DC Motor Parameter Identification Using Speed Step Response

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ABSTRACT

The objective of this paper is to estimate the parameters of a DC motor based on its speed response as a step voltage input is applied. A series of measurements which represent input and output data of the DC motor were taken in the lab. DC motor model was created and built into Matlab/Simulink. Off-line identification methods were used to identify the motor parameters and to develop an approximate transfer function. The parameters under consideration are the motor armature-winding resistance and inductance, back e.m.f. constant, motor torque constant, moment of inertia, and the viscous friction. The parameters were obtained using two identification methods; the MATLAB Parameter Identification Toolbox and Constraint Optimization Toolbox. In both methods, the comparison between the experimental and simulated step responses showed good agreement. The parameters of the DC motor were found to be as follows: motor armature-winding resistance = 2.937Ω, inductance =0.040437 H, back e.m.f. constant =0.6571v/rad/sec, moment of inertia =0.064744 kgm², motor torque constant =0.6571 Nm/A, and the viscous friction coefficient= 0.04867 Nm/rad/sec.

Keywords: Parameters Identification, Constrained Parameters Optimization, ITAE PID Tuning

1. Introduction

DC motors are electromechanical machines widely used in industry due to their small size, low friction, low construction cost and high torque [1]. Modeling and simulation of DC motors are broadly studied in engineering for better understanding of their characteristics and in order to control and improve their performance. For proper modeling of DC motors, some mechanical and electrical parameters are required. Even if these parameters are documented in the user's manual, it may be necessary to determine them if the system has been used for a few years. The reason for this is that these parameters will change due to aging, wear and tear of the system [2]. The process of finding out these parameters is called system identification. Several research studies have shed the light on system identification as it has many industrial applications. There are two types of system identification; off-line and on-line. In off-line system identification a series of

measurements are taken and then through calculations system parameters are obtained, where in on-line system identification the parameters are obtained while the system is running [3]. In this study, off-line system identification has been considered for two reasons; firstly, lab equipment required for on-line identification is not available and secondly, the simplicity of off-line comparing with on-line identification. Two different off-line identification methods have been carried out to find the motor parameters, viz. Matlab system identification toolbox and constrain optimization toolbox.

2. Methods

In the following subsections, modeling of a DC motor, experimental set-up as well as the identification methods used in this study is presented.

2.1 DC Motor Modeling

DC motors can be represented by the schematic diagram shown in figure 1. The motor input is the voltage applied while the output is the angular speed. From fig. 1, we can derive equations (1) and (2) based on Kirchhoff's voltage law and Newton's 2nd law [4].
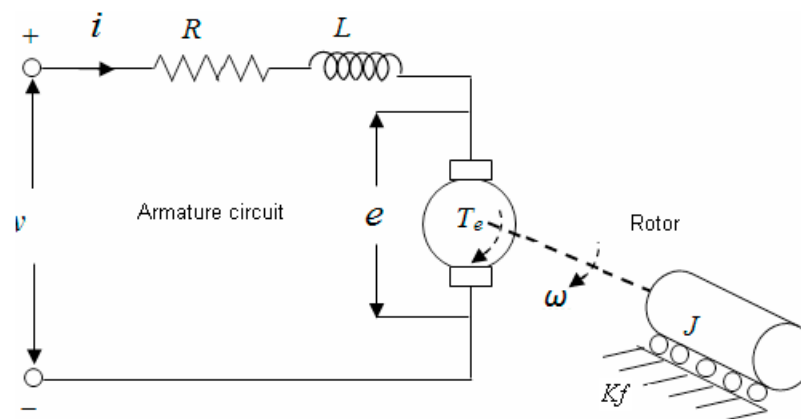

Figure 1. DC Motor Schematic Diagram

$$v(t) = R\,i(t) + L\frac{di(t)}{dt} + e(t) \tag{1}$$

$$Te(t) = Kf\,\omega(t) + J\frac{d\omega(t)}{dt} \tag{2}$$

Where $v(t)$ motor armature voltage in Volts
          R motor armature winding resistance in Ohms
          L motor armature winding inductance in Henry
          $i(t)$ motor armature current in Amps
          $e(t)$ back electromotive force in Volts
          J moment of inertia in kgm²
          $Te(t)$ motor electromagnetic torque in Nm
          Kf viscous friction coefficient in Nm/rad/sec
          $\omega(t)$ angular speed in rad/sec

