Original Research Article

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

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 Generatormathematical model.

i) To built block simulink

ii) Estimate the parameters of the DC Motor-Gear-Generator mathematical model.

1. Introduction

Mathematicalmodels are useful fordesigners, engineers and mathematician to forecast system behaviors and system controllers. Knowledge onparameter estimationare important for describinga dc motor –gear-ac generatormathematical 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/SimulinkData 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]. DC-motor output mechanical energy to provide rotary motion through the gears to run the generator.

2. Motor- Gear-GeneratorEquation

The mathematical model for DC Motor-Gear-AC Generator is found using Kirchhoffs voltage law[4] Ohms law[5] and Newtons second law of motion[6]

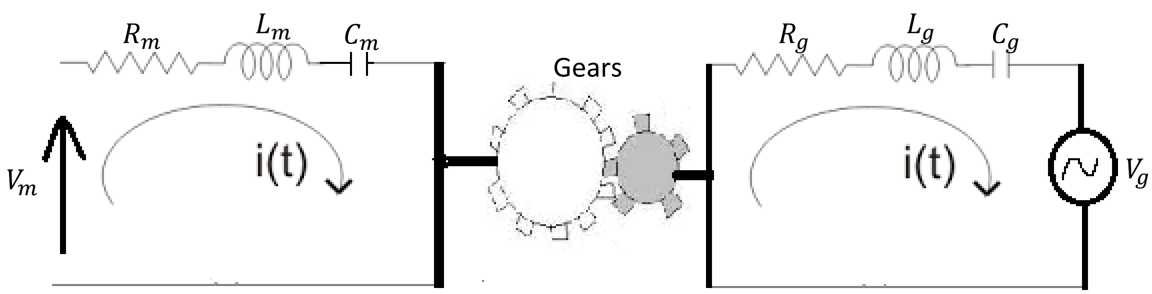

Figure 1: Schematic Representationof a DC Motor-AC Generator.[7]

The parameters of the equation to be estimated are the one discused by Tarus, Koech and Obogi [7] in the equation below

$$\frac{V_g}{V_m} = Gr\left[\frac{C_m(C_gSK^2 - \left(R_gC_gS + L_gC_gS^2 + 1\right)(J_gS + B_g))}{C_g((R_mC_mS + C_mL_mS^2 + 1)(J_mS + B_m) + C_mS\,K^2))}\right] \coloneqq G(s) \quad (1)$$

Or

$$G(s) = Gr\left[\frac{-AS^3 - BS^2 - CS - D}{Hs^3 + GS^2 + FS + E}\right] \quad (2)$$

Where,

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

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

$$G = C_m C_g R_m J_m + \ C_m C_g L_m B_m,\ H = C_m C_g L_m J_m$$

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[8]. This condition is satisfied by transfer function in equation (2) for the mathematical model derived by Tarus, Koech and Obogi.

3. Parameters Identification

Parameter estimation used is the one outlined in Koubaa [9]. This method is built in Simulink Parameter Estimation software in MATLAB for the parameters identification of the dc Motor – gear-ac Generator block model. The Simulink Parameter Estimation algorithm is used to set and estimate the system parameters[10]. The algorithm supports the transient estimation, initial condition estimation and the table values at set breakpoints.

4. Simulink Parameter Estimation Software

The Simulink Parameter Estimation algorithm compares empirical data with the output generated by the Simulink model[11]. By employing the optimization techniques, the software approximates the parameter and the initial conditions of states in a way that the user-selected cost function is reduced[12]. The cost function characteristically calculates the least-square error between the model and the empirical data signals.

5. Parameter estimation algorithm

Simulink estimation software have inbuilt techniques which include, the gradient descent which is a first order iteratative 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 Methodcan 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 Methodinvolve a shift through aset of basic feasible solutions until the optimal basic feasible solution is identified whenever it exists.

