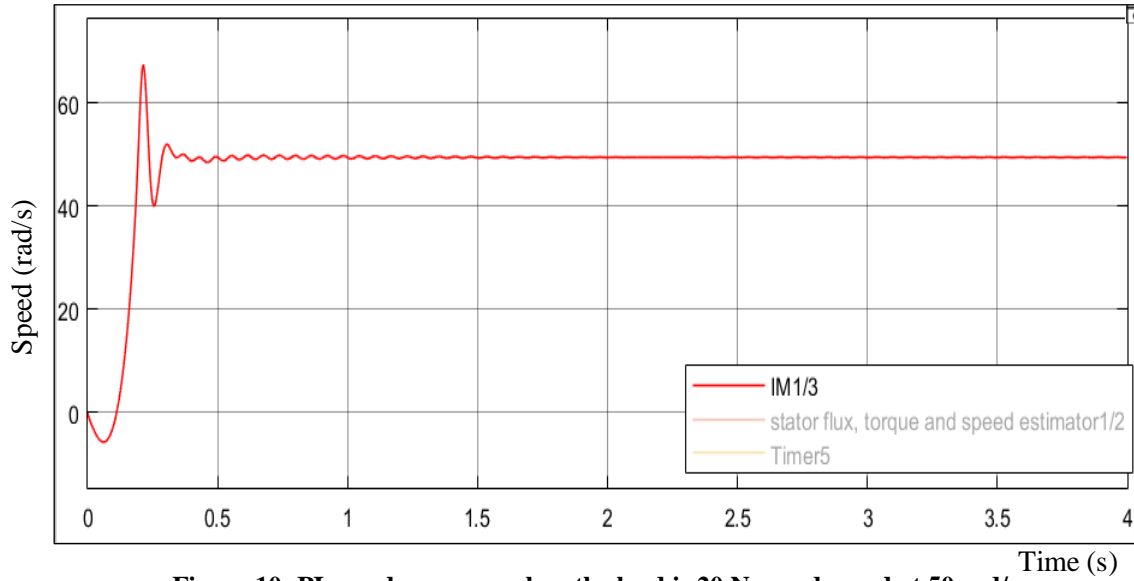


Figure 10: PI speed response when the load is 20 Nm and speed at 50 rad/s

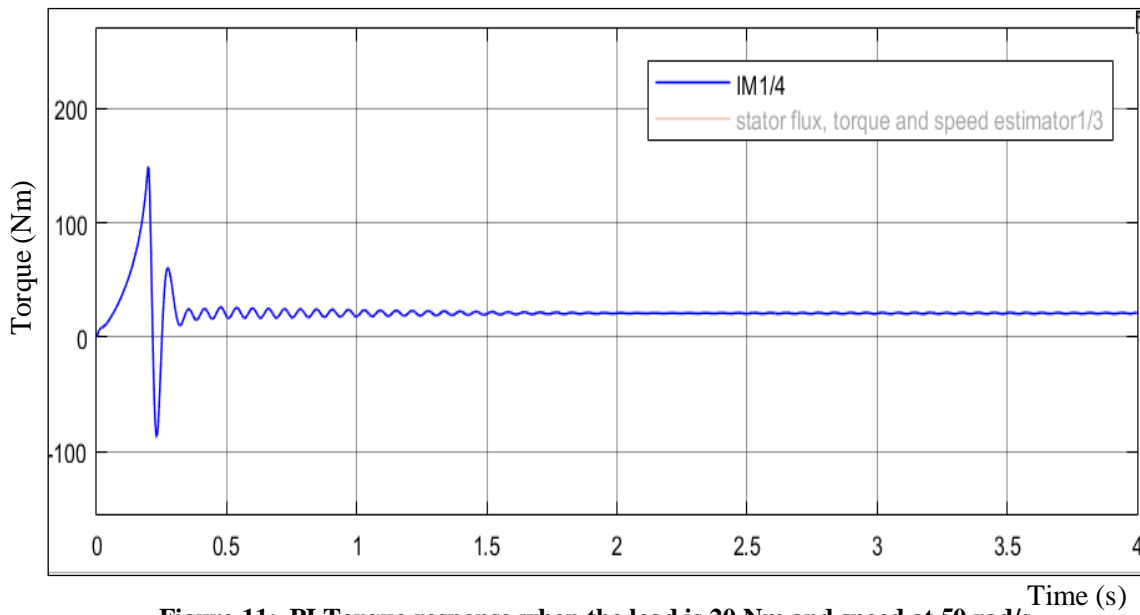


Figure 11: PI Torque response when the load is 20 Nm and speed at 50 rad/s

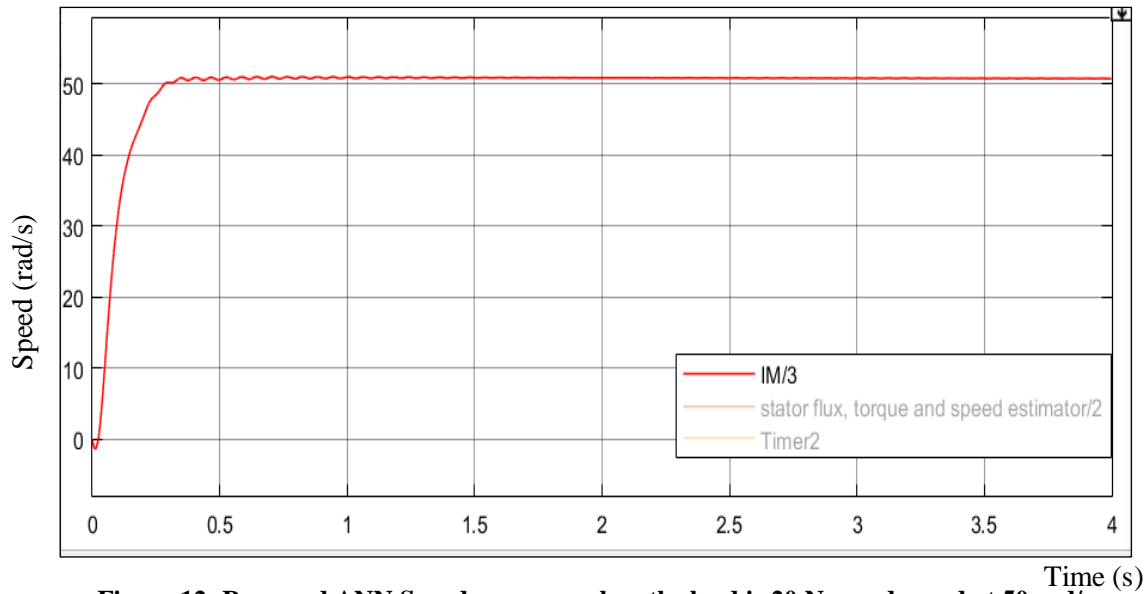


Figure 12: Proposed ANN Speed response when the load is 20 Nm and speed at 50 rad/s

