Parameter Estimation of a dc Motor-Gear-ac Generator Mathematical Model

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Authors’ contributions

This work was carried out in collaboration between both authors. Author PKT designed the study, performed the analysis, wrote the protocol and wrote the first draft of the manuscript. Author WCK managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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Abstract

Mathematical models and there parameters are essential for designers to predict the close loop behaviors of the plant so that systems are stable. A block model is develop in the MATLAB/simulink for the DC Motor-Gear-AC-Generator mathematical model in this paper, the block built is used to estimate the parameters in the estimation node using the gradient descent, simplex search and nonlinear least square algorithm. Gradient descent curve match that of the experimental data and its values are used in the DC Motor-Gear-AC Generator mathematical model.

Objective:

i) To built block simulink
ii) Estimate the parameters of the DC Motor-Gear-Generator mathematical model.

Keywords: Simulink; motor; generator; parameters.

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1 Introduction

Mathematical models are useful for designers, engineers and mathematician to forecast system behaviors and system controllers. Knowledge on parameter estimation are important for describing a dc motor–gear-ac generator mathematical model in implementing an accurate mathematical model, designing precise controllers and predicting the closed loop behavior of the system. Parameter estimation can be done by the use of MATLAB/Simulink Data Acquisition Toolbox which allows the use of MATLAB as a single, integrated environment to support the entire data acquisition, data analysis, and application development process [1,2]. Data Acquisition Toolbox supports Simulink with blocks model and allows verification and validation of data [3]. Parameters to be estimated are done as outlined by Koubaa [4]. The Simulink Parameter Estimation algorithm is used to set and estimate the system parameters [5], this algorithm support the creation of transient estimation, initial condition estimation, table values and simulation curves. The Simulink Parameter Estimation algorithm has inbuilt systems with ideal data which are related against the output data generated by the Simulink model [6]. By the use of optimization techniques, the software approximates the parameter and the initial conditions are stated in a way that the user-selected cost function is reduced [7]. The cost function characteristically calculates the least-square error between the model and the empirical data signals.

2 Motor- Gear-Generator Equation

The mathematical model for DC Motor-Gear-AC Generator is found using Kirchhoffs voltage law [8] Ohms law [9] and Newtons second law of motion [10].

Fig. 1. Schematic representation of a DC Motor-AC generator [11]

The parameters of the equation to be estimated is the one discussed by Tarus, Koech and Obogi [11] in the equation below

\[
\frac{V_g}{V_m} = G(s) = \frac{C_m(SK^2 - (R_gC_gS + L_gC_gS^2 + 1)(L_mS + B_m))}{C_g((R_mC_mS + C_mL_mS^2 + 1)(L_mS + B_m) + C_mS K^2))} = G(s) \tag{1}
\]

Or

\[
G(s) = \frac{-AS^3 - BS^2 - CS - D}{HS^3 + GS^2 + FS + E} \tag{2}
\]

Where,

\[
A = L_gC_gC_mL_g, \quad B = R_gC_mC_gL_g + L_gC_gC_mB_g, \quad C = C_mL_g + C_mC_gR_gB_g - C_gC_mK^2
\]
\[
D = C_mB_g, \quad E = C_gB_m, \quad F = C_mC_gR_mB_m + C_mC_gK^2 + C_gJ_m
\]
\[
G = C_mC_gR_mJ_m + C_mC_gL_mB_m, \quad H = C_mC_gL_mB_m
\]

Equation (2) is the transfer function of DC Motor-AC Generator coupled Model
In control theory, a proper transfer function is a transfer function in which the degree of the numerator does not exceed the degree of the denominator [12]. This condition is satisfied by transfer function in equation (2) for the mathematical model derived by Tarus, Koech and Obogi.