When the motor is rotating, back electromotive force $e(t)$ is generated and is proportional to the angular speed $\omega(t)$ by a back e.m.f constant Kb, that is,

$$e(t) = Kb\ \omega(t) \tag{3}$$

Also, the motor torque $Te(t)$ is proportional to the armature current $i(t)$ by a motor torque constant Kt as shown in equation (4)

$$Te(t) = Kt\ i(t) \tag{4}$$

We know that Kb and Kt are the same. Therefore,

$$Kb = Kt = K \tag{5}$$

By re-arranging equation (1) and (2) using equation (3) and (4) and (5), we can write:

$$\frac{di(t)}{dt} = -\frac{R}{L}i(t) - \frac{K}{L}\omega(t) + \frac{1}{L}v(t) \tag{6}$$

$$\frac{d\omega(t)}{dt} = \frac{K}{J}i(t) - \frac{Kf}{J}\omega(t) \tag{7}$$

Taking the Laplace transform of equations (5) and (6)

$$Ls\ i(s) = -R\ i(s) - K\omega(s) + v(s) \tag{8}$$

$$J\omega(s) = K\ i(s) - Kf\ \omega(s) \tag{9}$$

From equations (8) and (9) we can draw the block diagram shown in figure 2 and derive the motor transfer function in equation (10)
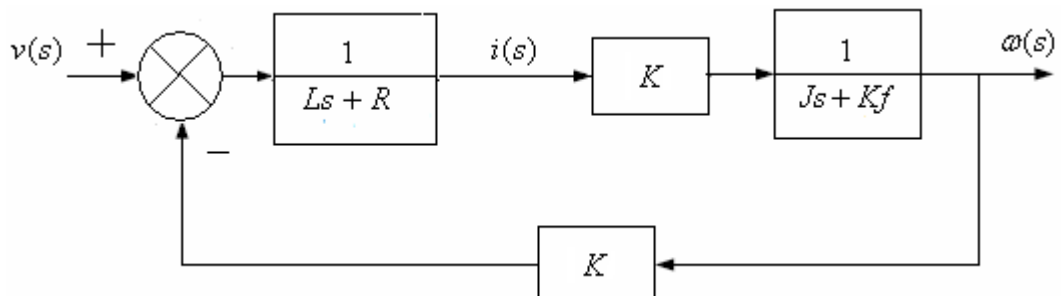

Figure 2. DC Motor Block Diagram

$$\frac{\omega(s)}{v(s)} = \frac{K}{(Ls + R)(Js + Kf) + K^2} \tag{10}$$

From equation (10), it is obvious that the parameters need to be identified for developing a DC motor transfer function are the following: the motor armature-winding resistance and inductance, back emf constant, moment of inertia, in addition to motor torque constant and viscous friction coefficient which are assumed to be the same.

2.2 DC Motor Simulink Model

Modelling of DC motor in Matlab/Simulink is performed using Simscape environment as shown in Figure 3. This Simulink model of the open-loop DC motor is subsequently used for developing the DC motor parameters estimation and simulation of the speed PID control system.
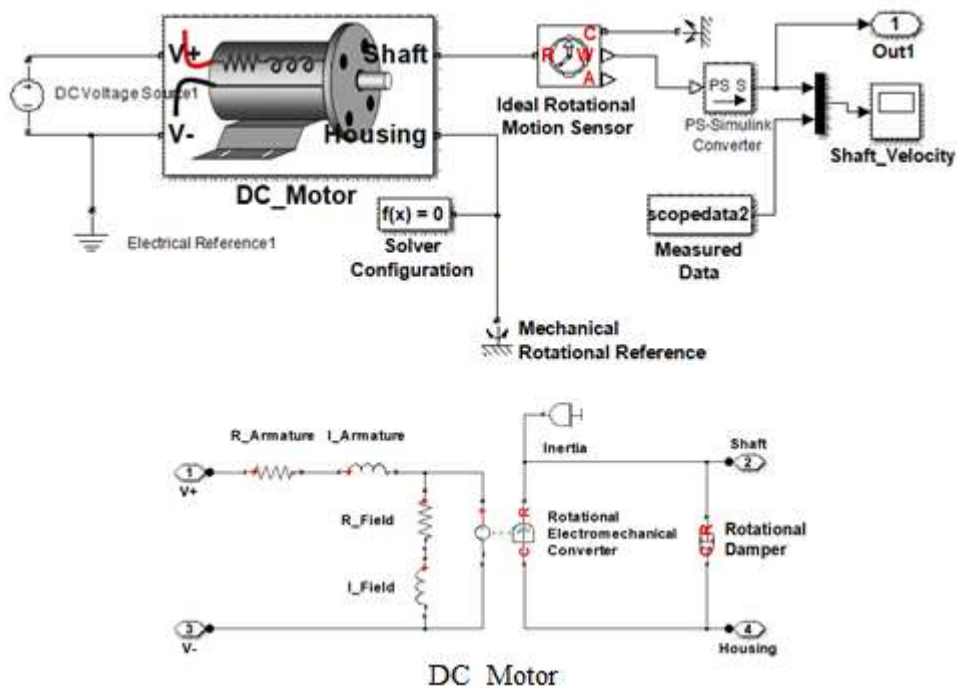

