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System Identification Based Data Driven Control Of DC Motor Using NARX Neural Network

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Abstract

DC motors are mostly used in industries. In DC motor system should be produce some changes in the unpredictable, load dynamics, variable and disturbances, unknown parameters. It will result in motor performances. Therefore the motor should be controlled and analysed. Without the plant model, the design of controller for the DC motor is very difficult. Using Data driven control method, it requires only the measured input data and measured output data of the plant, the system identification model and controller design. The designing of mathematical model of the DC motor by using system identification technique is based on perceived system data. By utilizing simscape Simulink, DC motor model is being constructed. The measured input data as (voltage) and output data as (speed) of the DC motor are used to execute system identification process. The results of the system identification process are to be compared with the performances of NARX neural network architecture. The Simulink model for the DC motor is developed and implementation of data driven control system of the DC motor using system identification.

Keywords— DC motor, NARX neural network, data driven, Simulink.

I. INTRODUCTION

A DC motor is any class of rotary electrical motors that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic; to periodically change the direction of current in a part of the motor. DC motors are widely used as the power can be supplied from direct current power systems. The common methods are changing the strength of the current in the field windings or by using a variable supply voltage. DC motors are also differentiated based on their sizes. Small DC motors are used in toys, tools, and smaller appliances whereas large dc motors are used in propulsion systems of vehicles, robotic and industrial control systems, and transportation. The advancement of power electronics in recent years has made the possibility of replacing the dc motors in place of ac motors on as many applications as possible. Data-driven control is a designed when no plant model is available and it requires the measured input data or measured output data of the plant model, system identification process, and controller design. System identification is not easy way to derive their mathematical models for the complex system. For systems with multiple inputs and multiple outputs artificial neural network can be used.

Identification of any continuous non-linear function with acceptable accuracy can be obtained with the assistance of neural networks in the system identification process [1]. DC Motors can be used in motion control of wheeled mobile robots that completely depends on the design desire. Specification of DC Motor that can be used with desire WMR is to be determined by using MATLAB Simulink model. DC Motor Modeling can be analyzed with control techniques of Step response, Impulse response, and Bode plot by using MATLAB Simulink. All data based on the internal circuits of simple DC Motor and its features can be analyzed both by Control System design calculation and by MATLAB software [2]. Neural networks can be used effectively for the identification and control of nonlinear dynamical systems. Static and dynamic back-propagation methods for the adjustment of parameters are discussed [3]. The traditional methods adapted by the motion control industry with motor drives have been the approach of linearizing the system dynamics and designing a linear feedback controller. However, high-performance motor drives result in poor speed and position tracking. Adaptation is needed to ensure optimal performance [4]. The best-known controllers used in industrial control processes are proportional-integral-derivative (PID) controllers because of their simple structure and robust performance in a wide range of operating conditions. The setting of PID parameters is called tuning. The classical tuning method is to use the famous Ziegler- Nichols tuning formula. The PID controller parameters can be manipulated to produce various response curves [5]. Component based on the modeling of the real DC motor in Simscape workspace to simulate and acquire data, using simscape the obtaining of voltage as an input and speed as a output of the DC motor, the system identification tools and NARX network is used to identify the system [6].

II. SYSTEM DESCRIPTION

DATA DRIVEN CONTROL

Most of the industrial processes has complex physical model and it is difficult to design the controller. So, data driven control is approached. In Data driven control system, the identification of the process model and the design of the controller are based entirely on experimental data collected from the plant. Data driven control allow fitting a system model to the experimental data collected, choosing it in a specific model class. Data driven control method allows tuning the controller without the identification of system model. Data driven control means the control theory and method in which the controller is designed directly using online or offline I/O data obtained from the control system or knowledge from data processing instead of first modelling the controlled plant and then designing the controller using the process physical model obtained. Data driven control are completely based on the observations and measurements of the real time system and only require a minimum amount of prior knowledge of the system. It replace process models with data. The voltage as a input data and speed as a output data of the DC motor is measured. These measured data is used to execute system identification process.