3 Parameter Estimation Algorithm

Simulink estimation software have inbuilt techniques which include, the gradient descent which is a first order iterative optimization algorithm for finding the minimum of a function by finding a minimum error [13]. Nonlinear Least Square approach seeks to define the objective function that might reach its minimum [14]. Pattern Search Method can be utilized to determine parameters with insignificant error and compares it with the nonlinear least square method, pattern search operate by searching a set of point which expand or shrinks and the search stops after a minimum pattern size is reached [15]. Simplex Search Method involve a shift through a set of basic feasible solutions until the optimal basic feasible solution is identified whenever it exists. Before the model is run, numerical values are assign to each of the variables used in the model as the initial guess. For the dc Motor-ac Generator system the following values in Table 1 below are used. Fig. 2 shows the Simulink block diagram for the system used alongside the throttle sensor inbuilt in the MATLAB and the parameter symbols with assign digit in the editor.

Table 1. Specification of the motor-generator parameter initial values used for simulation

| No | Parameter Description (units) | Motor values | Generator values |
|----|--------------------------------|--------------|------------------|
| 1  | Gear Ratio                    | 1            | 1                |
| 2  | Armature Resistance ( Ω )     | 1            | 1                |
| 3  | Inductance ( H)               | 1            | 1                |
| 4  | Viscous Friction Coefficients (Nm/(rad/s)) | 1 | 1 |
| 5  | Moment of Inertial (kgm²)     | 1            | 1                |
| 6  | Capacitance ( F )             | 1            | 1                |

Fig. 2. Block diagram of DC motor-AC generator system

\[
A = L_g C_g C_m J_g , \quad B = R_g C_m^2 C_g L_g + L_g C_g C_m B_g , \quad C = C_m J_g + C_m C_g R_g B_g - C_g C_m K^2
\]

\[
D = C_m B_g , \quad E = C_g B_m , \quad F = C_m C_g R_m B_m + C_m C_g K^2 + C_g J_m
\]

\[
G = C_m C_g R_m J_m + C_m C_g L_m B_m , \quad H = C_m C_g L_m J_m
\]
The Simulink estimation software formulates parameter estimation as an optimization problem and the optimization problem solutions are the estimated parameter values. A new data set is created in MATLAB Simulink on the parameter estimation tools, where the transient data node is created for use as estimation and validation, three data sets are opened; the first one is used for parameter estimation and the remaining two for validating the response of the Simulink model with the estimated parameters. The DC Motor-AC Generator data does not match with the measured data because the parameters are incorrect. Hence we used Simulink design optimization to automatically tune DC Motor-AC Generator model parameters. Fig. (3) shows the voltage response of the model using the initial parameter values in the model with a unit input voltage. Fig. (4) show the required step response.

Fig. 3. Output response of the motor-generator using initial values

Fig. 4. Expected response of the motor-generator
4 Definition of Variables

Variables for estimation are stated to establish which parameters of the simulation can be adjusted and any rules governing their values. Eleven unknown parameters of the model are selected: these parameters are the $R_m$ Armature Resistance of the Motor, $R_g$ Armature Resistance of the generator, $J_m$ Motor Inertial, $J_g$ Generator inertial, $L_m$ Inductance of the motor, $L_g$ Inductance of the Generator, $C_m$ Capacitance of the Motor, $C_g$ capacitance of the Generator, $B_m$ Viscous friction coefficients of the motor, $B_g$ Viscous friction coefficients of the generator and the back e.m.f coefficient $k$. On the panel to the right of the list of parameters, the initial guesses for the parameter values are set and the minimum and maximum bounds on these values. The parameters of the system have positive values and the lower limits are set to zero shown in Fig. 5.

![Fig. 5. Selecting parameters for estimation](image)

In order to run estimation, an "Estimation" node is created. This is done on the "Estimation node and pressing the "New" button in the right-hand-side panel to create an estimation node called "New Estimation". The first panel is where data sets to be used in estimation is selected. It is possible to use one or more data sets at once in a given estimation. This model uses estimation data set. The next panel called "Parameters" is where parameters to be adjusted are selected for estimation. Eleven parameters are selected for estimation.