6. System Parameters

Using Equation (2), the design parameters are the $R_m$armature resistance of the motor,R_gArmature Resistance of generator,L_m inductance of the motor,L_g Inductance of the generator, B_m viscous friction coefficients of the motor, $B_g$viscous friction coefficients of the alternator,C_m capacitance of the motor, $C_g$capacitance of the generator,$K_m$torque constant of the motor, $K_g$torque constant of the generator and the G_r gear ratio. Before running the model, we need to assign numerical values to each of the variables used in the model. For the dc Motor-ac Generator system, we assume the following values in Table 1 below

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 (kgm^2)	1	1
6	Capacitance (F)	1	1

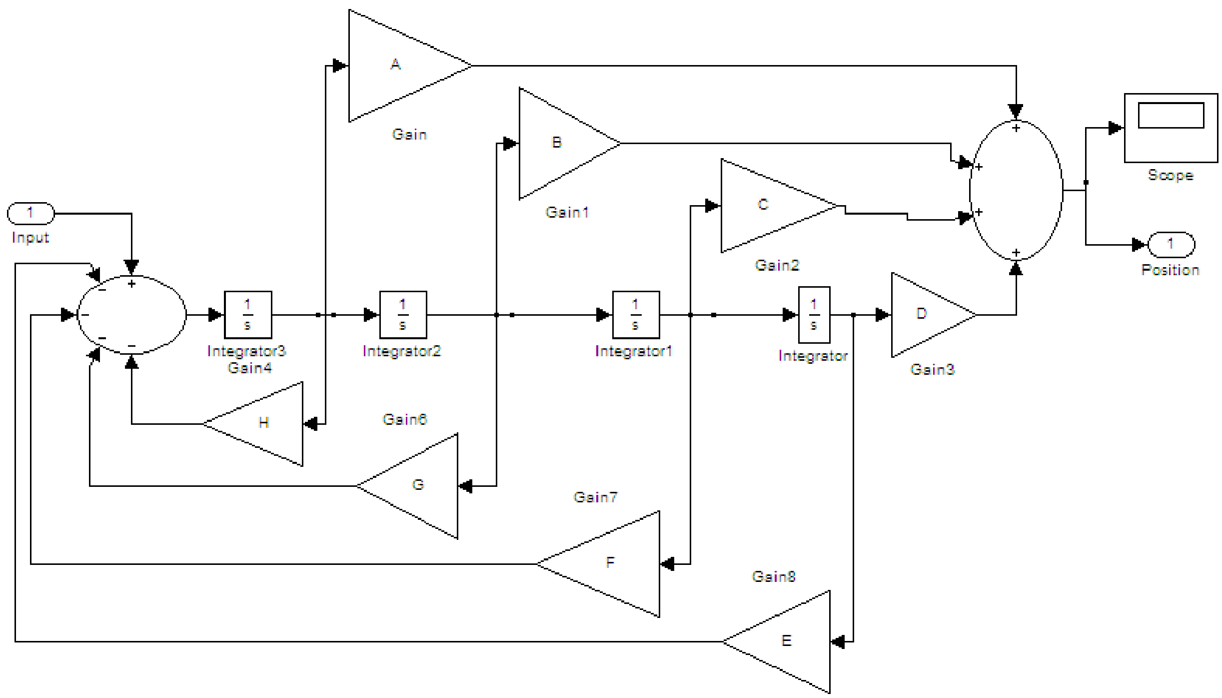

Figure 2 : Block Diagram of DC motor- AC Generator system.

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

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

$$G = C_m C_g R_m J_m + \ C_m C_g L_m B_m \ , H = C_m C_g L_m J_m$$

Figure (3) shows the voltage response of the model using the initial parameter values in the model with a unit input voltage. Figure (4) show the required step response. The Simulink estimation software formulates parameter estimation as an optimization problem and the optimization problem solutions are the estimated parameter values.

7. Data Estimation

A new data set is created in MATLAB Simulink on the parameter estimation tools, where the transient data node is created to be used for 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 the measured data because the parameters are incorrect. Hence we used Simulink design optimization to automatically tune DC Motor- AC Generator model parameters