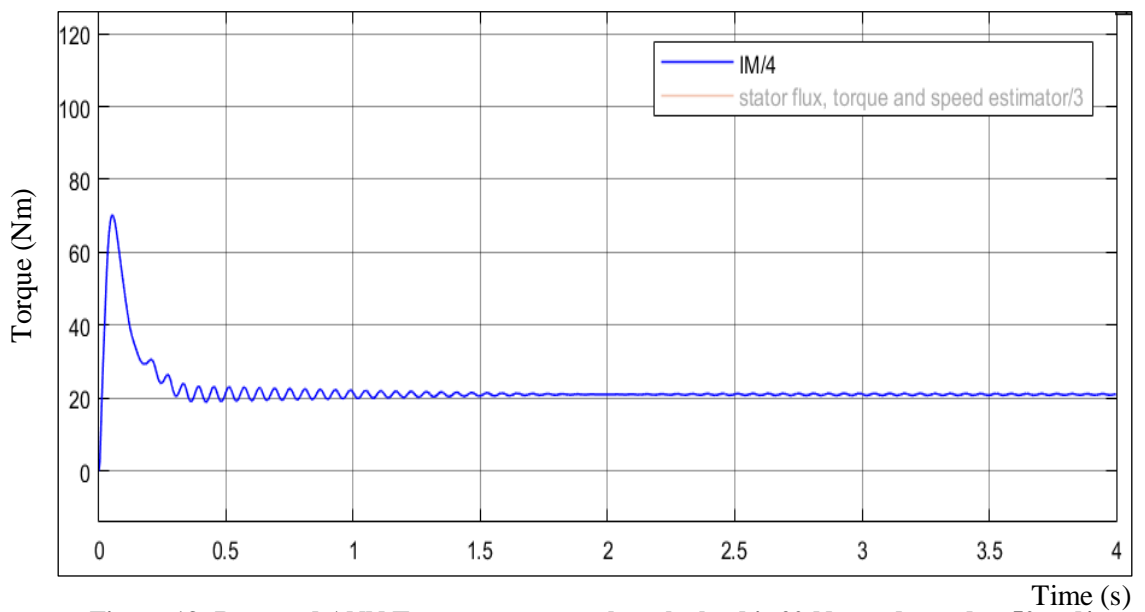


Figure 13: Proposed ANN Torque response when the load is 20 Nm and speed at 50 rad/s

The testing is repeated for a higher speed which is 140 rad/s but with the same load, 20 Nm. The results of speed and torque performance is shown in Figure 14 to Figure 17. The increased input speed in the system increase the starting torque of the system as well. Here it can be proved that the desired output speed magnitude of both controllers is achieved as it's the same as input magnitude but ANN has a better response without spark at the start and no ripple compare to PI speed response. ANN control system are very stable even at high speed. For torque response, PI system stable after about 0.6 s which is higher settling time compares to the ANN system that only 0.4 s. As PI produced big ripples and has settling time of about 0.6s and starting torque overshoot to over 200 Nm. The ANN output speed is very efficient and torque has less ripples.