5 Results and Discussions

Two plot types are created to view the estimation results. The plot below shows the expected data against the simulated data. The simulated data come from the model with the estimated parameters. The results of the estimation appear satisfactory as the estimated (red) and (green) curve closely matches the measured results. Fig. (6) shows voltage response after 100 iterations. The plot in Fig. (7) shows the trajectory of the parameters at each iteration of the estimation process. It is shown that the parameters settle to their final values as the estimation process converges to a solution. Table (3), shows the results of Gradient descent algorithm, simplex search algorithm and nonlinear least square algorithm after 100 iteration.
### Table 2. Parameters for estimation

| Name | Value | Estimate | Initial Guess | Minimum | Maximum | Typical Value |
|------|-------|----------|---------------|---------|---------|---------------|
| Bg   | 1     | ✔️       | Bg            | -Inf    | +Inf    | Bg            |
| Bm   | 1     | ✔️       | Bm            | -Inf    | +Inf    | Bm            |
| Cg   | 1     | ✔️       | Cg            | -Inf    | +Inf    | Cg            |
| Cm   | 1     | ✔️       | Cm            | -Inf    | +Inf    | Cm            |
| Jg   | 1     | ✔️       | Jg            | -Inf    | +Inf    | Jg            |
| Jm   | 1     | ✔️       | Jm            | -Inf    | +Inf    | Jm            |
| K    | 1     | ✔️       | K             | -Inf    | +Inf    | K             |
| Lg   | 1     | ✔️       | Lg            | -Inf    | +Inf    | Lg            |
| Lm   | 1     | ✔️       | Lm            | -Inf    | +Inf    | Lm            |
| Rg   | 1     | ✔️       | Rg            | -Inf    | +Inf    | Rg            |
| Rm   | 1     | ✔️       | Rm            | -Inf    | +Inf    | Rm            |

**Fig. 6. Voltage response for the actual and estimated models**

**Fig. 7. Trajectories for parameters**
Table 3. Parameter estimation results

| Symbol | Name                        | Initial Guess | Min Set Value | Max Set Value | GD   | NLS | S.S |
|--------|-----------------------------|---------------|---------------|---------------|------|-----|-----|
| Bg     | Generator Viscous Friction  | 1             | 0             | +infinity     | 4.137| 0.012| 0.545|
| Bm     | Motor Viscous Friction      | 1             | 0             | +infinity     | 0.013| 0.004| 0.844|
| Cg     | Motor Capacitances          | 1             | 0             | +infinity     | 15.055| 4.649| 1.288|
| Cm     | Generator Capacitances      | 1             | 0             | +infinity     | 7.867| 3.384| 1.304|
| Jg     | Generator Moment of Inertia | 1             | 0             | +infinity     | 7.112| 4.105| 1.398|
| Jm     | Motor Moment of Inertia     | 1             | 0             | +infinity     | 13.898| 4.935| 0.966|
| K      | Torque constant             | 1             | 0             | +infinity     | 1.127| 1.194| 1.077|
| Lg     | Generator Inductances       | 1             | 0             | +infinity     | 3.635| 1.576| 1.371|
| Lm     | Motor Inductances           | 1             | 0             | +infinity     | 14.579| 4.287| 0.368|
| Rg     | Generator Resistances       | 1             | 0             | +infinity     | 1.563| 0.636| 0.940|
| Rm     | Motor Resistances           | 1             | 0             | +infinity     | 1.937| 0.581| 0.974|

The results from the gradient descent are the best since the voltage response from the graph is more same to that of the experimental data and substituting the parameter values of the gradient descent into equation (2) the transfer function is

\[
G(s) = \frac{-3062.05023S^3 - 3097.853178S^2 - 671.426095S - 32.54648418}{23996.498S^3 + 3210.1686S^2 + 362.5291438S + 0.188413325}
\]  

(3)

Equation (3) is the transfer function of DC Motor- Gear-AC Generator model.

6 Estimated Parameters of the DC Motor-AC Generator System

The Tables (4) and (5) shows specific parameters of the DC Motor-AC Generator system as obtain from the MATLAB/Simulink using gradient descent algorithm.