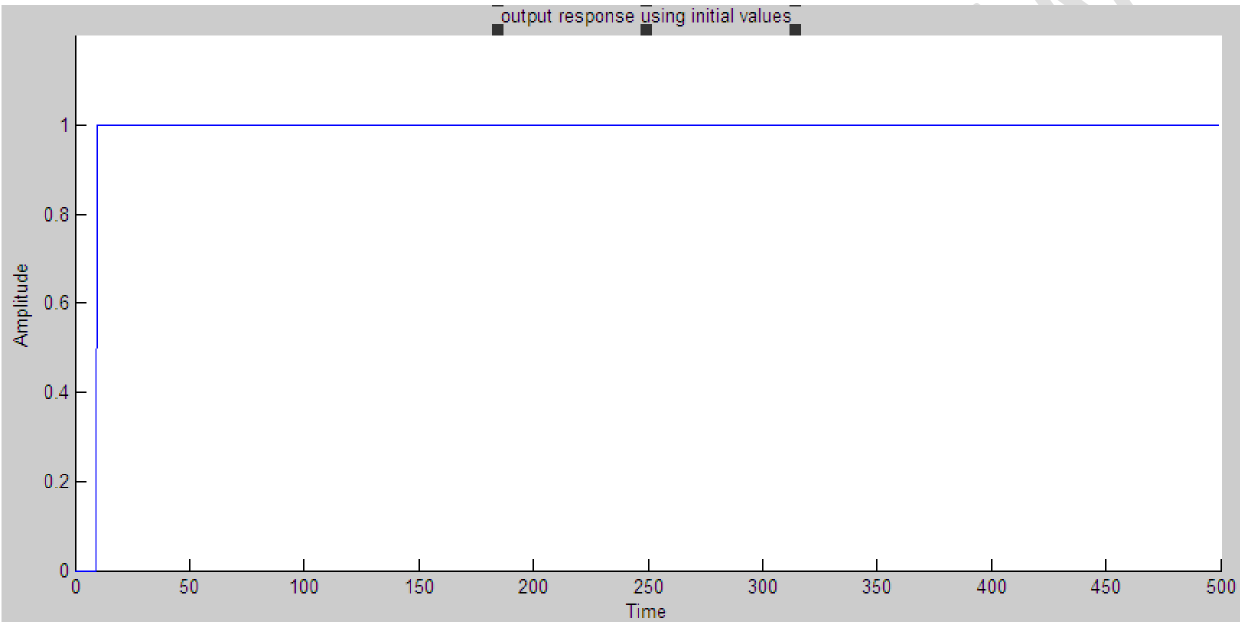

Figure 3: Output response of the Motor-Generator using initial values

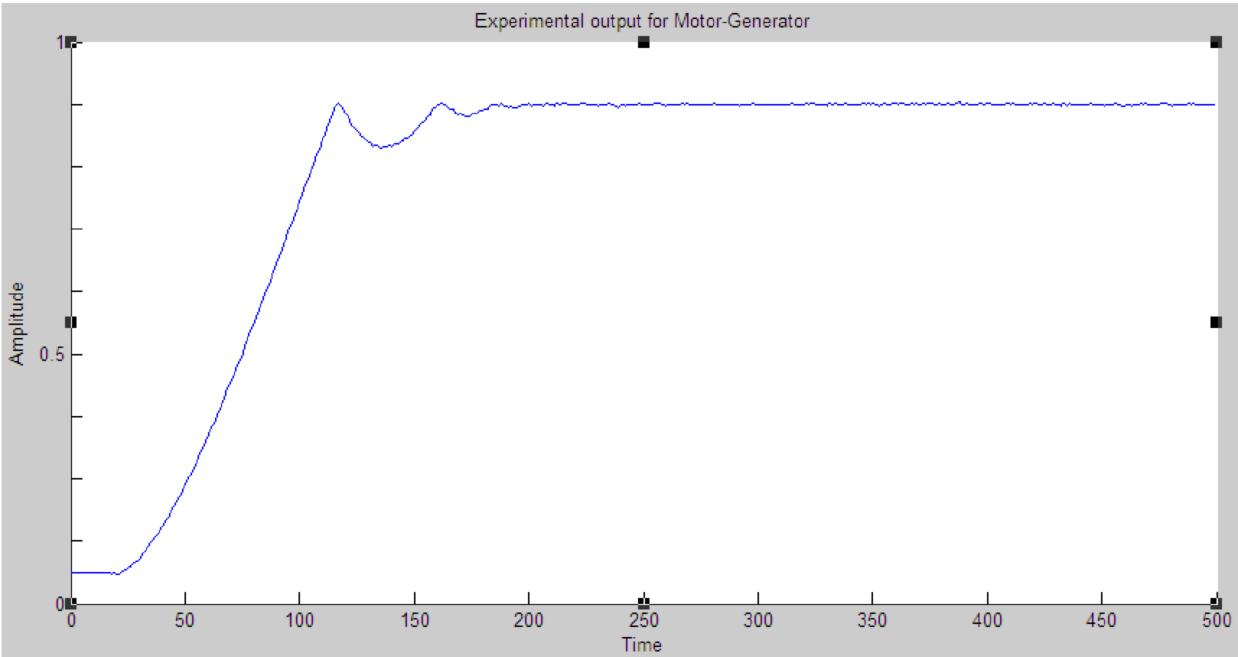

Figure 4: Expected Response of the Motor- Generator

8. Definition of Variables

Variablesfor estimation are stated to established 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_gGenerator inertial, L_mInductance of the motor,L_m Inductance of the Generator,C_m Capacitance of the Motor, $C_g$capacitance of the Generator B_mViscous 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 setto zero. Figure 5 are the selected parameters.