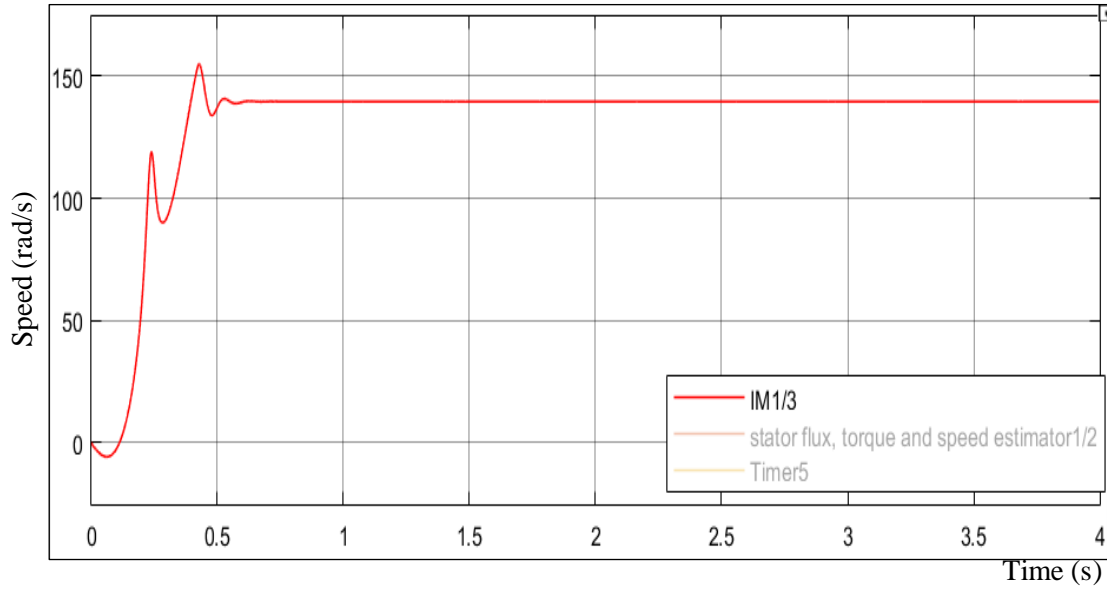


Figure 14: PI Speed response when the load is 20 Nm and speed at 140 rad/s

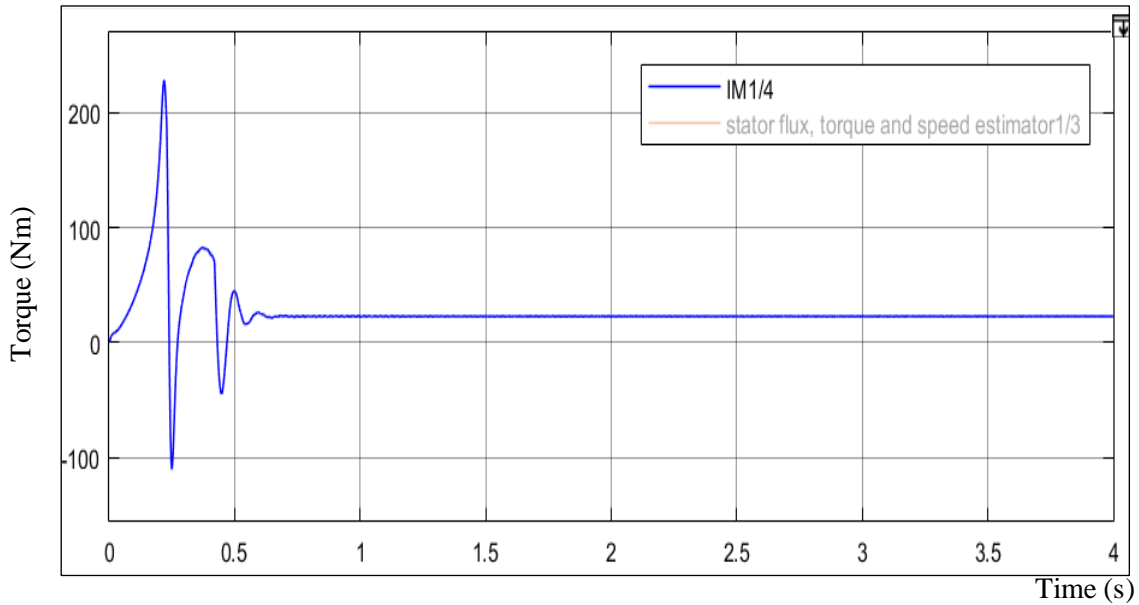


Figure 15: PI Torque response when the load is 20 Nm and speed at 140 rad/s

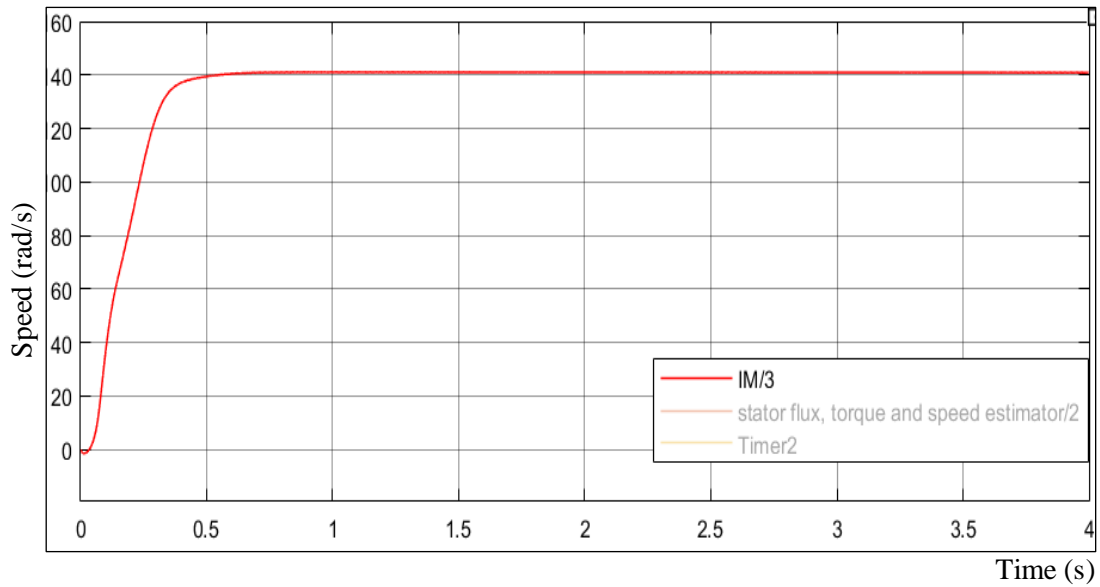


Figure 16: Proposed ANN Speed response when the load is 20 Nm and speed at 140 rad/s

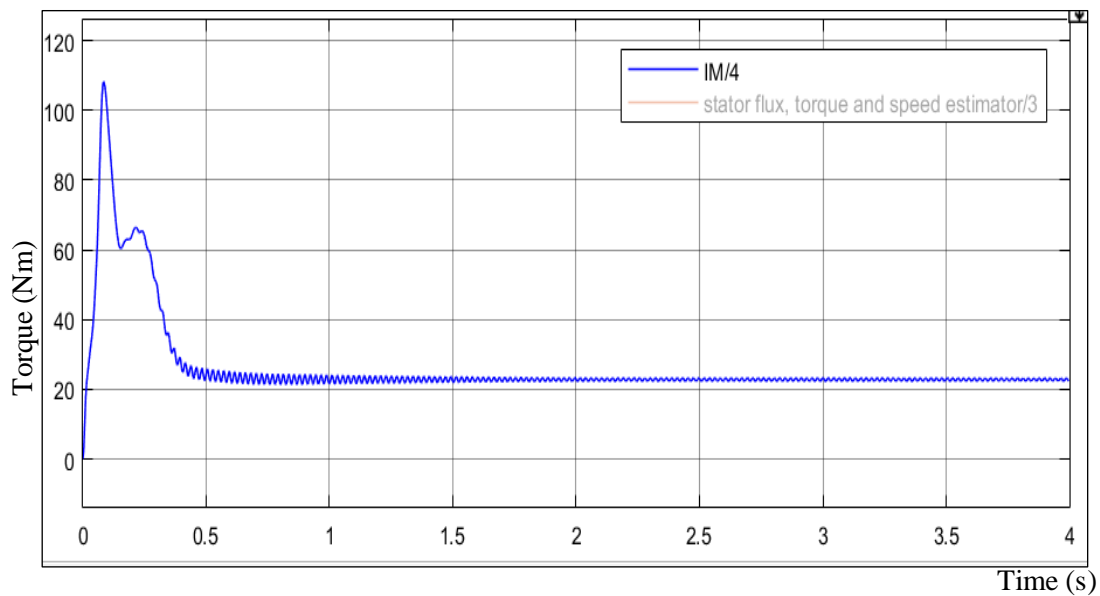


Figure 17: Proposed ANN Torque response when the load is 20 Nm and speed at 140 rad/s

3.2 Constant speed with load disturbance

The testing is continued by adding load disturbance into the system with constant speed which 50 rad/s. Referring to Figure 18 to Figure 21 which are the responses when varies the magnitude of load torque is applied during the operation. The value of torque is 40, 10 and 20 Nm with 0.2 s, 0.5 and 1.3 s respectively. From both systems, it can be seen the settling time of ANN much faster than the PI system. Also, the PI speed system overshoot to 80 rad/s at the starting of the IM that lasts after 0.3 s.

