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Analysis of Improve Performance and Dynamics of an Induction Motor using an Artificial Neural Network Controller and a Conventional Proportional Integral Derivative Controller

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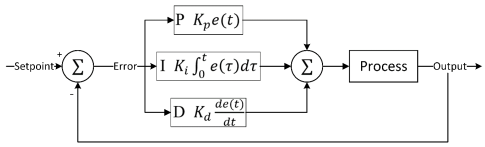
ABSTRACT



Systems vary depending on the changing operating conditions. Some include linear systems, which previous studies have proven can be controlled using conventional systems, while non-linear systems require expert and intelligent controllers. To verify this, the current study compares expert artificial neural networks (ANNs) with traditional PID controllers for controlling the rotational speed of an induction motor. Traditional PID controllers are simple and easy to implement, but they lack the ability to handle changing operating conditions and do not have the capacity to adapt to load fluctuations as expert systems such as neural networks do. They also have the ability to handle load disturbances and are considered more effective, efficient, and robust compared to traditional PID controllers. PID controllers are easy to adjust and simple in structure, and are widely used with linear industrial systems. PID controllers have degraded performance when the load changes, i.e., when the system is non-linear, their performance deteriorates. ANN, on the other hand, are characterized by their ability to adapt to varying conditions and changing loads. In non-linear systems, they have the ability to adapt and handle system disturbances. ANNs are expensive and require precise design, data for network architecture, and training. The feasibility of tracking induction motor speed is investigated using motor simulation models, conventional PID controllers, and expert neural networks, and the simulation results are analyzed and compared. The simulation results demonstrate that ANNs outperform PIDs in response speed and lower overshoot and undershoot limits under various operating conditions. From the above, it can be concluded that expert neural networks can effectively control and improve dynamic response of induction motors due to their adaptive and learning capabilities, and they can handle nonlinear systems such as changing load conditions. It is proposed to conduct simulation tests of an electric motor using MATLAB engineering software, by mathematically representing it using a transfer function according to characteristics suitable for applications similar to the proposed characteristics. Simulation tests are conducted for an open circuit system, a closed circuit system without control, and a closed circuit system with control. The second method involves self-tuning the conventional controller to achieve the best design by optimizing performance, response speed, overshoot rate, and rise time, according to the proposed operating algorithm. The results demonstrate the superiority of the neural network over conventional controllers.

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1. INTRODUCTION

Machines convert energy into other energy, for example, a generator produces electrical energy from kinetic energy, while a motor works in reverse, producing mechanical energy from electrical energy [1]-[3]. Machines consist of a fixed part containing coils connected to the power source (electrical energy) and another part, the rotor, connected to the source of movement (mechanical energy) [4]-[6]. Machines have electrical quantities related to electrical energy, including electrical power, voltage, and electrical current, while mechanical power is related to other quantities, including torque and speed [7]-[9]. Mathematical models can be built for electrical and mechanical components and a relationship can be written between them [10]-[13]. The presence or absence of electrical quantities has an effect when the engine is rotating, stopped, or braking. This means that the speed is zero rpm as a result of the electrical quantities zero amperes and zero volts [14]-[16]. While there are other cases where the engine rotates at a specified speed due to the loss of effort exerted on the engine terminals, which are the values written on the engine identification plate [17]-[20].

Induction motors have gained significant attention in recent years, especially in industrial applications requiring high precision [21]-[23]. This is due to their numerous advantages, including high power density, reliability, high efficiency, ease of achieving high motor performance control, and high torque [24]-[27]. However, there are several uncertainties, such as external loads, noise, and frictional forces, that affect the system's performance. PID controllers are characterized by their simple structure and good performance, making them widely used in various control applications [28]-[30]. However, one problem with PID controllers is that they do not meet high precision requirements when operating in a nonlinear system such as induction motors, where the motor is operated under harsh conditions. The performance of a PID controller is related to its PID parameters [31]-[34]. Therefore, scientists have proposed a technique for tuning and monitoring PID parameters, which is one of the smart ways to improve the PID's ability to resist motor disturbances and improve dynamic response [35]-[38]. The performance of induction motors using PID is measured using MATLAB/Simulink software. To achieve effective results in motor performance, use a PID controller to reduce ripples in torque and current, and improve response speed. An optimal and robust control design for solving the unknown parameter problem of an induction motor system based on neural networks. Neural networks are used to develop a model to predict motor torque and four temperature parameters (windings, teeth, stator yoke, and surface of induction motors) without installing any additional sensors [39]-[42]. Two novel approaches are presented to obtain the optimal parameters for a PID controller to regulate the rotational speed of induction motors. The best parameters are obtained using neural network algorithms and motor performance is compared. Induction motor simulations are conducted using mathematical analysis for different cases, one without a controller and the other using a PID controller [43]-[45]. PID insufficient for nonlinearities harsh conditions sudden load changes. Prior work lacks comparative analysis of PID vs. neural networks under conditions e.g., sudden load changes. Neural networks are suited for this problem e.g., adaptability to nonlinearities.