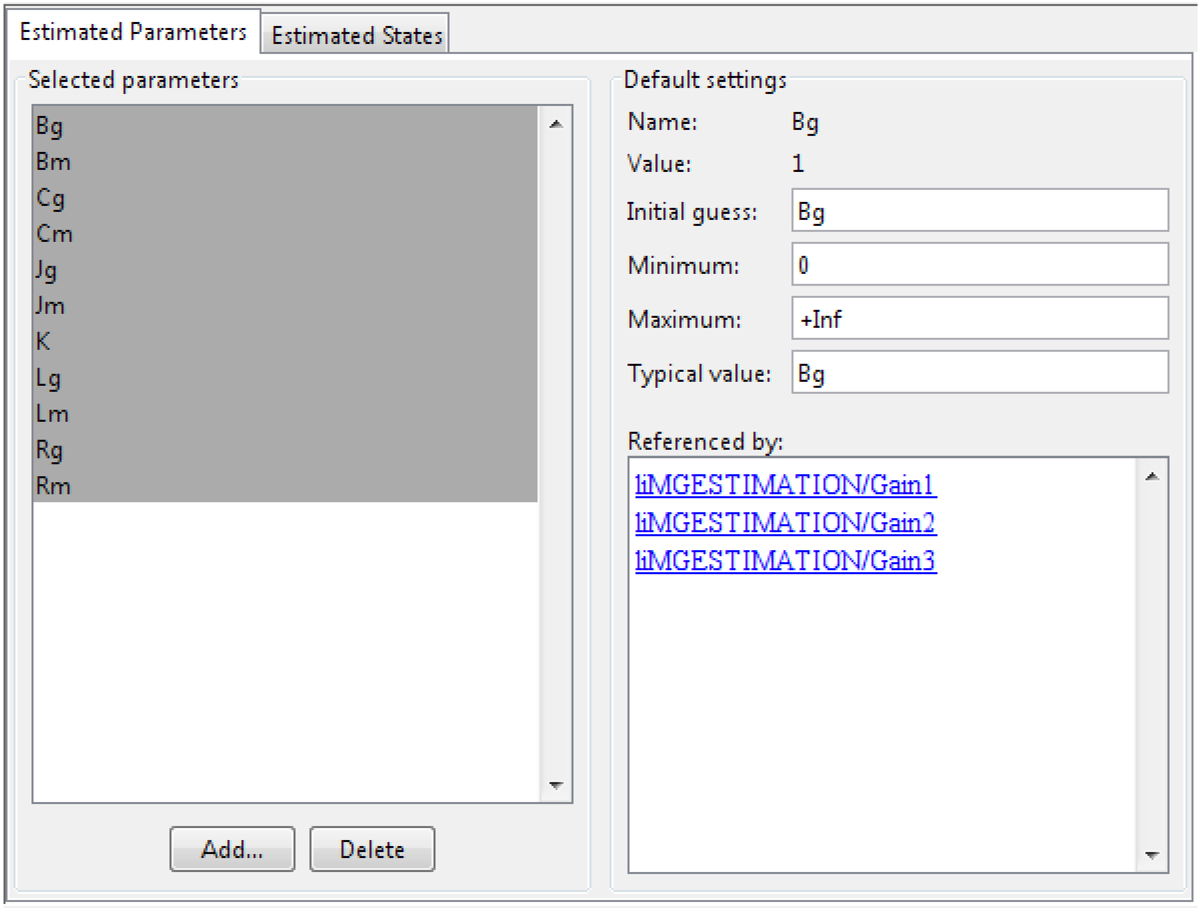

Figure 5: Selecting Parameters for Estimation

9. The Estimation Task

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

Table 2: Parametersfor Estimation

Data Sets | Parameters | States | Estimation

Estimation parameters

Name	Value	Estimate	Initial Guess	Minimum	Maximum	Typical Va...
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

10. 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. Figure (6) shows voltage response after 100 iterations. The plot in Figure (7) shows the trajectory of the parameters at each iteration of the estimation process.