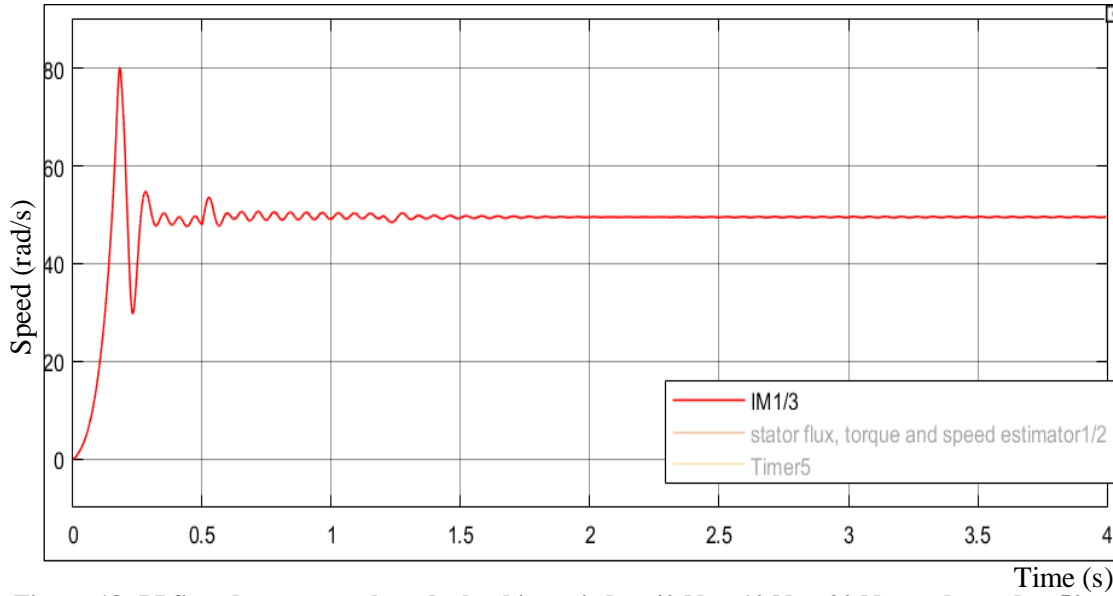


Figure 18: PI Speed response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 50 rad/s

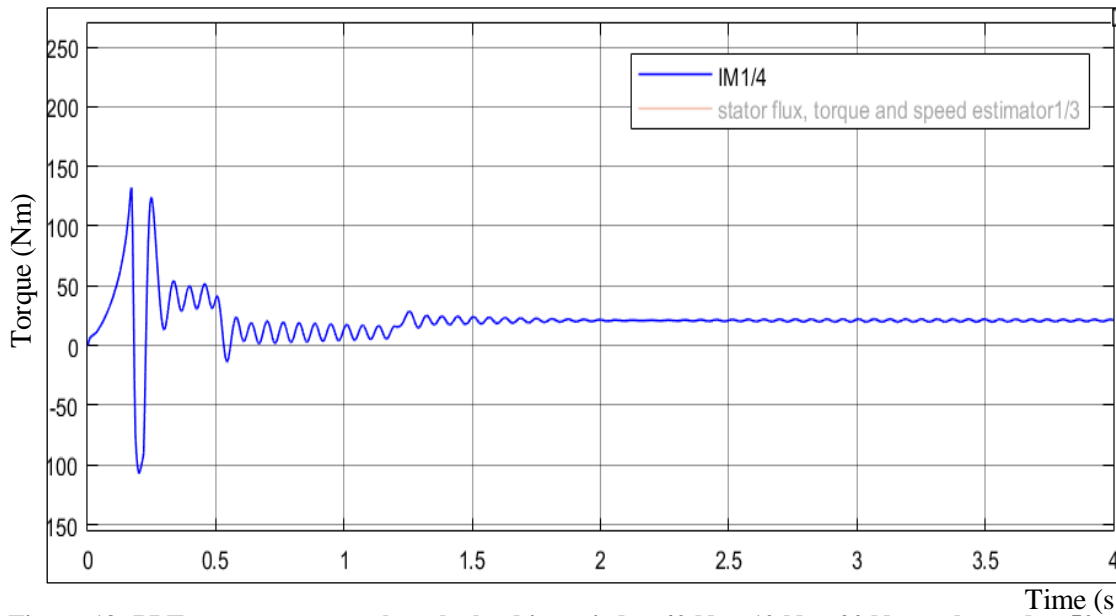


Figure 19: PI Torque response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 50 rad/s

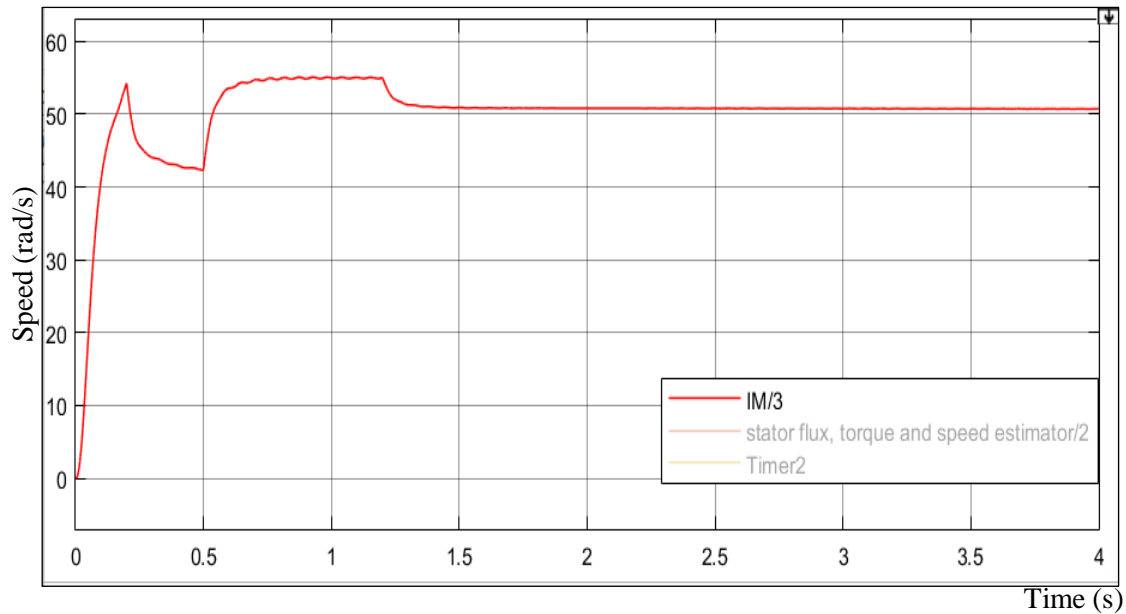


Figure 20: Proposed ANN Speed response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 50 rad/s