Figure 3. Simulink model of DC motor

2.3 Experimental Set-up and Data Measurement

Figure 4 shows the block diagram of the experimental set-up to measure the open-loop responses of the DC motor to step inputs to be used in parameters identification and estimation of the DC motor. The equipment used includes MS150 Modular Position Servo System [5]. It consists of Power supply (PS150E), DC motor (DCM150F), servo amplifier (SA150D) and tacho unit (GT150X). The power supply provides +15V and -15V DC volts for the motor and control system. The motor (DCM150F) has a permanent magnet stator and single armature winding. The rotating direction of the motor shaft is

controlled by the direction of the electric current through the armature winding of the motor. The Dc motor and the tacho unit mounted on a common shaft. An analogue input signal to the motor circuit in the range 0 to ±10V enables variable shaft speed of rotation in either direction to be achieved. An analogue voltage signal proportional to speed, in the range 0 to ±10V, is available at the tacho unit output.
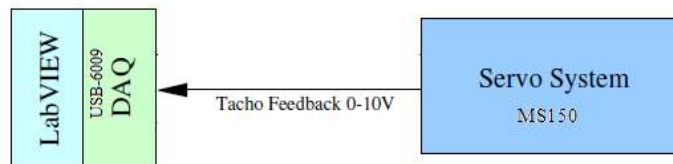

Figure 4. Block diagram of experimental set-up

NI USB-6009 [6] data acquisition device was used for the acquisition of the analogue signals into a computer. DAQ was connected with the computer using USB port. It drew power (5 V) from the USB port of the computer. It transmitted the signal information serially to the computer using USB port. A LabVIEW program was made to acquire the signals from the USB acquisition device. LabVIEW VI program used to collect the data sets is depicted in figure 5.
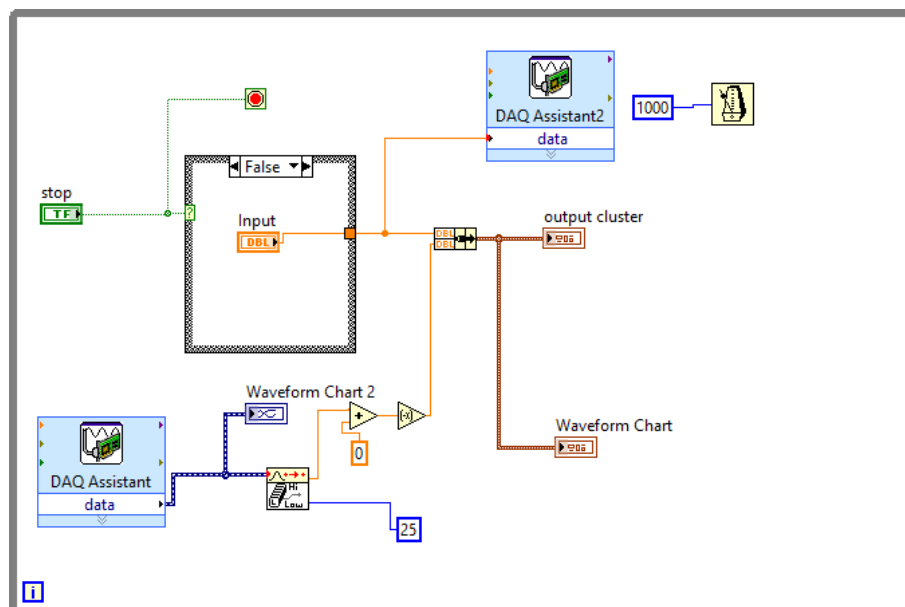