Expert systems, including neural networks, are used to control the rotational speed of electric motors, including induction motors. These systems are characterized by their high speed and parallel structure, and their ability to adapt to changing operating conditions and system disturbances and address them through learning and training. They operate as an efficient, high-performance system that is highly efficient in handling nonlinear systems. They process the behavior and data of each cell, have an activation function, and are capable of predicting and making control decisions. Neural network control has the ability to improve the performance of nonlinear systems. It is used in electrical power applications, including industrial ones. In modeling and simulation of expert systems, specifically artificial neural networks, they are modeled from two networks: the first includes the control function, and the second models the factory. The first is called nonlinear control with feedback or automatic moving average regression. The second has the ability to estimate the factory model by transforming the systems from nonlinear to linear dynamics. The performance and operation of the neural network can be described by naming and encoding the system inputs, considering them as pre-set values, for example. The output is also encoded, in addition to encoding the control voltage as a first step. The second step involves re-arranging the inputs and training them. Here, the model can have multiple layers depending on the multiplicity and change of values, i.e., depending on the quantity to be controlled, whether voltage, speed, torque, current, etc.

This demonstrates the superiority of this controller in terms of high accuracy and rapid response under different conditions, i.e., working with linear systems to optimize motor performance. This simulation model and induction motor simulation results present several cases, each of which includes: (i) open loop, (ii) closed loop without a controller, (iii) closed loop with a PID controller, and (iv) closed loop with a neural network controller.

2. SIMULATION MODEL AND SIMULATION RESULTS

In this section there are many part include, Model of three Phase Induction Motor, Model of PID Controller and Model of neural network controller. To simulate electric motors, the motor is mathematically modeled and constructed by calculating the transfer function. One of the tests that are suggested is controlling the rotational speed or position of the rotor. By representing the motor with a diagram representing the equivalent circuit, the simulation model is designed and analyzed. PID controller, to control the rotational speed of an induction motor when it is within linear system applications. This type of controller succeeds by calculating the error value and calculating it from the comparison of the actual and reference values. The traditional PID controller can be represented as in Figure 1. In this section there are four part include, the first part open loop of induction motor that show in 2.1. Second part close loop of induction motor that show in 2.2. Third part PID Controller for close loop of induction motor that show in **2.3**. Fourth part ANN for close loop of induction motor that show in **2.4**.

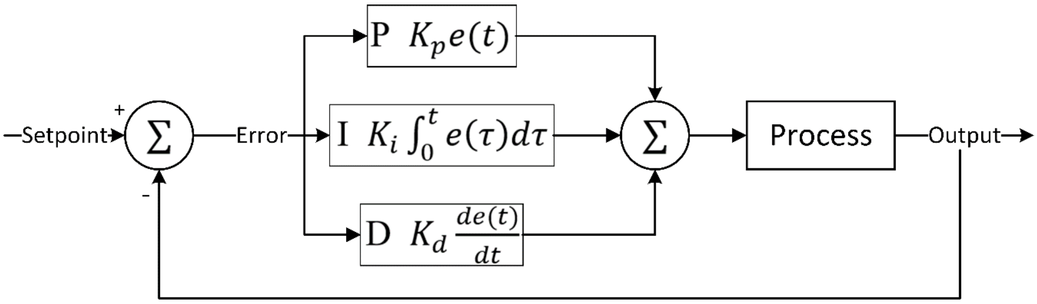


Figure 1. Traditional PID controller

2.1. Open Loop of Induction Motor

In this section there are two part include, simulation Model of open loop for induction motor that show in **2.1.1**. Second part simulation response of open loop for induction motor that show in **2.1.2**.

2.1.1. Simulation Model of Induction Motor

Motor specifications and system characteristics the parameters of the induction motor to be used in the current simulation can be defined, including a 50 Hp induction motor with a frequency of 50 Hz and a voltage from a three-phase supply of 420 V can be seen in Figure 2. To represent the motor with a simulation model to understand the system's behavior under different operating conditions, a mathematical representation is written and the appropriate transfer function [46] is calculated based on the motor parameters in Table 1.