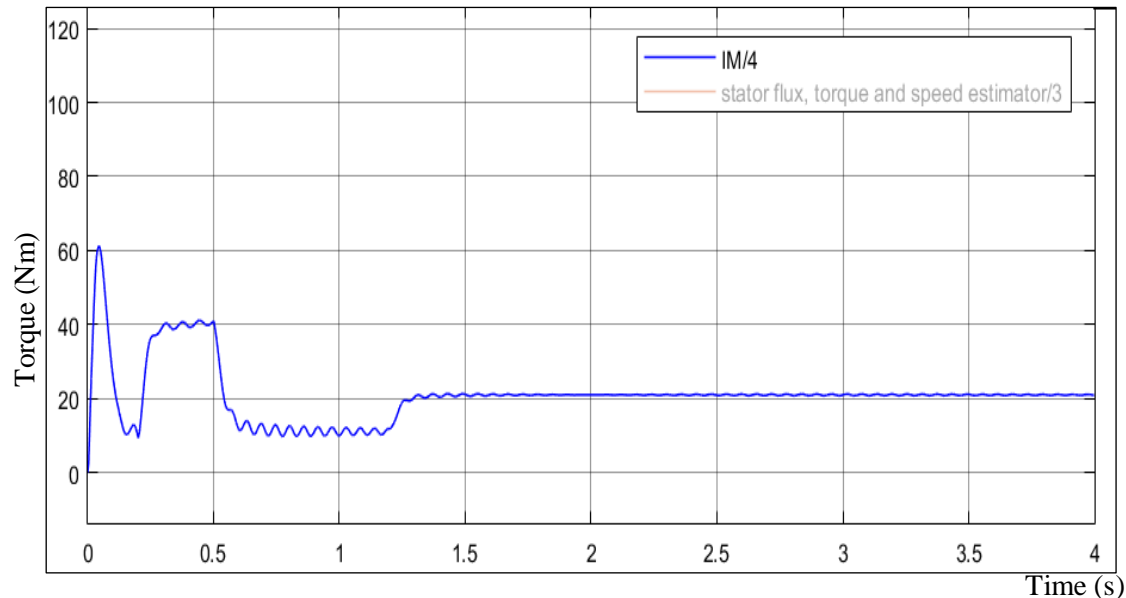


Figure 21: Proposed ANN Torque response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 50 rad/s

Then, the test is repeated by increasing the input speed to 140 rad/s with same value of load disturbance. The results are shown from Figure 22 to Figure 25. For high speed performance, the PI system cause big ripples during starting. This proves that its control performance parameters are sensitive to the system parameters variations and load disturbances. Meanwhile ANN shown good response with least disturbance during high speed.

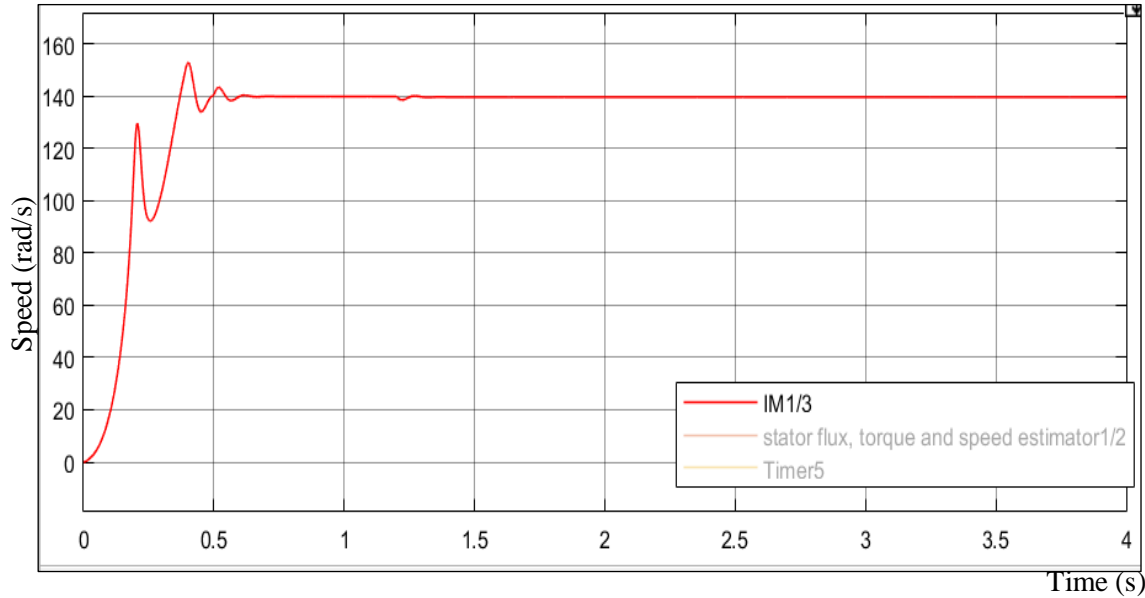


Figure 22: PI Speed response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 140 rad/s