Figure 5. LabVIEW VI for data collection

After the experiment had been set up, the DC motor was subjected to step input of 8.5V. A series of speed measurements were taken to form the output speed response. The voltage step input and output speed response of the motor are shown in figure 6. The input and output data has been saved in the form of two columns u1 and y1 respectively. This data is required later for processing by system identification techniques.
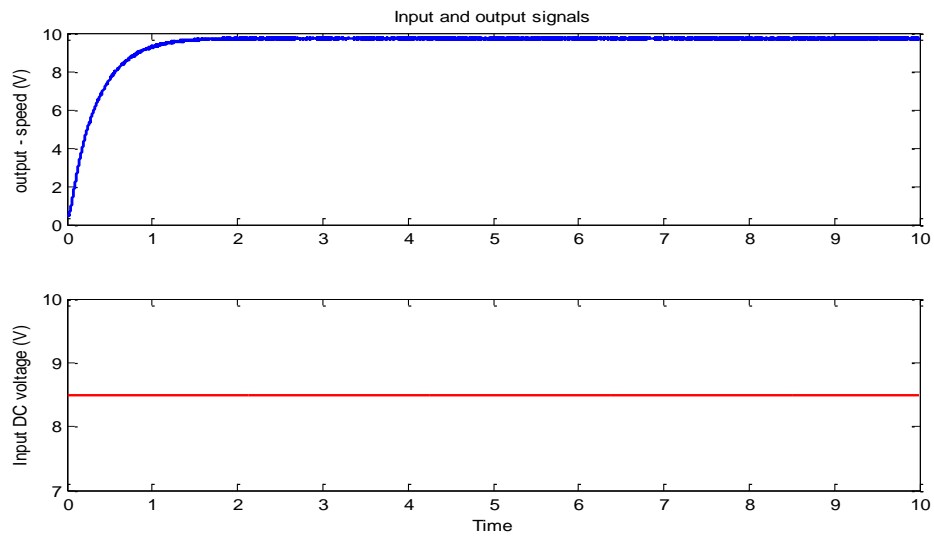
Figure 6. Experimental Output and Input Signals

2.4 Matlab System Identification Toolbox Method

As mentioned earlier, one of the identification techniques considered in this paper involves the use of Matlab system identification toolbox. Matlab system identification toolbox provides tools for generating system transfer functions based on measured input and output data. Figure 7 shows the main graphical user interface (GUI) of the Matlab system identification toolbox which helps in the organization of data and models. Steps taken for this technique include loading the data columns u1 and y1 into the Matlab workspace, importing the data columns from Matlab workplace into the system identification toolbox, plotting and processing data for estimation, estimating linear models, and finally identifying transfer function models [7]. Results obtained are presented in section 3.
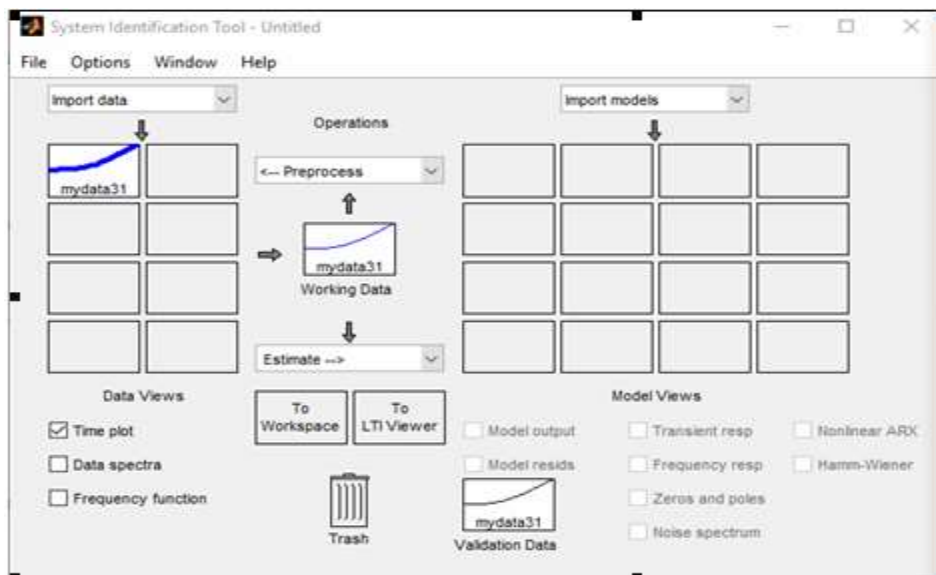