Table 1. Parameters of Induction Motor [46]

Parameter Name	Parameter Symbol	Parameter Value
Stator Resistance	R_s (Ω)	0.288
Rotor Resistance	R_r (Ω)	0.158
Stator Inductance	L_s (H)	0.0425
Rotor Inductance	L_r (H)	0.0418
Magnetizing Inductance	L_m (H)	0.0412
Inertia	J (Kg.m2)	0.4
No. of pole	P (pole)	2

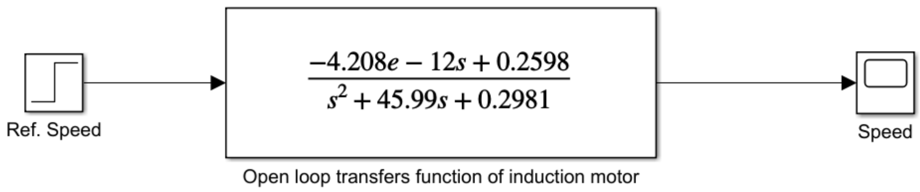


Figure 2. Simulation Model of induction motor with open loop system

$$G_s = \frac{-4.208e^{-12}s + 0.2598}{s^2 + 45.99s + 0.2981} \tag{1}$$

2.1.2. Simulation Response of Induction Motor

Using the simulation model in Figure 2, an open-loop system test can be conducted to identify the behavior of the induction motor, and the output signal can be plotted as in Figure 3. In fig.3. show the simulation response of induction motor with close loop system with time running test equal 1500 sec the input and output step per unit but the value in stability system is less than one.

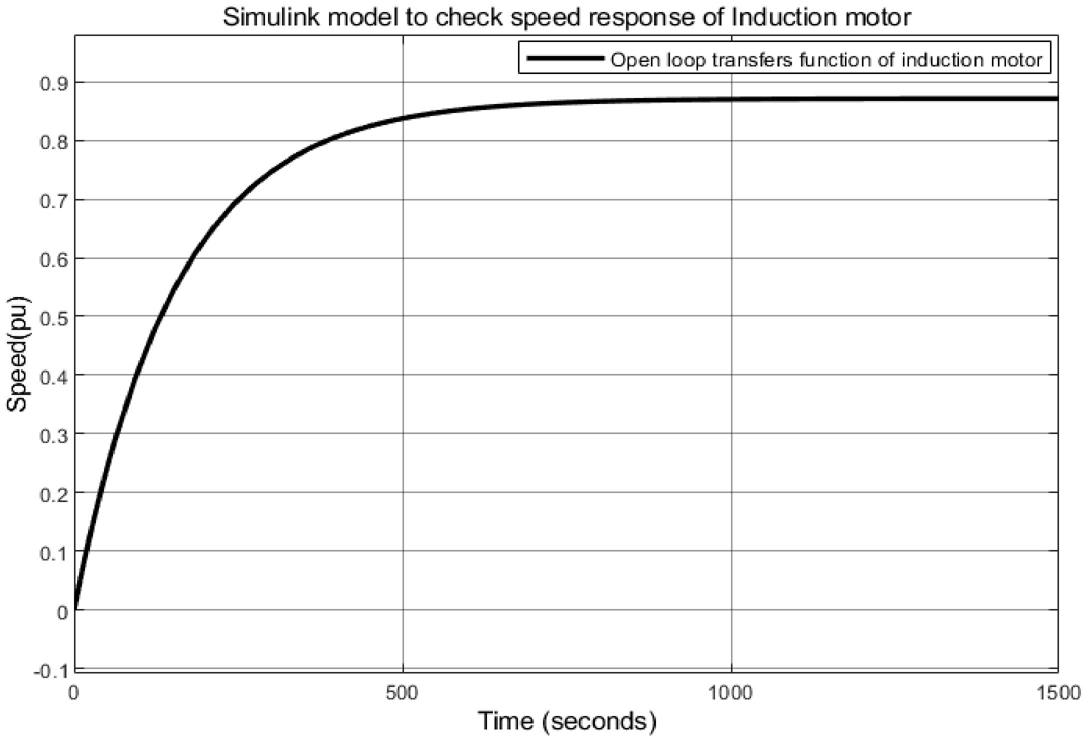


Figure 3. Simulation response of induction motor with open loop system

2.2. Close Loop of Induction Motor

In this section there are two part include, simulation Model of close loop for induction motor that show in **2.2.1**. Second part simulation response of close loop for induction motor that show in **2.2.2**.

2.2.1. Simulation Model of Induction Motor

In the second test, feedback is added to the output signal and compared to the reference input signal, and the error rate between the two signals is identified. The simulation model can also be used as in Figure 4.

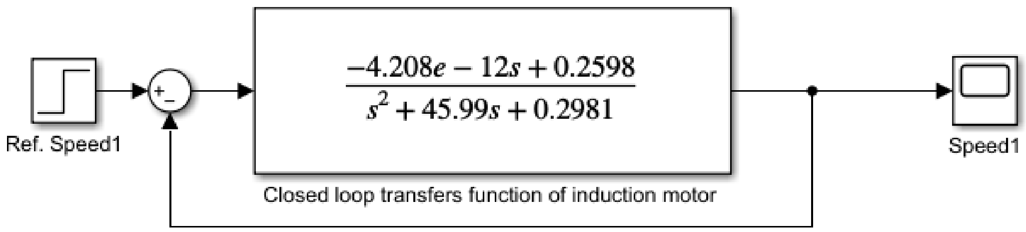


Figure 4. Simulation Model of induction motor with close loop system

2.2.2. Simulation Response of Induction Motor

Using the simulation model in Figure 4, a close-loop system test can be conducted to identify the behavior of the induction motor, and the output signal can be plotted as in Figure 5. In Figure 5 show the simulation response of induction motor with close loop system with time running test equal 1500 sec the input and output step per unit but the value in stability system is less than one.