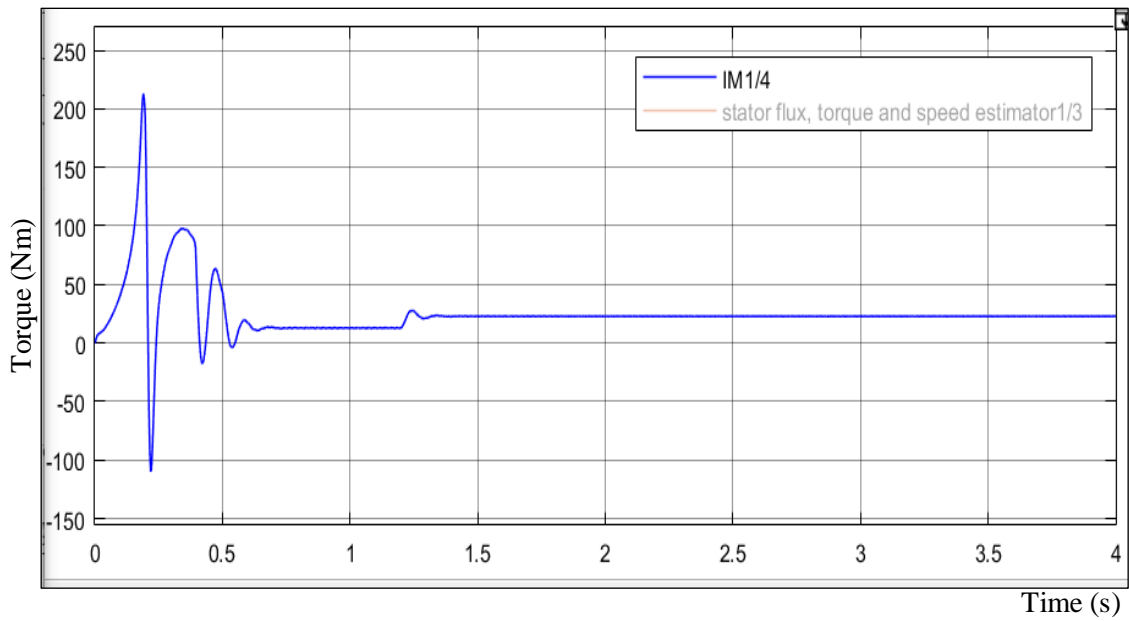


Figure 23: PI Torque response when the load is varied at 40 Nm, 10 Nm, 20Nm and speed at 140 rad/s

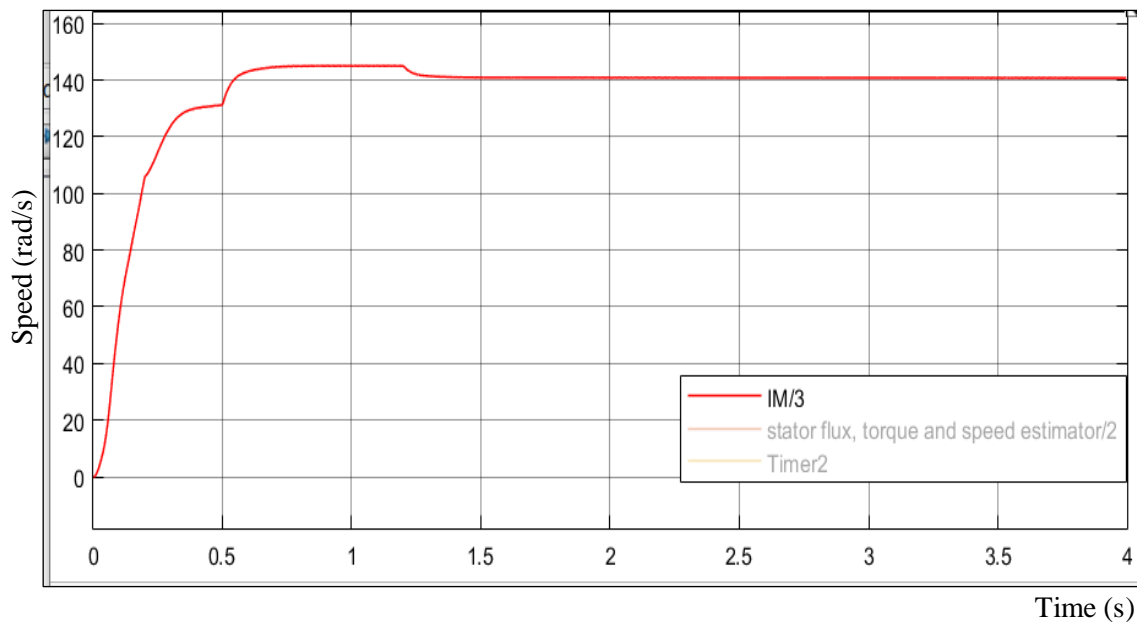


Figure 24: Proposed ANN Speed response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 140 rad/s

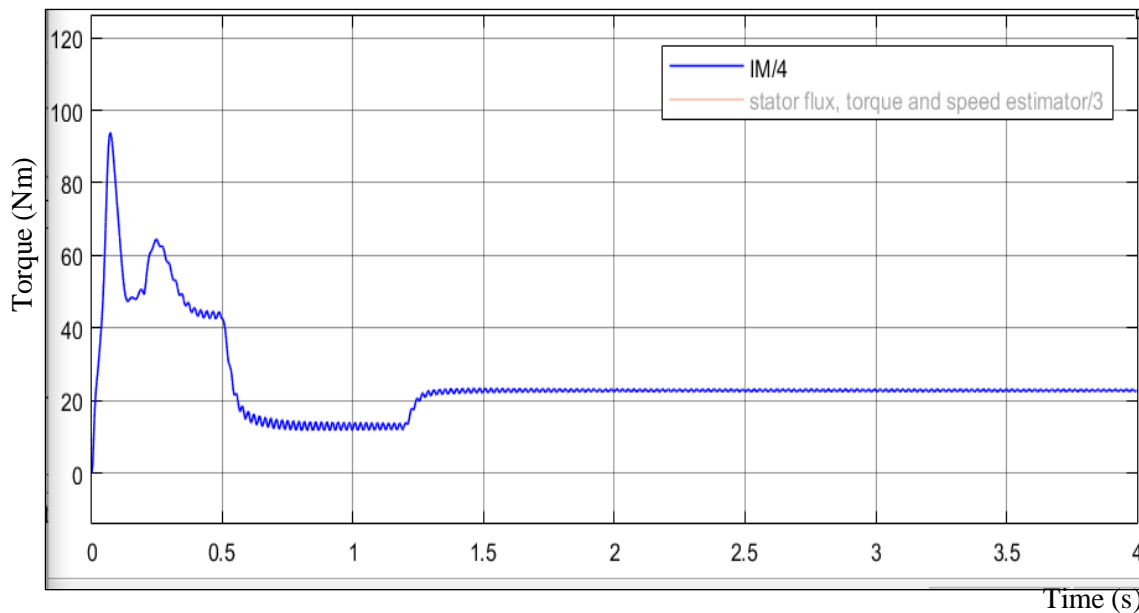


Figure 25: Proposed ANN Torque response when the load is varied at 40 Nm, 10 Nm, 20 Nm and speed at 140 rad/s