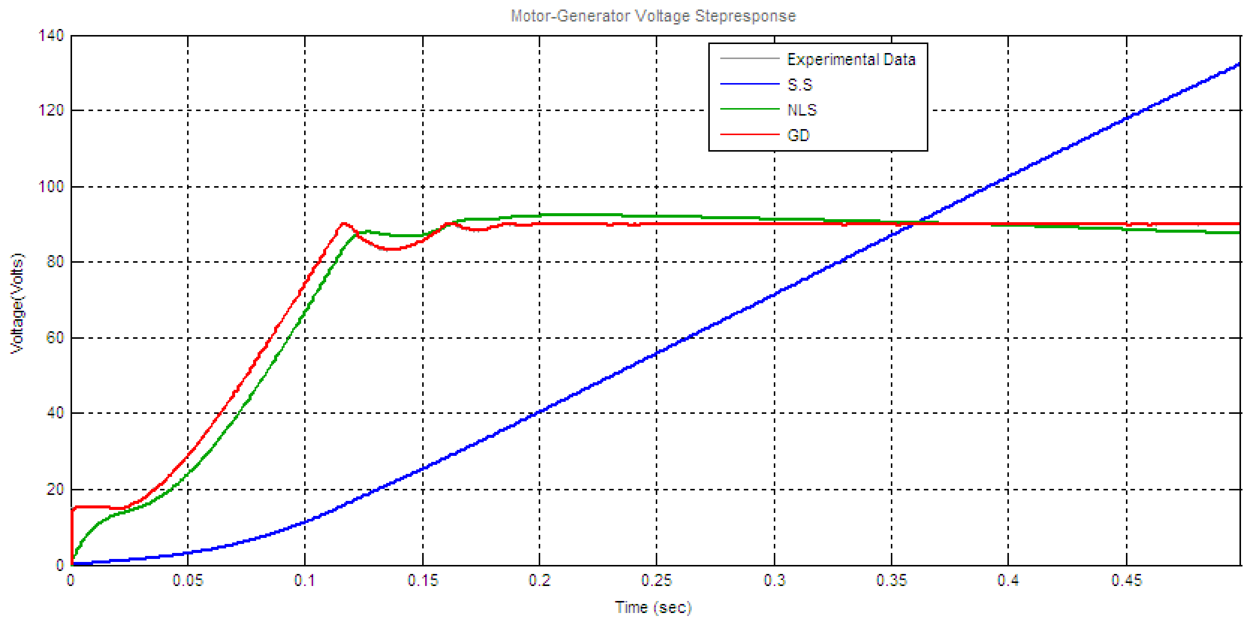

Figure 6: Voltage Response for the Actual and Estimated Models

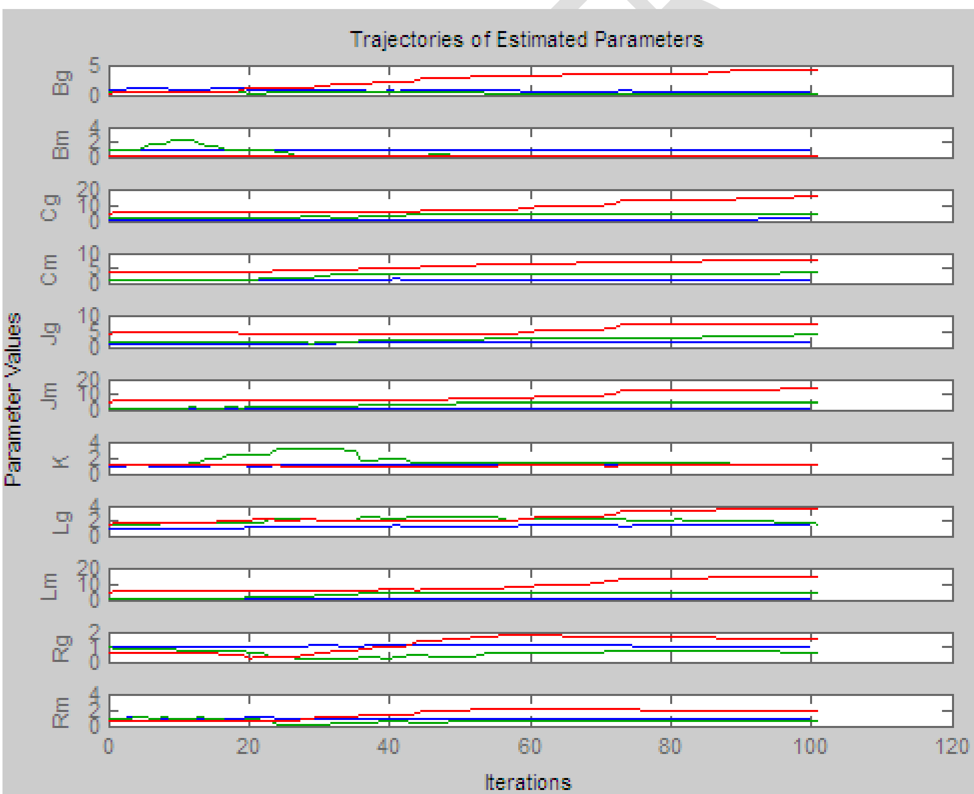

Figure 7: Trajectories for Parameters

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 3:Parameter Estimation Results

					Estimation on Three Algorithms		
Symbol	Name	Initial Guess	Min Set Value	Max Set Value	S.S	GD	NLS
B_g	Generator Viscous Friction	1	0	+infinity	4.137	0.012	0.545
B_m	Motor Viscous Friction	1	0	+infinity	0.013	0.004	0.844
C_g	Motor Capacitances	1	0	+infinity	15.055	4.649	1.288
C_m	Generator Capacitances	1	0	+infinity	7.867	3.384	1.304
J_g	Generator Moment of Inertia	1	0	+infinity	7.112	4.105	1.398
J_m	Motor Moment of Inertia	1	0	+infinity	13.898	4.935	0.966
K	Torque constant	1	0	+infinit	1.127	1.194	1.077

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L_g	Generator Inductances	1	0	+infinity	3.635	1.576	1.371
L_m	Motor Inductances	1	0	+infinity	14.579	4.287	0.368
R_g	Generator Resistances	1	0	+infinity	1.563	0.636	0.940
R_m	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

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

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

11. 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	$C(F)$	$V(V)$	$B \frac{Nm}{rad}$ /sec	$J(Kgm^2)$	K	$L(H)$	$i(A)$	$R(\Omega)$	$T(Nm)$	$\omega(rad/s)$
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	$B\ (\frac{Nm/rad}{s})$	$C(F)$	$J(Kgm^2)$	K	$L(H)$	$R(\Omega)$	$\omega(rad/s)$	$V(V)$	Excess Voltage
1	4.14	15.06	7.11	1.13	3.64	15.06	10.62	12.00	0
2	4.14	15.06	7.11	1.13	3.64	15.06	21.24	24.00	12
3	4.14	15.06	7.11	1.13	3.64	15.06	31.86	36.00	24

4	4.14	15.06	7.11	1.13	3.64	15.06	42.48	48.00	36
5	4.14	15.06	7.11	1.13	3.64	15.06	53.10	60.00	48
6	4.14	15.06	7.11	1.13	3.64	15.06	63.72	72.00	60
7	4.14	15.06	7.11	1.13	3.64	15.06	74.41	84.00	72

12. Conclusion

Three method 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 are found to be in agreement 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. Identificationprocess was built and done using the MATLAB. More work can be done using microcontrollers controllers and digital signal controllers.

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