SYSTEM IDENTIFICATION PROCESS

System identification is a methodology for building the mathematical models of the dynamic systems using the measurements of the input and output signals of the system. The mathematical models of the dynamical systems are obtained by using system identification process which uses statistical methods. The requirements for the process of system identification which are as follows:

- To measure the input and output signal from the system in time or frequency domain.
- To select the model structure.
- To apply an estimation method to estimate values for the adjustable parameters in the candidate model structure.
- To evaluate the estimated model to see if the model is adequate for the application needs

GREY BOX MODEL

Grey box model is the combination of partial theoretical structure with the data to complete the model. It have a number of unknown free parameters which can be estimated using system identification. It contains a simple hyperbolic relationship between substrate concentration and growth rate. Linear regression techniques are much more efficient than most non-linear techniques. The model can be deterministic or stochastic depending on its planned use.

BLACK BOX MODEL

Black box modeling is a method for the development of models based on the process data. It includes data preconditioning, model complexity, model linearity and model extrapolation. It is designed based on the inputoutput behavior of the process and consequently the model describes the overall behaviour. It consists of certain structure of which the parameters are determined by means of experimental results. Therefore, they are called as experimental models.

ARTIFICIAL NEURAL NETWORK

Artificial Neural Network (ANN) is the component of artificial intelligence that is meant to simulate the functioning of a human brain. It is a nonlinear statistical data which complex relationship defines between input and output. The General structure of ANN is shown in the below Fig. 1.

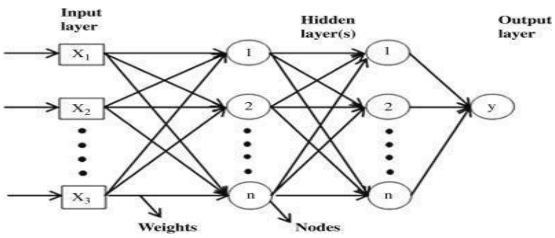

Fig. 1. General structure of ANN

BLOCK DIAGRAM

ANN is made of three layers namely input layer, output layer and hidden layer. The input layer takes the data from the network. The hidden layer receives the raw information from the input layer and processes them. Then, the obtained value is sent to the output layer which will also process the information from the hidden layer and give the output. The interconnection of the nodes between the layers can be divided into two basic classes, namely the feedforward neural network and recurrent neural network. In feedforward ANN, the information movement from inputs to outputs is only in one direction. On the other hand, in the recurrent ANN, some of the information moves in the opposite direction. The Feedforward and Recurrent Neural Network is shown in the below Fig. 2. & Fig. 3.

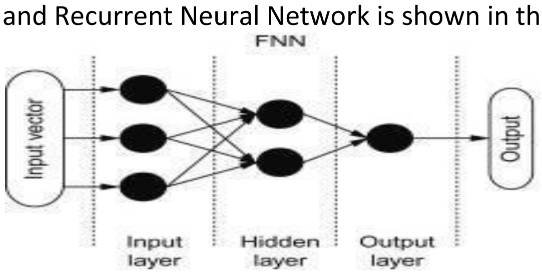

Fig. 2. Feedforward Neural Network

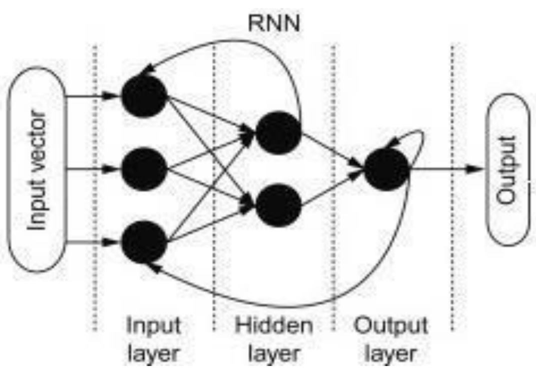

Fig. 3. Recurrent Neural Network

WORKING OF ARTIFICIAL NEURAL NETWORK

Each arrow represents a connection between two neurons. Also, they used to indicate the pathway for the flow of information. Artificial neural networks are modeled on biological neural networks in the brain. The brain is made up of cells called neurons, which send signals to each other through connections known as synapses. Neurons transmit electrical signals to other neurons based on the signals they themselves receive from other neurons. An artificial neuron simulates how a biological neuron behaves by adding together the values of the inputs it receives. As it was noticed that each connection has a weight, an integer number. That used to control the signal between the two neurons. If the output is good that was generated by the network then we don't require adjusting the weights. Although, if poor output generated. Then surely system will alter the weight to improve results

ADVANTAGES OF ARTIFICIAL NEURAL NETWORK

The following are the advantages of artificial neural network:

- Parallel processing capability
- Storing data on the entire network
- Capability to work with incomplete knowledge
- Memory distribution Fault tolerance.