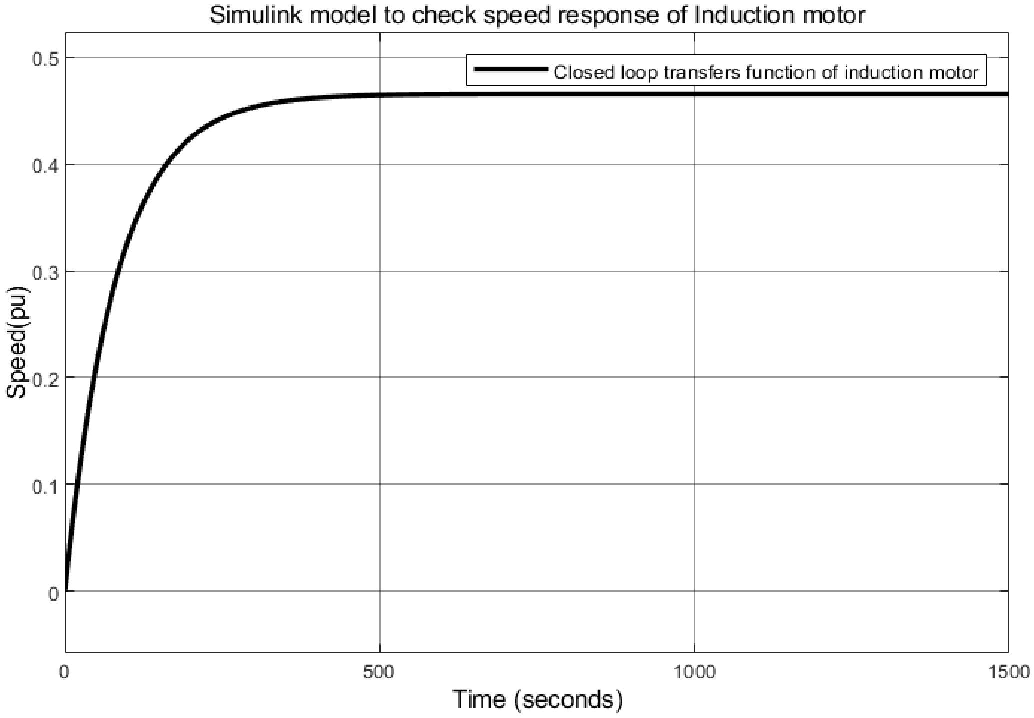


Figure 5. Simulation response of induction motor with close loop system

2.3. PID Controller for Close Loop of Induction Motor

In this section there are two part include, simulation Model for PID Controller of close loop induction motor that show in **2.3.1**. Second part simulation response for PID Controller of close loop induction motor that show in **2.3.2**.

2.3.1. Simulation Model for PID Controller of Close Loop Induction Motor

In the second test, PID Controller and feedback are added to the output signal and compared to the reference input signal, and the error rate between the two signals is identified. The simulation model can also be used as in Figure 6.

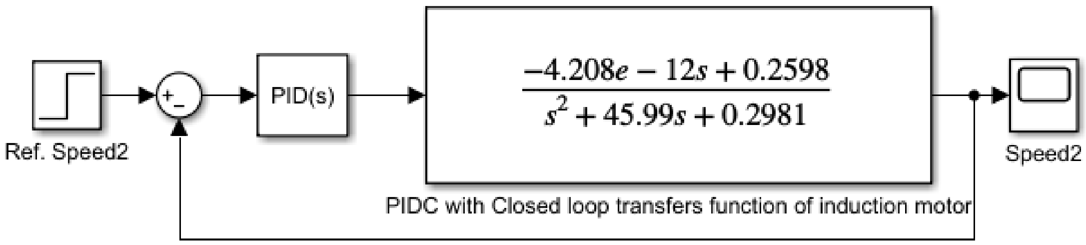


Figure 6. Simulation Model of PID Controller for induction motor

2.3.2. Simulation Response of Induction Motor

Using the simulation model in Figure 6, an of PID Controller for induction motor system test can be conducted to identify the behavior of the induction motor, and the output signal can be plotted as in Figure 7.