Table 4. Motor specification

| Gr | C(F) | V(V) | B B N m J K L i R T \omega |
|----|------|------|-----------------------------|-----------------|----------------|-----------------|-----------------|----------------|-----------------|----------------|
| 1  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 2  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 3  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 4  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 5  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 6  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
| 7  | 7.87 | 12   | 0.01 | 13.90 | 1.13 | 14.58 | 0.09 | 1.94 | 0.11 | 10.62 |
Table 5. Generator specification

| Gr | \( \frac{\text{Nm}}{\text{B (rad/s)}} \) | C(F) | J(Kg m²) | K | L(H) | \( \omega (\text{rad/s}) \) | V(V) | Excess Voltage |
|----|-----------------|------|---------|---|------|-----------------|------|----------------|
| 1  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 10.62| 12.00          |
| 2  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 21.24| 24.00          |
| 3  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 31.86| 36.00          |
| 4  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 42.48| 48.00          |
| 5  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 53.10| 60.00          |
| 6  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 63.72| 72.00          |
| 7  | 4.14            | 15.06| 7.11    | 1.13| 3.64 | 15.06           | 74.41| 84.00          |

7 Conclusion

Three methods of parameter estimation were created in the transient data node of the MATLAB Simulink, these include gradient descent, nonlinear least square and the simplex search methods. The curve of the gradient descent converges to that of experimental data curve making it the appropriate for the system. The estimated parameters are used to generate simulation curves for voltage and time step responses. These curves agree with actual curves within the precision level of the model. The values obtained from the gradient descent are substituted to the unknown values of the formulated equation. Identification process was built and done using the MATLAB. More work can be done using microcontrollers controllers and digital signal controllers.

Competing Interests

Authors have declared that no competing interests exist.

References

[1] Aung WP. Analysis on modeling and Simulink of DC motor and its driving system used for wheeled mobile robot. World Academy of Science, Engineering and Technology. 2007;32:299-306.

[2] Salah MS. Parameters identification of a permanent magnet DC motor. The Islamic University of Gaza. 2009:94.

[3] Bature A, Muhammad M, Abdullahi AM. Parameter identification of a class of dc motor. Int. J. Res. Eng. Sci. 2013;1(5):69-72.

[4] Koubaa Y. Asynchronous machine parameters estimation using recursive method. Simulation Modelling Practice and Theory. 2006;14(7):1010-1021.

[5] Appel M, Grepl R. Parameter estimation for engineers: a new tool for effective search for simulink model parameters. Engineering Mechanics. 2017;2017:90-93.

[6] Erdal H, Dogan B, Buldu A. Realtime parameter estimation, calibration and simulation of a DC motor. Tech. Technol. Educ. Manage. 2011;6(3):606-614.

[7] Koech W, et al. Parameter estimation of a DC motor-gear-alternator (MGA) system via step response methodology. American Journal of Applied Mathematics. 2016;4(5):252-257.

[8] Glattli C. Violation of Kirchhoff's laws for a coherent RC circuit. in Réunion" Nanocomposant" de l'Observatoire des Micro et Nanotechnologies (Ministère de la Recherche); 2006.

[9] Mohan N, Undeland TM. Power electronics: Converters, applications, and design. John Wiley & Sons; 2007.
[10] Milton GW, Willis JR. On modifications of Newton's second law and linear continuum elastodynamics. in proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. The Royal Society; 2007.

[11] Tarus P, Koech W, obogi R. Modelling of motor-gear-generator system. Asian Journal of Mathematics and Computer Research. 2018;275-284.

[12] Parekh S, et al. Using control theory to achieve service level objectives in performance management. Real-Time Systems. 2002;23(1-2):127-141.

[13] Mason L, et al. Boosting algorithms as gradient descent. in Advances in neural information processing systems; 2000.

[14] Hopgood AA. Intelligent systems for engineers and scientists. CRC press; 2011.

[15] Wetter M, Polak E. Building design optimization using a convergent pattern search algorithm with adaptive precision simulations. Energy and Buildings. 2005;37(6):603-612.

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