NARX NEURAL NETWORK

A nonlinear autoregressive exogenous model (NARX) is an autoregressive model which has exogenous inputs in a time series modeling. It relates to the current value of a time series to both the past values and current and past values of the exogenous series. The NARX network is designed without the feedback loop of delayed outputs, which reduces substantially its predictive performance. The NARX is a recurrent dynamic neural network. It has feedback connections which enclose several layers of the network. In order to obtain the full performances of the NARX neural network for nonlinear time series prediction, it is interesting to utilize its memory ability using the past values of predicted or true time series. To solve complex classification problems, Multilayer perceptron (MLP) was introduced. MLP has universal approximation property, they were used as nonlinear regression models and time series modeling and forecasting. It is trained in the open loop, using the real target values as a response. The nonlinear autoregressive model is written in the form is shown in equation. The Architecture of the nonlinear autoregressive neural network is mentioned in the below Fig. 4.

$$Y_t = h(Y_{t-1}, Y_{t-2}, \ldots, Y_{t-d}) + \varepsilon t \qquad (1)$$

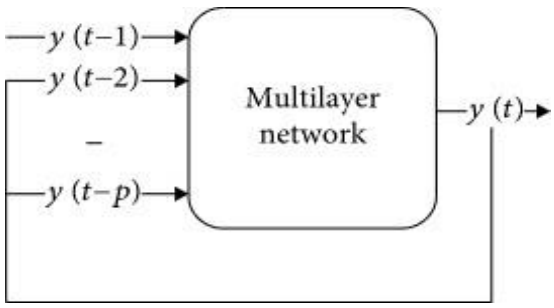

Fig. 4. Nonlinear autoregressive NN

CONTROLLER DESIGN

The proportional-integral-differential (PID) controller is highly effective and widely used type controller which offers high accuracy, while controlling the process. The PID controller produces an output signal using equation (2)

$(t)= K\ e(t) + K \int t\ e(t) dt + K$ (2)

PID controller is used for represented plant model. Loop tuning is the adjustment of the control parameter to the optimum values for the desired control response. There are various types of tuning method is used to tune the PID controller.

III. SOFTWARE IMPLEMENTATION

MATLAB SOFTWARE

MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms and create models. MATLAB is a proprietary multi-paradigm programming language and numeric computing environment developed by Math Works. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages. MATLAB toolboxes are professionally developed, rigorously tested and fully documented. MATLAB is used for control systems, deep learning, image processing and computer vision, machine learning, predictive maintenance, robotics, signal processing and wireless communications.

DC MOTOR MODEL

DC motor model is built by using simscape tools, the physical component diagram of the simscape extension. The physical components are found in the simscape library. Without the mathematical equations, the DC motor model is built. The electrical components of the model solve up the voltage and current values. The simscape physical plant of DC motor is mentioned in the below Fig. 5.

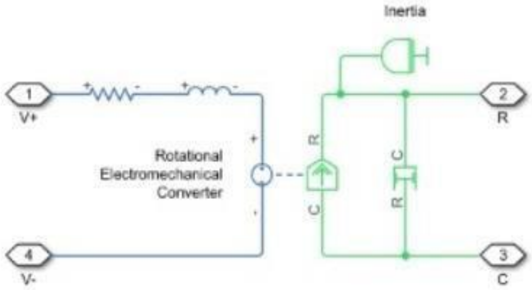

Fig. 5. Simscape model of physical plant DC motor

The following are the blocks to build the DC motor model:

- Controlled Voltage Source Block
- Simulink Converter Block
- Current Sensor Block
- Solver Configuration Block
- Electrical Reference Block

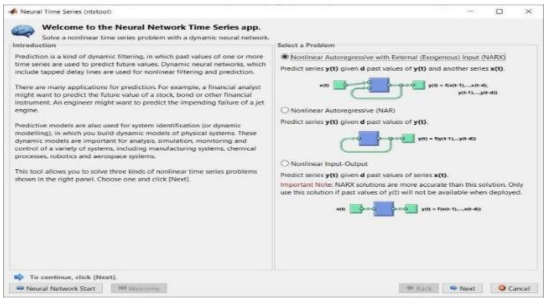

Fig. 6. Simscape model of DC motor

The Neural Network Time Series app leads through solving three different kinds of nonlinear time series problems using dynamic network. It is used to select the data, divide into training, validation and testing sets, define network architecture and train the network. The network is trained and its performances are evaluated by using mean squared error and regression analysis. If the results are not satisfied, the network is retrained with large data sets. The training process is customized by generating the MATLAB scripts. It also provides the option to generate various deployable version of trained network. Dynamic neural network are good at timeseries prediction. There following are the two ways to solve this problem.

- Use a graphical user interface, ntstool, as described in using the Neural Network time series.
- Use Command line functions.

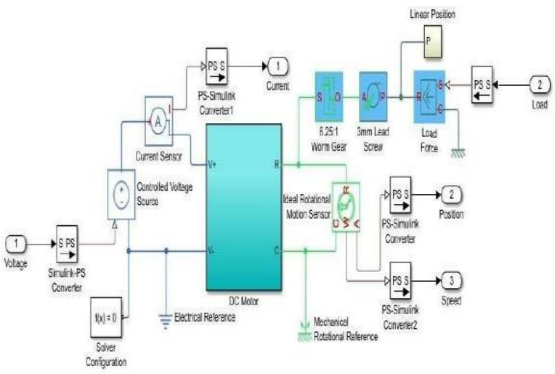

Fig. 7. Selection of Problem in Neural Network

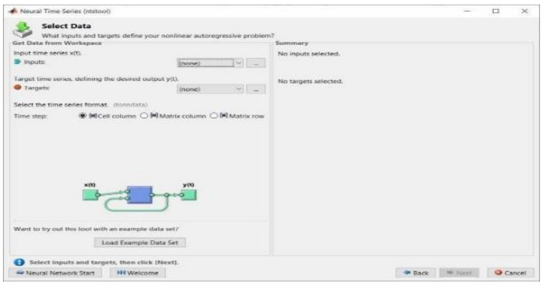

Fig. 8. Input data and Output data of NARX

The standard NARX neural network is a two-layer feedforward network, with a sigmoid transfer function in the hidden layer of the neuron and a linear transfer function in the output layer of the neuron. This network also uses tapped delay lines to store previous values of the x(t) and y(t) sequences. Note that the output of the NARX network, y(t), is fed back to the input of the network (through delays), since y(t) is a function of y(t – 1), y(t – 2), ..., y(t – d). However, for efficient training this feedback loop can be opened. Because the true output is available during the training of the network, you can use the open-loop architecture shown above, in which the true output is used instead of feeding back the estimated output. This has two advantages. The first is that the input to the feedforward network is more accurate. The second is that the resulting network has a purely feedforward architecture, and therefore a more efficient algorithm can be used for training. This network is discussed in more detail in "NARX Network" (narxnet, closeloop). The default number of hidden neurons is set to 10. The default number of delays is 2 and change it to 4. You might want to adjust these numbers if the network training performance is poor. The architecture of the neural network is shown in the below Fig. 9.