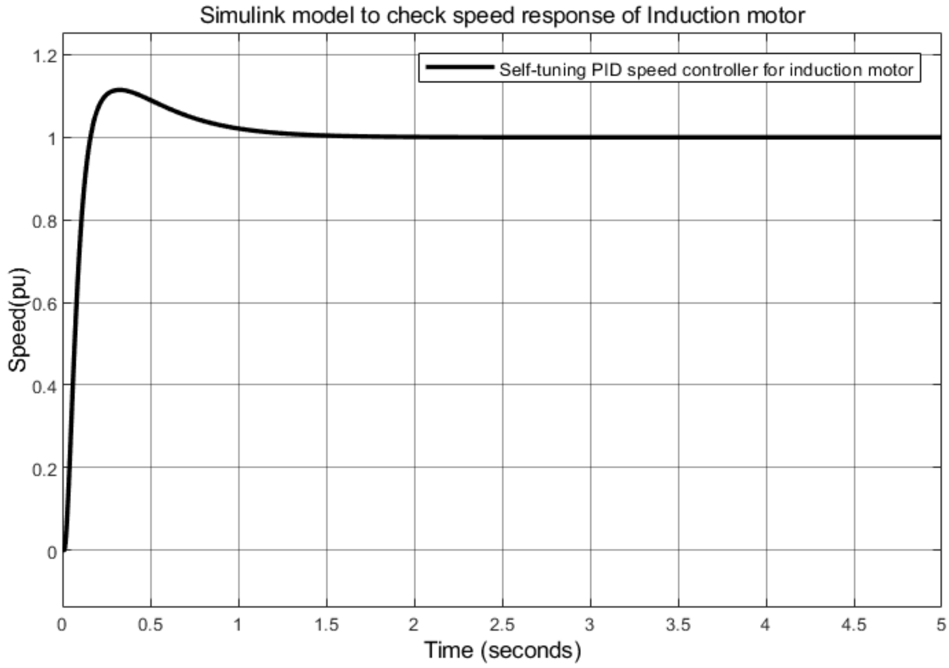


Figure 7. Simulation response of PID Controller for induction motor

2.4. ANN for Close Loop of Induction Motor

In this section there are three part include, simulation Model for PID Controller of close loop induction motor and simulation Model for ANN of close loop induction motor. PID Controller and feedback are added to the output signal and compared to the reference input signal, and the error rate between the two signals is identified. Also by using ANN of close loop induction motor. The simulation model can also be used as in Figure 8 and Figure 9. Using the simulation model in Figure 8, an of ANN for induction motor system test can be conducted to identify the behavior of the induction motor, and the output signal can be plotted as in Figure 10. In Figure 11 to Figure 15 show the value of tr equal 98.167msec, overshoot equal 11.798% and undershoot equal -1.640% that response for PIDC- IM while in fig.11 b show the value of tr equal 90.808msec, overshoot equal 5.851% and undershoot equal 1.383% that response for ANN – IM.

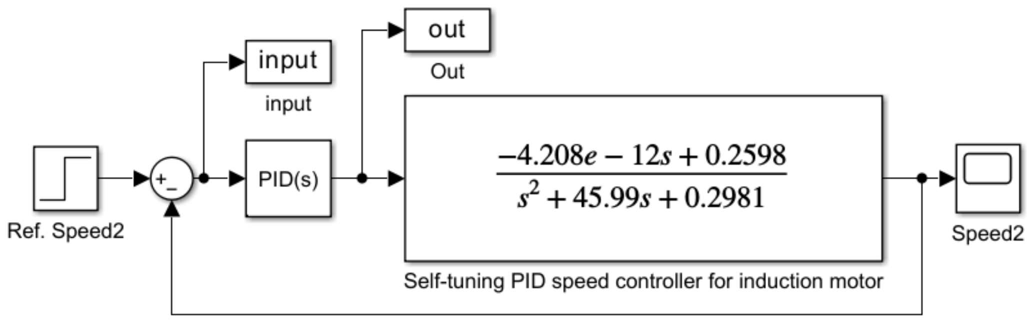
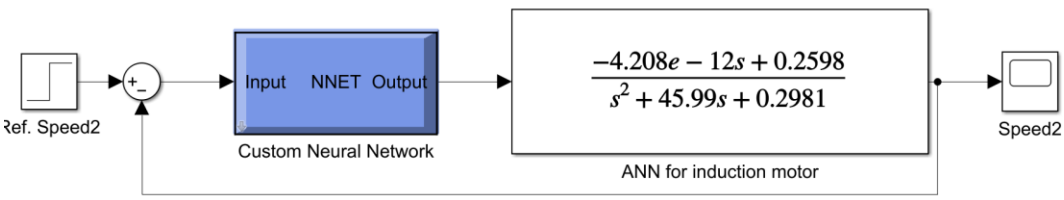


Figure 8. Simulation model of self-tuning PID controller for IM before using ANN with IM