Figure 7. Main Graphical User Interface

2.5 Constrain Optimization Toolbox

Multiple solutions may easily be achieved when identifying parameters but finding the optimal one is a quite challenging task. For this reason, optimization toolbox in Matlab was used. Optimization toolbox is a collection of predefined M-file functions that extend the capability of Matlab and helps researchers to identify the optimal solution from a number of possible options by using measured input and output data. Capability of the optimization toolbox can also be extended by writing our own M-files, or by using it in combinations with other toolboxes. The toolbox includes many types of optimization methods and algorithms. In this study, constrained non-linear least squares method type was used. Algorithms of pattern search, NLS (Levenberg), NLS(Trust region) and gradient decent were selected. Steps followed include creating an objective function, creating constrains, solving the problem, and finally examining the results [8]. Results achieved via this method are presented in section 3.

3. Results and Discussion

For the system identification method 1, comparison of experimental and simulated data is shown in figure 8. Simulation results show that this method successfully estimates the motor parameters.
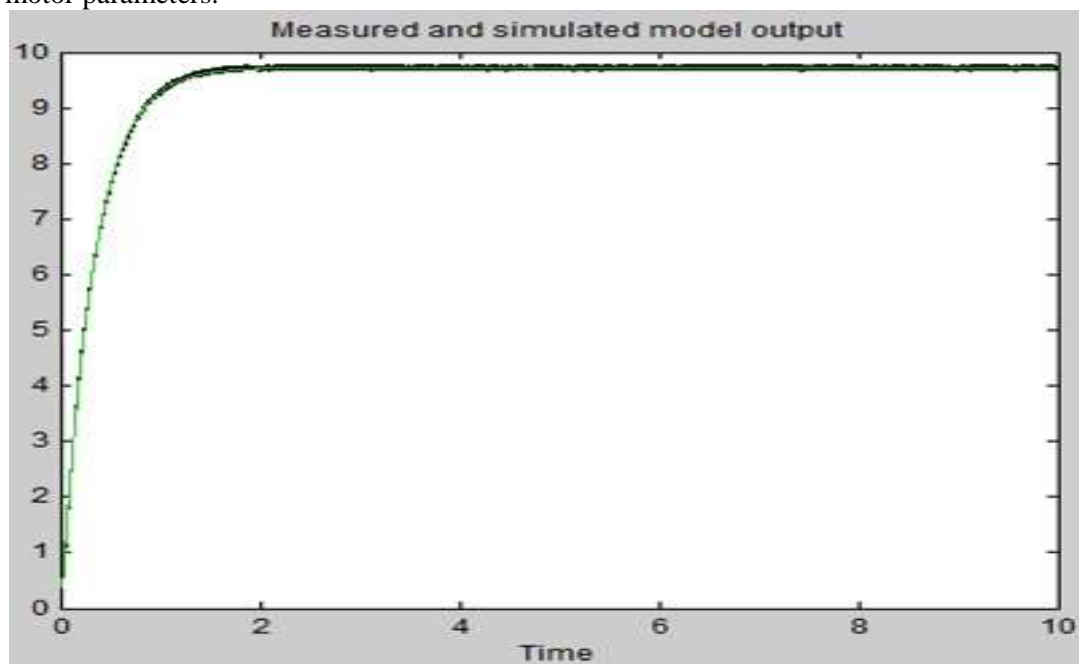