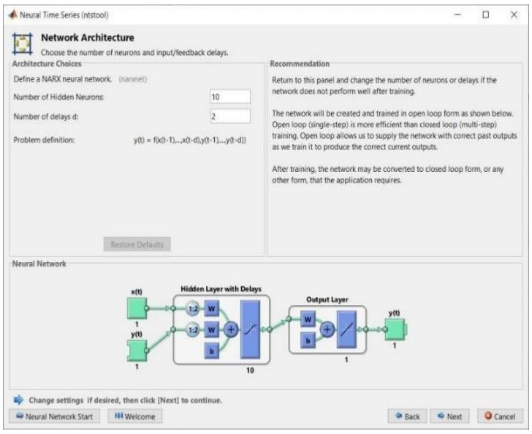

Fig. 9. Architecture of the neural network

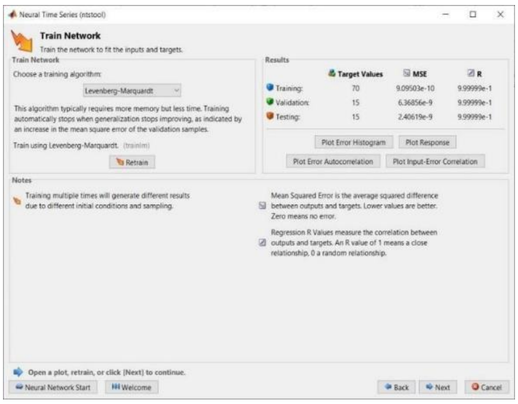

Fig. 10. Neural Network Training controller design

For controlling the torque of the DC motor, PID is used to increase the stability and decrease the steady state error. Kp, Ki, Kd gain can be set manually or by using ZN tuning method. The input for controlling the speed of the DC motor is voltage, current and load. Speed is the desired output variable. The Transfer function for the DC motor was obtained and the system was s used in closed loop configuration. The PID controller design for the system is mention the below Fig 11.

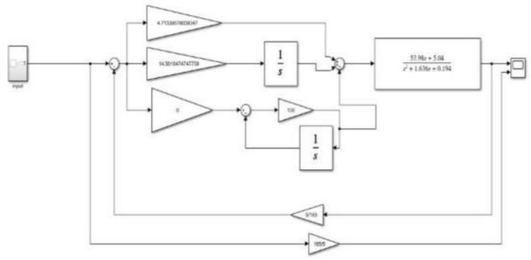

Fig. 11. PID controller design

DATA DRIVEN CONTOL OF DC MOTOR

In system identification tools, non-linear black box model structures are used for represent the continuous time transfer function of the DC motor. The derivation for the mathematical models of the DC motor uses system identification process, this is difficult. By using artificial neural network, multiple input data and multiple output data are obtained and easier to estimate the continuous nonlinear function. The comparative model is mention in the below Fig. 12.

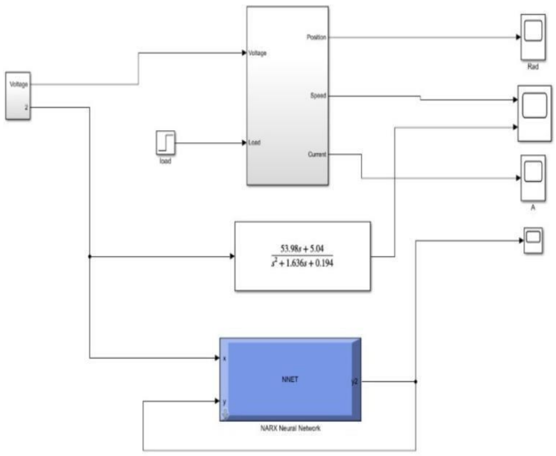

Fig. 12. Comparative Model

TUNING OF SPEED CONTROLLER

The current and velocity loop in the system level model are tuned by using the control system tuner by using MATLAB. The control system consists of two integrated subsystem speed and current controller blocks. Fig. 13. shows the system level model which is suitable for speed and current controller tuning