.**Figure 9.** Simulation model of ANN for IM

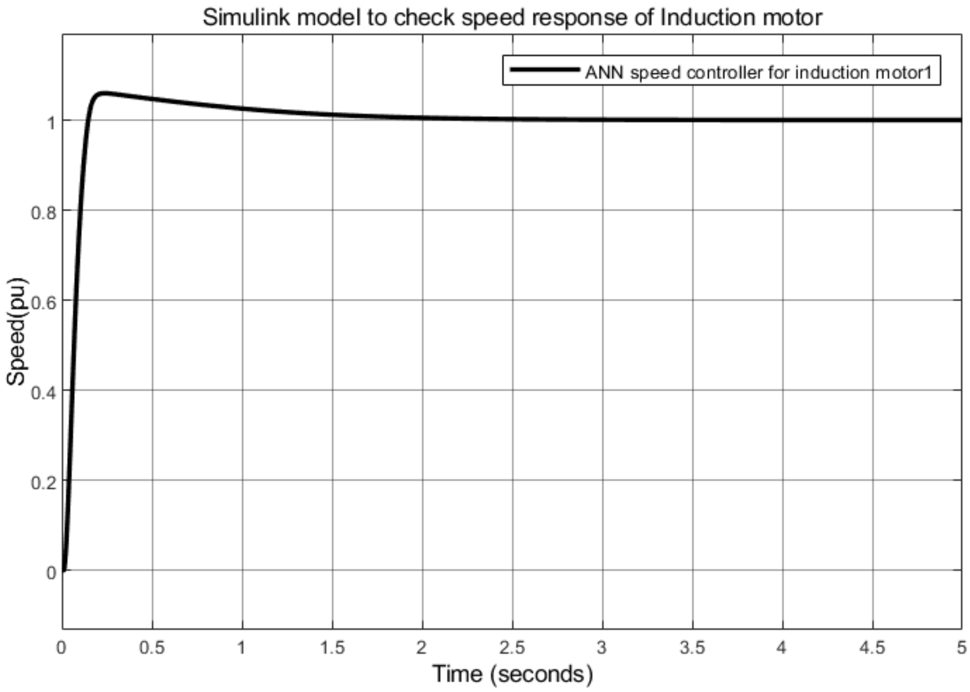
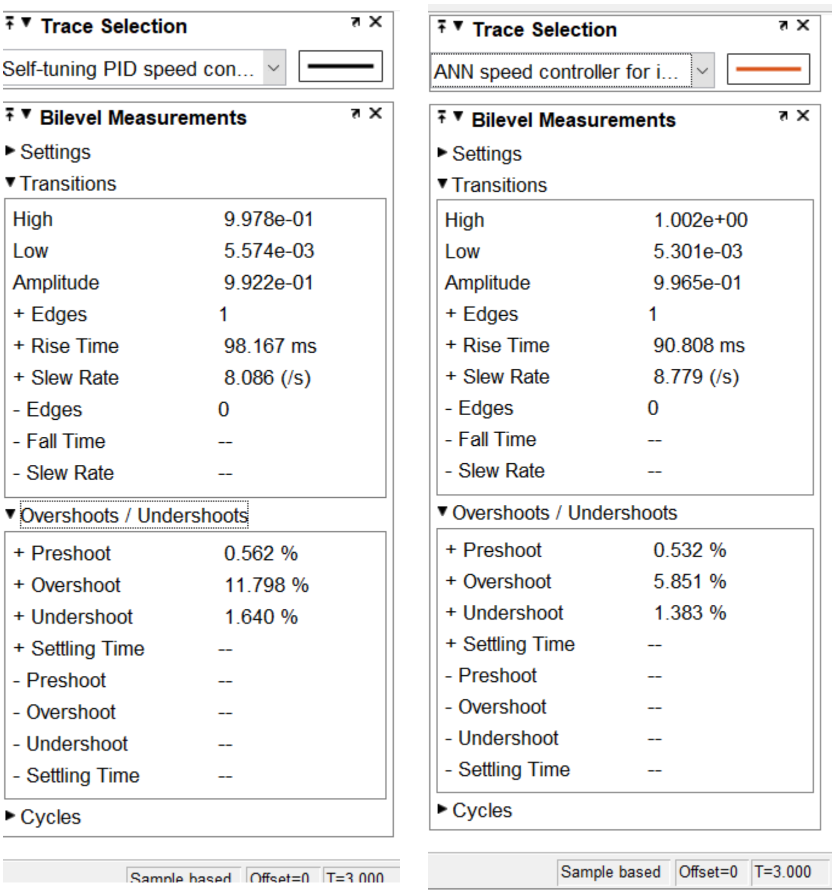


Figure 10. Simulation Response of ANN for IM



a. PIDC- IM b. ANN- IM

Figure 11. Simulation results of overshoot, undershoot & rise time (tr)