Figure 8. Measured and Simulated Output Speed Response Using Method 1

Accordingly, the generated transfer function obtained via this method is presented below.

```
From input "u1" to output "y1":
          233.4
    ---------------------
    s^2 + 68.26 s + 204.1
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Regarding method 2, constrained non-linear least squares optimization method was used. Experimental and simulated results based on four different algorithms were compared. As

can be noticed from figure 9, the output speed responses of pattern search, NLS (Levenberg), NLS (Trust region) and gradient decent algorithms were considered. All responses are almost identical with the exception of pattern search which is not precise. More research is required to find out why pattern search has behaved inaccurately.
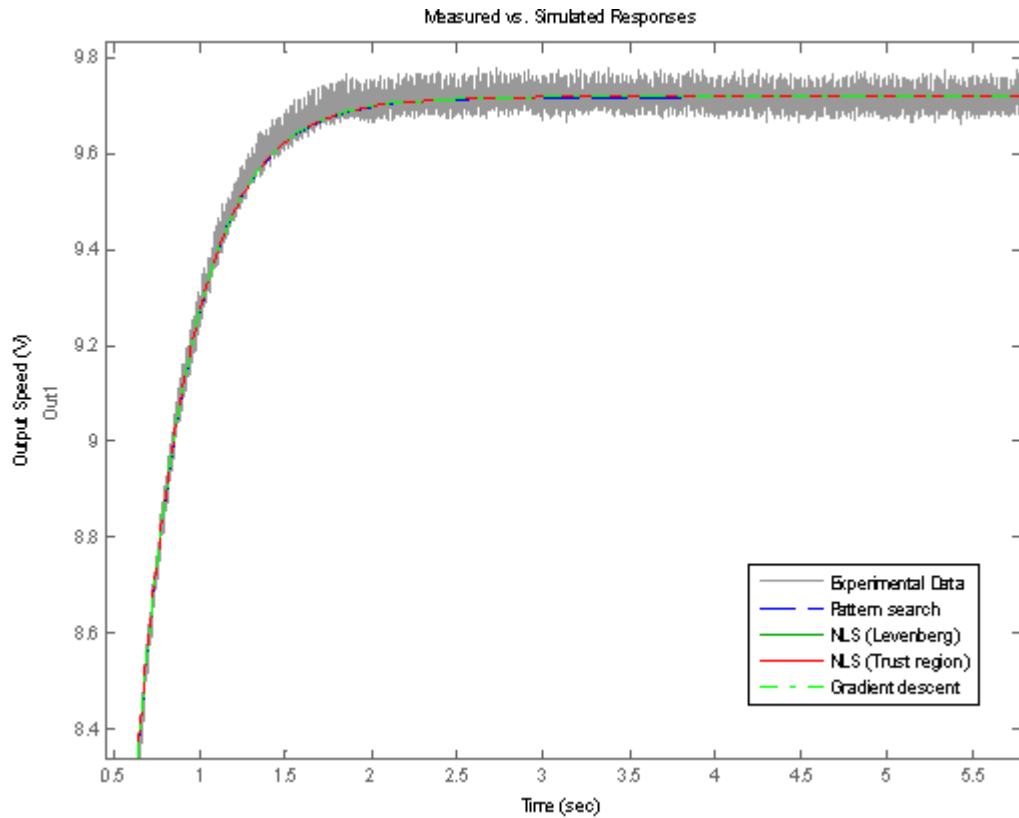

Figure 9. Measured and Simulated Output Speed Response Using Method 2

Figure 10 indicates the error when comparing all methods to measured data, the fluctuation shown is due to noise and all methods except pattern search have the same error.
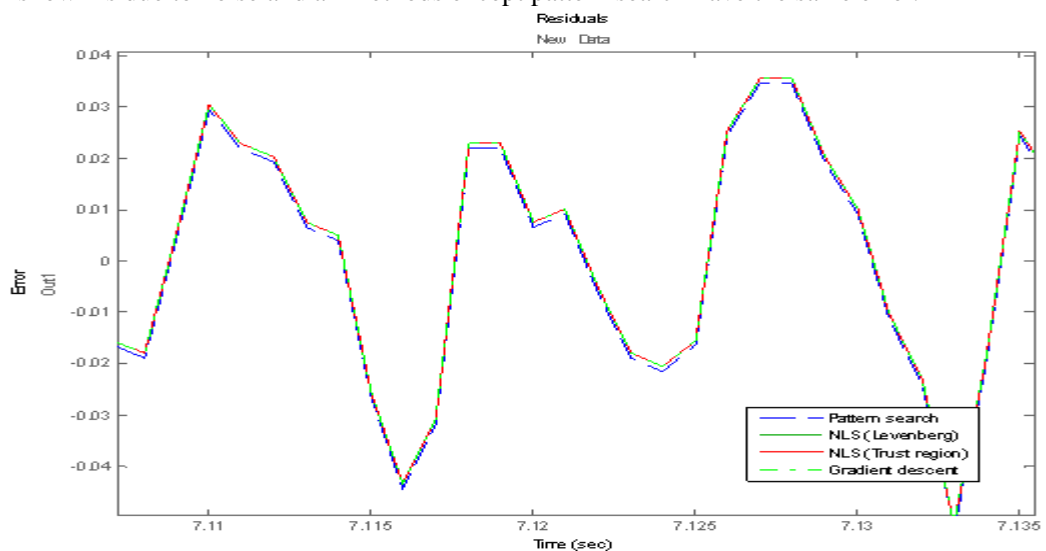

Figure 10 Difference in Measured and Simulated Data

Consequently, the generated transfer functions using this method are presented below. Generated transfer function using NLS (trust- region -reflective):

$$\frac{251.2}{s^2 + 73.43 \ s + 219.7}$$

Generated transfer function using Gradient descent:

$$\frac{251}{s^2 + 73.38 \ s + 219.5}$$

Generated transfer function using NLS (Levenberg) :

$$\frac{252.2}{s^2 + 73.37 \ s + 221}$$

Generated transfer function using pattern search:

$$\frac{247.7}{s^2 + 73.57 \ s + 214.8}$$

Also, a comparison between system identification method 1 and Gradient decent estimation in methods 2 has showed excellent agreement as indicated in figure 11.
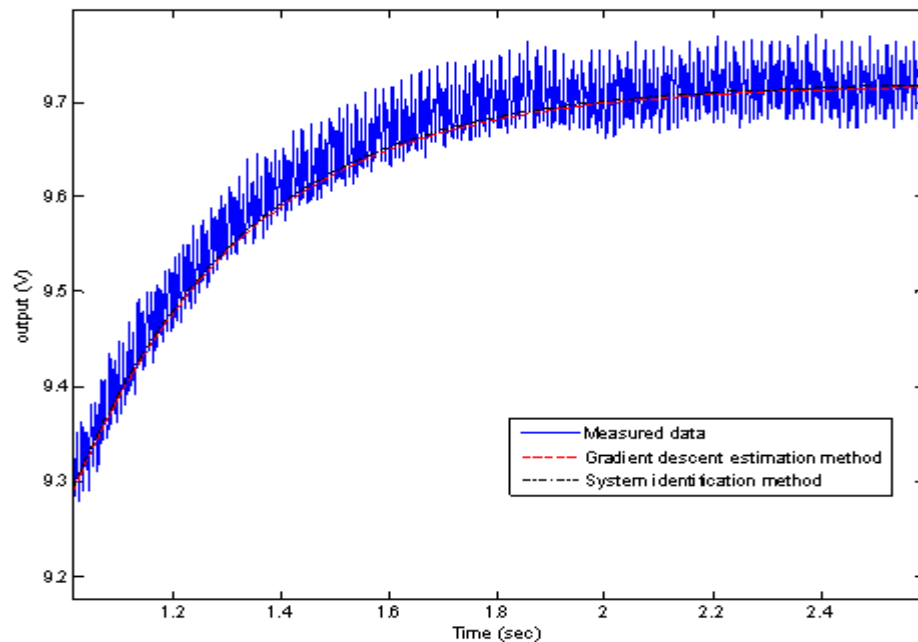

Figure 11. Simulated Output Response for Both Methods

As a result, motor parameters can be estimated as follows: motor armature-winding resistance = 2.937Ω, inductance =0.040437H, back e.m.f. constant =0.6571v/rad/sec, moment of inertia =0.064744 kgm², motor torque constant =0.6571 Nm/Amps, and the viscous friction coefficient= 0.04867 Nm/rad/sec.

4. Conclusions

DC motor model was developed considering armature voltage as an input and rotor speed as an output. Dynamic equations were used for obtaining a transfer function to find out which DC motor parameters are needed for identification. Experimental data of Motor speed response versus step input voltage were required for the process of parameter identification. Matlab identification toolbox and constrain optimization toolbox techniques were employed to identify the DC motor parameters. Results via both techniques showed excellent agreement. The parameters were found to be as follows: motor armature-winding resistance = 2.937Ω, inductance =0.040437 H, back e.m.f. constant =0.6571v/rad/sec, moment of inertia =0.064744 kgm², motor torque constant =0.6571 Nm/A, and the viscous friction coefficient= 0.04867 Nm/rad/sec. Further work may include design and comparison of several DC motor controllers, viz. PID and state space controllers.

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