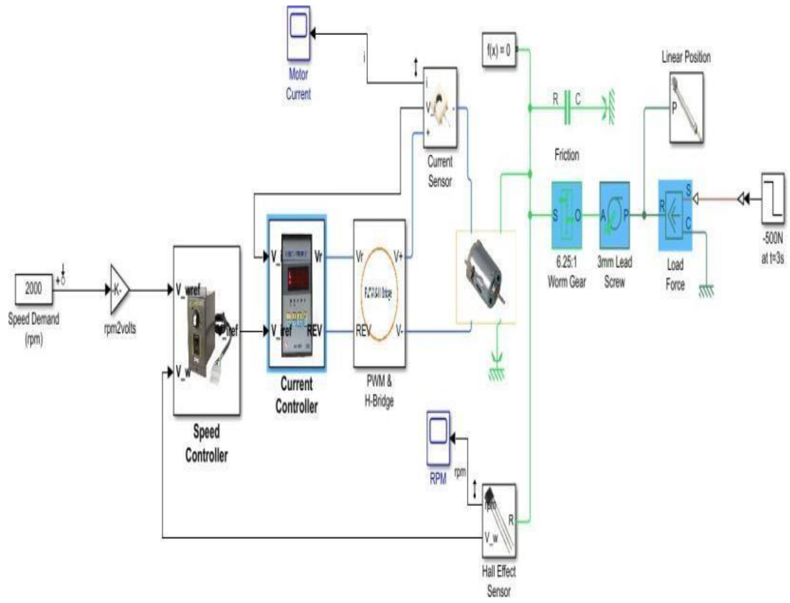

Fig. 13. System Level Model

IV. RESULTS AND DISCUSSIONS

The Multiple subsystems are combined together to form the Simulink model for the data driven control of DC motor. System identification process is performed on the input data as a voltage and output data as a speed of the dc motor. DC motor model is simulated and the simulation results are shown here.

CLOSED LOOP CONTROL SYSTEM OF DC MOTOR

The simulation output results for the comparative model of the DC motor using data driven technique is shown in the below figures.

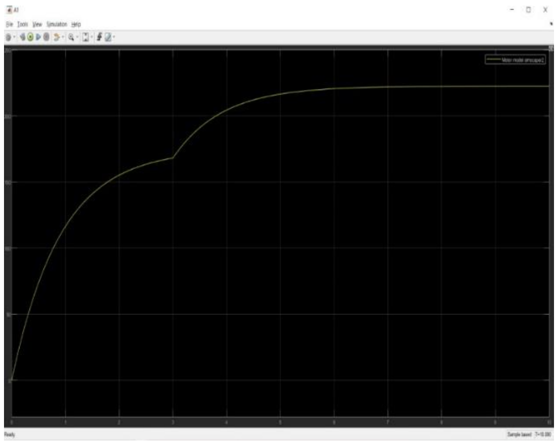

Fig. 14. Speed response of the DC motor system

In Fig. 14. shows the output graph of DC motor model. The DC motor system model is completed and the measured output data (speed) is obtained which is used to execute the system identification process.

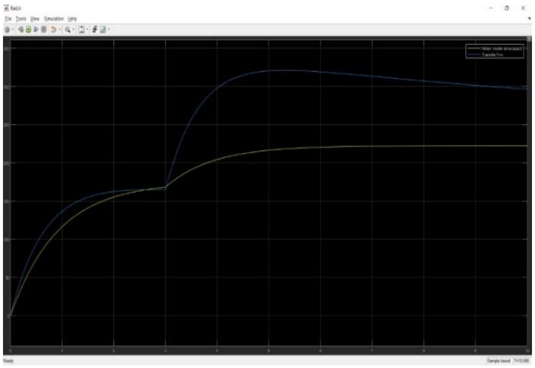

Fig. 15. Comparative Model Output

The Fig. 15. shows the output graph of DC motor model and Transfer function. The Transfer function is generated from the non-linear black box model structure by using system identification process and motor model simscape are compared.

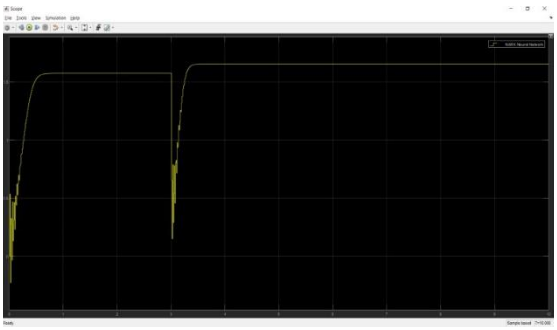

Fig. 16. Output of NARX Neural Network

The Fig. 16. shows the output graph of NARX neural networks to indicate the system identification of the dc motor. The dc motor data is used to train as an input data and target of the NARX. After the system identification process and the successful training of NARX network, the NARX network response is being obtained.