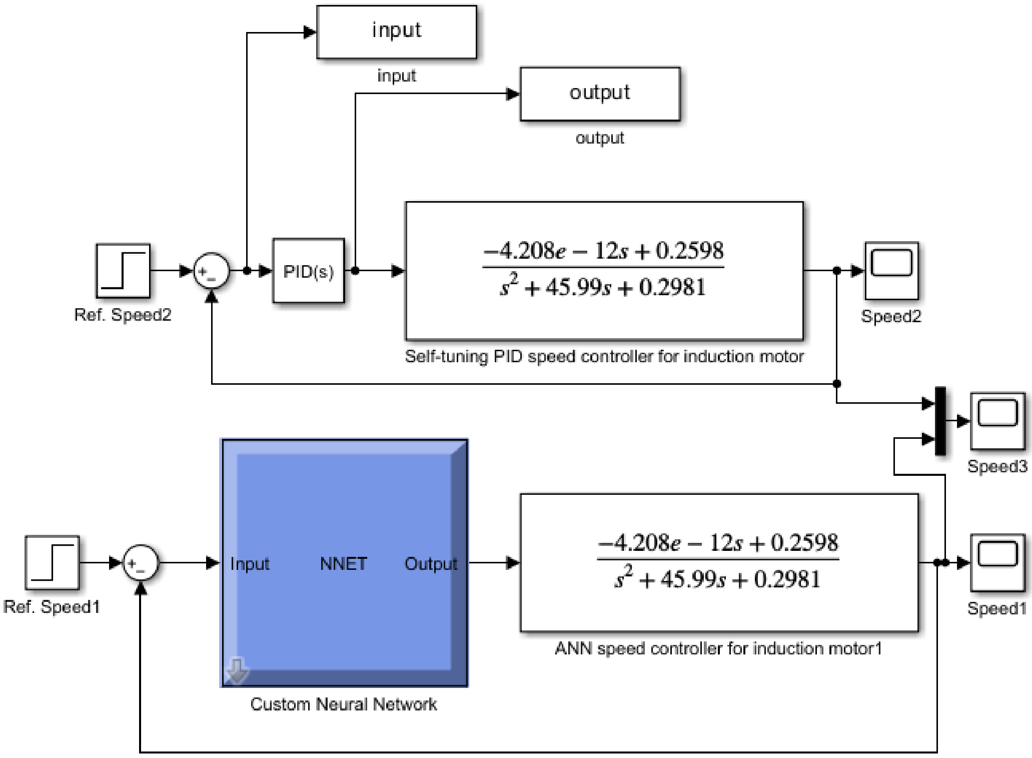


Figure 12. Simulation model for PID controller and ANN of close loop induction motor

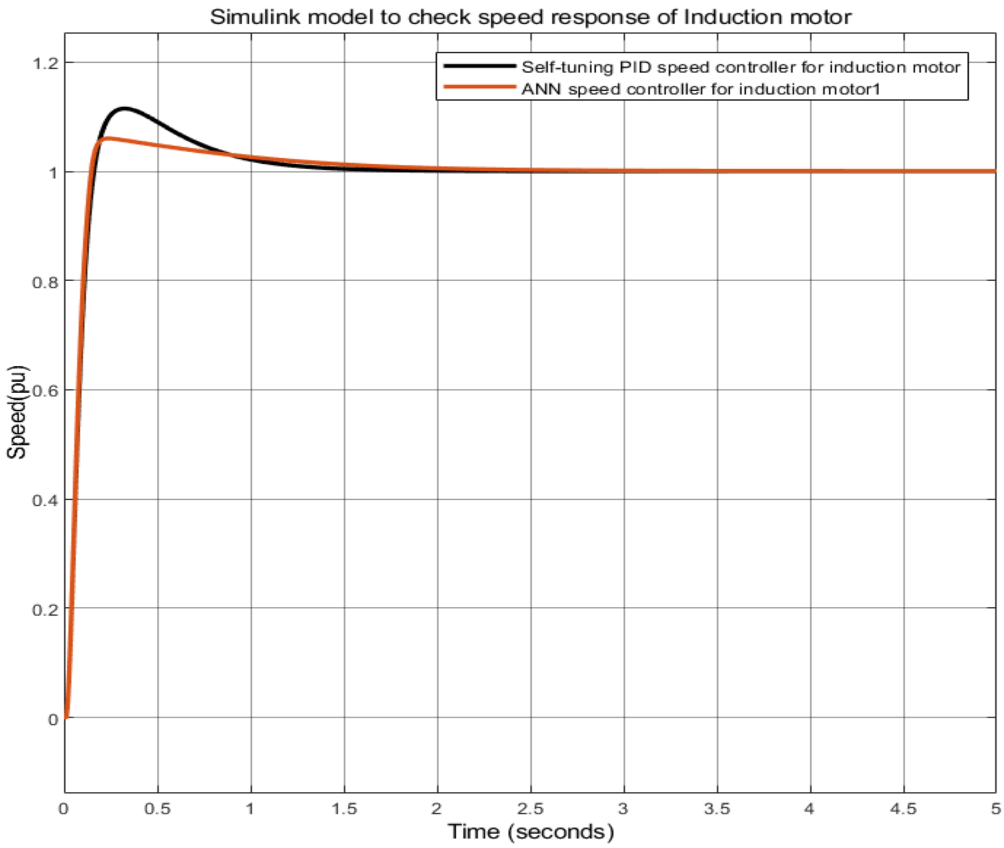


Figure 13. Simulation Response for PID controller and ANN of close loop induction motor