3.3 Variance speed with constant load

Next, the simulation is continued for the last condition to compare both system performance. Speed set to 40 rad/s at starting and step up to, 120 rad/s at 0.5second, and step down to 100 rad/s at 1.3 s with a static torque of 20 Nm. From Figure 26 to Figure 29, variance speed set for the system to run at a static load. Figure 26 is the PI speed response meanwhile Figure 27 is the torque response. The outcome shown there is disturbance in the PI system where its starting torque shoots intensely almost 140 Nm. As the speed increased to 120 rad/s its overshoot to almost 150 Nm which is a very unstable response with spark and slight ripple everytime the speed magnitude changed at speed response. Meanwhile, The ANN speed and torque responses accordingly with slight ripple and settling time about 1.8 s.

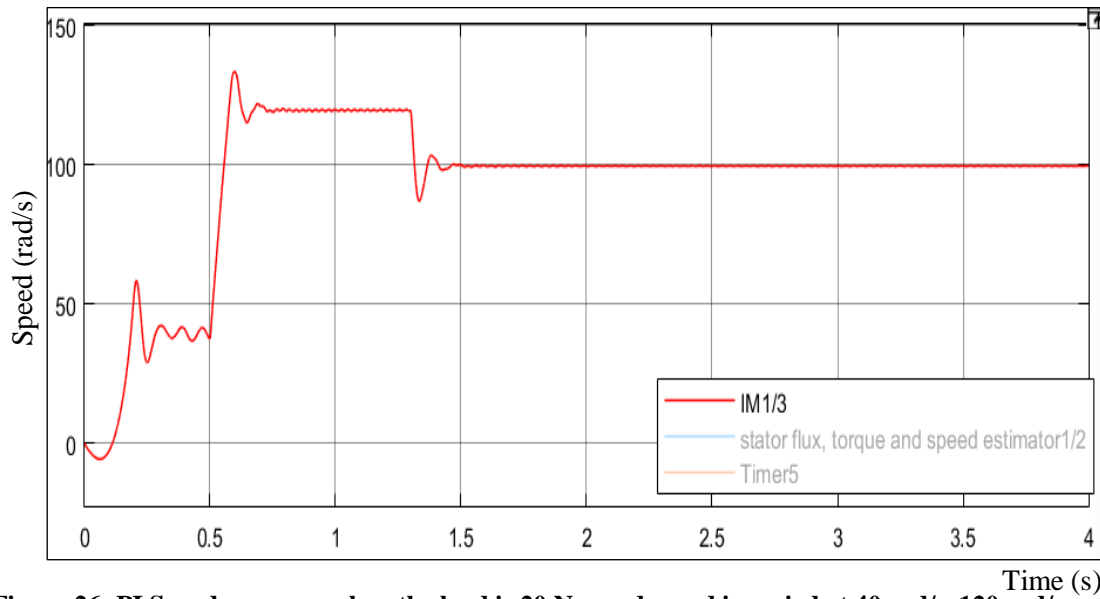


Figure 26: PI Speed response when the load is 20 Nm and speed is varied at 40 rad/s ,120 rad/s and 100 rad/s

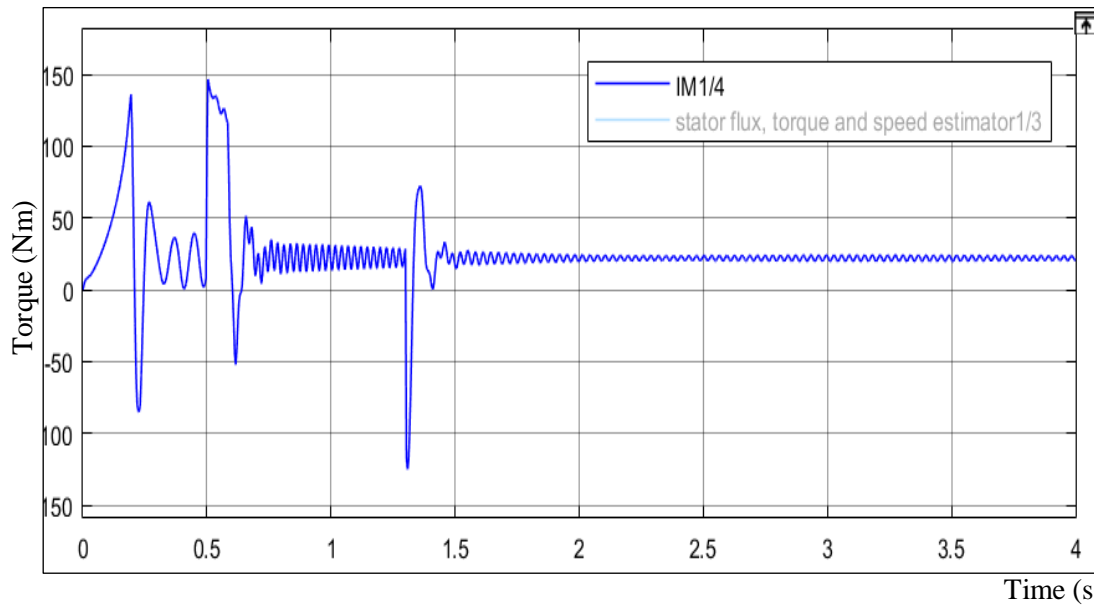


Figure 27 : PI Torque response when the load is 20 Nm and speed is varied at 40 rad/s ,120 rad/s and 100 rad/s