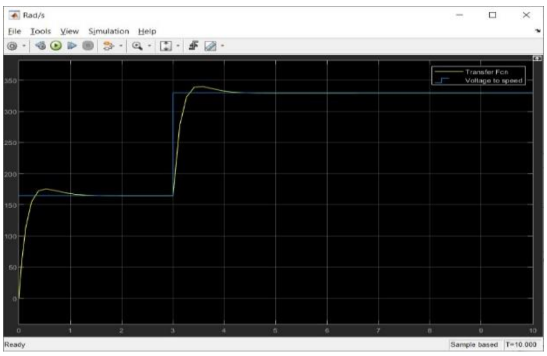

Fig. 17. Speed Control of DC Motor using PID

Fig. 17. shows the output graph indicates the desired response of the DC motor. The DC motor system model using PID controller is shown. The performance of the represented control system is highly effective and an acceptable response is obtained by simulating the model.

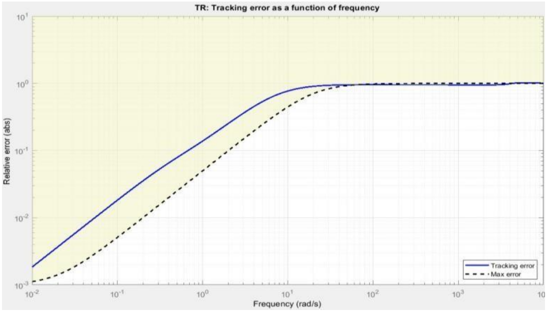

Fig. 18. Tracking Tuning Error of Speed Controller

The Fig. 18. shows tracking the response of the speed controller with integral gain and proportional gain. The error decreases and reach below the max error, this occurs when the frequency is increased. Therefore the error is being reduced and the speed controller is tuned.

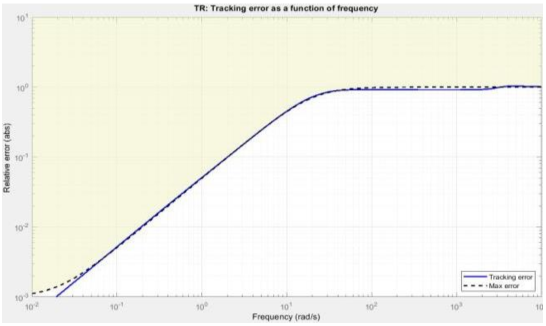

Fig. 19. The System is tuned and error is rectified

The Fig. 19. shows the verification of plotted closed loop response from speed demand (rpm) to speed. The tuned gain values are obtained and the design is being validated from the updated tracking plot

DISCUSSIONS

In this simulation design, the models of the physical systems are created by using MATLAB platform. Using data driven control method, the controller is being designed as it need only the measured input data and output data. From the system identification process method, the mathematical model for the physical systems is obtained from the measured system data. The continuous time transfer function is represented by using the system identification toolbox. The performance unknown nonlinear inputs (NARX) neural network and the transfer function of the plant is being compared. The response of the DC motor is acceptable in nature and it can be used for the real time testing of the DC motor. By using PID controller model, the speed response of the DC motor is being observed by simulating the model.

V. CONCLUSION

The system identification process method is being used to analyze the data-driven control of the DC motor. System identification tool and NARX neural network assists in DC motor model identification. For system identification process method, the measured input data and output data is voltage and speed of the DC motor. The non-linear black box model generates the transfer function by using system identification process. The responses of transfer function and motor model simscape are compared. As the result of comparison, the similarity in the response is observed. After the completion of system identification process, the NARX neural network is trained and the response for the NARX neural network is obtained. The proposed system response is acceptable for the industrial purpose and it can be used for real time implementation and testing of the DC motor. In addition to the system identification process method, the speed response of the DC motor is controlled by implementing PID controller. Proportional Integral Derivative (PID) acts as an optimal controller design for the obtained DC motor model.

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