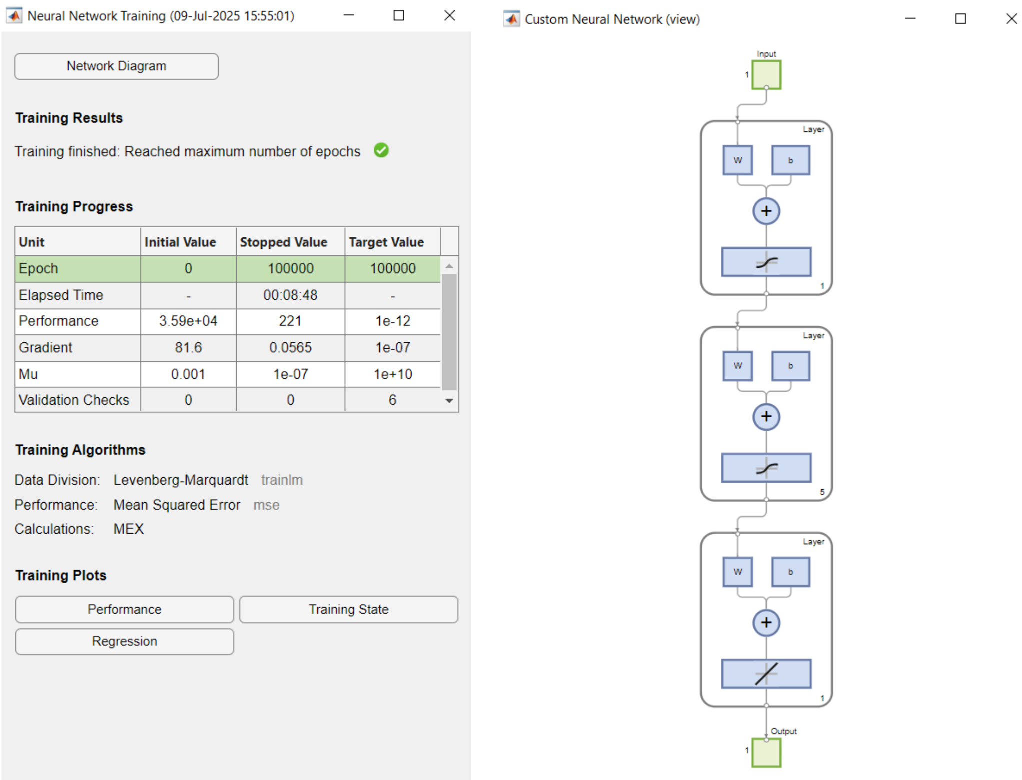


Figure 14. Simulation of ANN training and custom

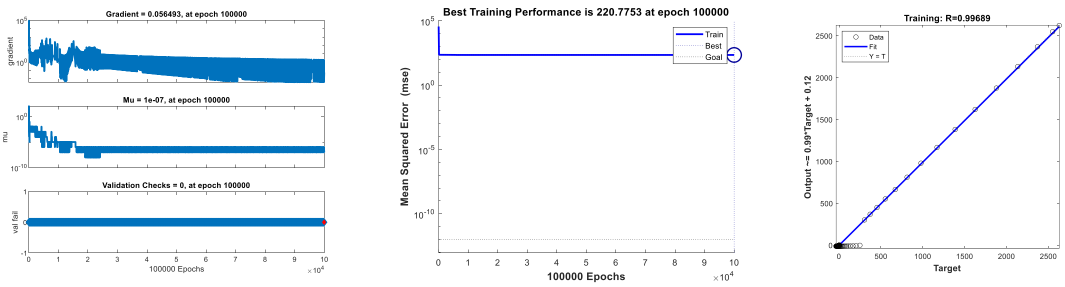


Figure 15. Simulation of best training performers for ANN

3. CONCLUSION

An induction motor (IM) was simulated using a transfer function model with four test cases: open-loop system, closed-loop system without control, closed-loop system with PID, and closed-loop with neural network control. The operating preferences at speed regulation and disturbance rejection. The value of tr equal 98.167msec, overshoot equal 11.798% and undershoot equal 1.640% that response for PIDC- IM while the value of tr equal 90.808msec, overshoot equal 5.851% and undershoot equal 1.383% that response for ANN – IM.The neural network controller reduced overshoot by 6% compared to PID.The neural network controller reduced undershoot by 0.3% compared to PID. Simulation results also indicate that the neural network's rise time (90.808 ms) is 8 ms faster than the rise time of the conventional motor (98.167 ms).

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