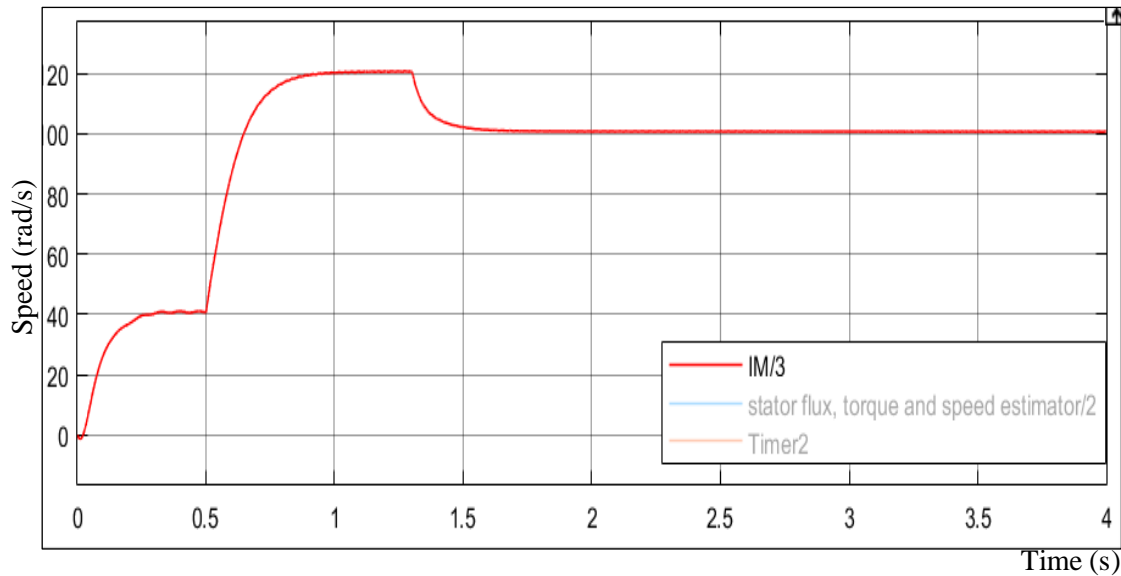


Figure 28: Proposed ANN Speed response when the load is 20 Nm and speed is varied at 40 rad/s, 120 rad/s, and 100 rad/s

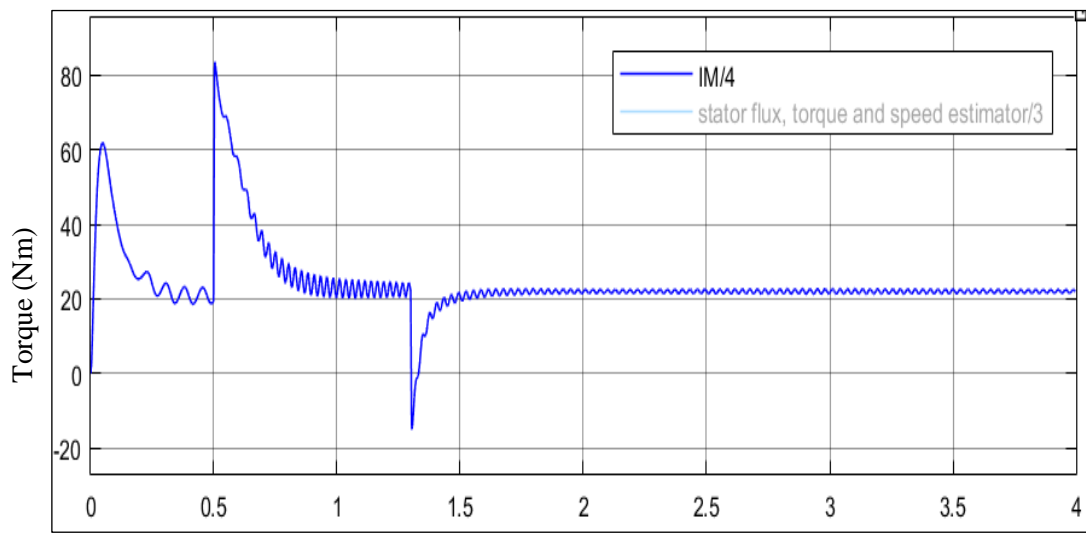


Figure 29: Proposed ANN Torque response when the load is 20 Nm and speed is varied at 40 rad/s, 120 rad/s, and 100 rad/s

3.4 Results analysis and discussion

Simulation data were collected includes the readings during certain operations. The data were taken when IM is applied with maximum and minimum speeds during static torque and during no-load condition. This is to compare the settling time and the unwanted overshoot response for both controllers for each condition. Table 1 below shows the information of the respective tests.

Table 1: Data comparison of IM speed performance in terms of settling time

Testing	PI Controller (settling time,s)	ANN controller (settling time, s)
Constant load-max speed	0.6s	0.3s (no ripple)
Constant load-min speed	2s	1s
No-load	0.6 s	0.4s (no ripple)

Table 1, shown the readings obtained from the simulation for a constant load of 20 Nm test for maximum and minimum speeds which is 150 rad/s and 40 rad/s respectively. Supposed the IM speed is 1500 rpm which is equal to 157.8 rad/s. From the tests, ANN control system has higher efficiency compare to PI control system at static torque. It has faster response in terms of settling time and it produced clean graph characteristics. The higher the speed, the better the the output response. The speed performance of both controllers is almost 100 % accurate during a normal state, the only difference is at the starting of operation where ripples and sparks occur for PI system. During no load state, systems are tested with maximum speed where resulted the same performance.

4. Conclusion

In conclusion, at the end of this study, it can be seen that the IM performance has been enhanced with the implementation of neural network into the system where the efficiency increases. Results have proved beyond doubt that the neural network controller has better dynamic behavior, with a rapid settling time, no overshoot, almost instantaneous rejection of load disturbance, perfect speed tracking, and deals well with parameter variations of the motor. Meanwhile, PI controller exhibits overshoot, large settling time and has zero steady state error. Therefore, the study aims has successfully achieved and proven. The output of this study can be applied into the real application scenario that would be really helpful in daily life since the application of AI technology starting to evolve in daily life especially in appliances such as smart washing machine and smart refrigerator that have electrical motor in it. With AI techniques in washing machines, users can reduce approx 30 % of detergent and power consumption while increasing the cleaning power and thus saving energy [13]. This is because AI can autonomously regulate the washing strength and detergent to be used according to the load weight and the type of fabric. Apart from this, using the ‘fuzzy logic’ system, the machine can ensure that once start button is pressed, smart sensors automatically detect the laundry load and water level. Other than that, the use of a deep learning algorithm, can remotely monitor and recognize food items inside the refrigerator. The whole information can be automatically stored into an inventory list, which will let the user take a note of everything in the refrigerator from anywhere[13].

Acknowledgement

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