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PARAMETER ESTIMATION OF EXCITATION SYSTEM CONNECTED TO SYNCHRONOUS GENERATOR

Engineering

KEYWORDS: estimation, excitation, simulation, optimization.

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ABSTRACT

This paper presents the novel approach in developing a methodology to simplify the process of parameter estimation. The process involves two parts; namely simulation and optimization. In the simulation process, the AC1A and AC8B excitation system models have been implemented in MATLAB/simulink. In the optimization process, the suitable parameters are searched by formulated the problem as a least square problem and applied Damped Gauss-Newton method (DGN) and Levenberg-Marquardt (LM) such that with the given same input, the simulation output should match the field data from the machine. We also determined that the process of parameter estimation of excitation systems is to try DGN method first and, if the simulation response does not match the measured response well, try LM method to get better initial parameters, and then try DGN again.

1. Introduction

The power system planning and design problems are addressed mostly by performing system simulations in time domain. Fairly standard models have been developed earlier to represent the system component for these studies – generators, transmission lines and loads. The most common studies are small signal, transient and dynamic stability analysis. The main challenges using simulation tools is the data required to represent the system components. The results are only as accurate as the underlying models and data used in the computer analysis. The generators are the most important components in this analysis. There are three main components of a generator, which are the synchronous machine, prime mover (turbine/governor) and the excitation system. Among these components, the excitation system plays a critical role of providing field current to the generator. Models are usually provided by manufacturers or industry standards, such as IEEE standard [4] [2], which are in frequency-domain representations. The standards also provide "typical" values for each model. These standards provide suitable models for different "types" of excitation systems. Currently it is quite common that in system studies, without any actual data, the engineers have to choose one of these sources to get the model parameter data they need for system studies. The manufacturers of the excitation systems provide data for their excitation systems. Another common problem is that the models available on the commercial software used for the study, such as PSS/E®, may not have the same model provided by the manufacturer. The need for more accurate equipment models and model parameter identification has been recognized by organizations responsible for system reliability, such as the (NERC) [1]. The engineer has to translate the data from one model to another "similar" model. The resulting models provide a much more accurate representation of generator/excitation system dynamic performance in computer simulations. NERC requires unit-specific dynamics data for the dynamic simulations performed by Transmission Planning organizations. Some of the benefits of improved models are as follows.

- Better assessment of a generator's dynamic stability margin.
- More confidence in simulation results
- Compliance with existing and future NERC reliability data requirements.
- Better assessment of a generator's transient stability margin.

Moreover, parameters change due to retuning, aging, and equipment changes. Model parameters, either manufacturer specified or "typical" values may be grossly inaccurate. Therefore, tools and methods are needed for deriving model parameters from staged tests on the units. Staged field tests, which provide sufficient information to identifying the parameters, are divided into two groups [1]. One is collecting steady-state measurements, which includes the open circuit saturation curve measurement and online measurements. The former one is the measurement of terminal voltage, field voltage and field current when the generator field excitation is varied. And the later ones are taken at different load level, the typical points of which are recorded at certain level when the reactive power output changes due to variation of generator field data. But for brushless excitation system, only terminal voltage can be measured. The other step is obtaining the dynamic response and the purpose of the dynamic tests is to provide a simple and safe disturbance to excite the system. The traditional way to "tune" the parameter is to have skilled engineers select initial parameters, calculate the difference between measured output and simulation output, and adjust the parameter to reduce the difference. As a result, the parameter derivation program is needed to simplify the process. However, the method requires familiarities with the equipment functions and the effects of the change of parameters toward the dynamic response.

2. Estimation using simulation(Simulink)

Simulink is a graphical tool useful for modeling, simulation as well as analysis of dynamic systems, in which the systems can be represented by blocks in frequency domain. With the initial parameters, when the structure of a system is decided, the simulation can be implemented by simply drawing the blocks from the library to Simulink window, connecting them and clicking the "run" button. Most of the blocks with certain functions can be found in Simulink library, a database in MATLAB, and users can write their own ones by using the "s-function" blocks. Here two models have been implemented namely AC1A excitation system and AC8B excitation system using Simulink library. Progress Energy gave us the data from "bump test", we are using the data to test the method for parameter estimation. The excitation system gets the terminal voltage as the feedback from generator and provides the excitation voltage to the generator. To accurately represent the excitation system, it is necessary to have adequate model structures and suitable parameter values. Models are usually provided by manufacturers or industry standards, such as IEEE standard [4][2], which are in frequency-domain representations (LaplaceTransform transfer functions).

2.1 Excitation system models

In order to estimate the parameters of excitation system two models have been implemented namely AC1A excitation system and AC8B excitation system using Simulink library.

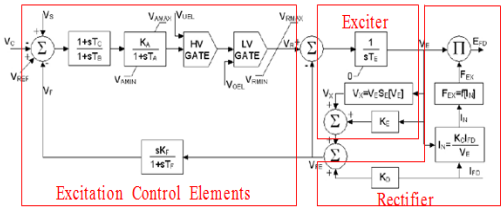

Fig 1: Partial AC1A Excitation System

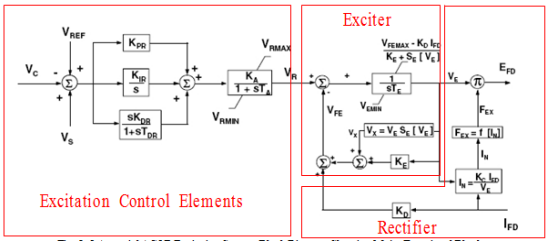

Fig 2: Partial AC8B Excitation System

Fig1 represents a partial AC1A Excitation System Block Diagram Showing Major Functional Blocks whereas the Fig2 represents the partial AC8B Excitation System Block Diagram Showing Major Functional Blocks

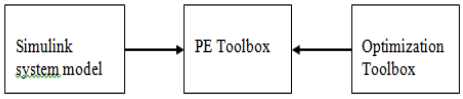

Fig 3: A sketch map showing how PE toolbox works

By selecting *various input parameters* we build different models such that the result obtained from the excitation system simulink model (AC1A, AC1B) approach almost nearer to the result obtained from the system using bump test parameters. The two models, AC1A and AC8B represents an Alternating Current (AC) type excitation system. The stage test involves applying a step change in the set point of the excitation system, which determines the terminal voltage of the generator, and the response obtained is the output, the terminal voltage of the generator. This test is referred in practice as the "bump test". The problem hence is to estimate the parameters of the selected model such that the response of the model will match the stage test results as closely as possible. "A comparison of the simulation output and the desired one is displayed for each successive pass of the optimization process."

3. Optimization

In the optimization process, the suitable parameters are searched which is then feed into the . This is achieved by formulating the problem as a least square problem and applied Damped Gauss-Newton method (DGN) and Levenberg-Marquardt (LM) such that for the given same input, the simulation output should match the field data from the machine

3.1 Parameter Estimation using Least Square Method

As discussed earlier, the whole problem was formulated as a least square problem and applied DampedGauss-Newton method (DGN) and Levenberg-Marquardt(LM) method to solve it. Since we want the simulation output of excitation model to follow the measured response at each time point, we can model the problem as a least square problem. To solve this least square problem, we tried the Damped Gauss Newton method and Levenberg Marquardt method, which are two basic method for non-linear optimization problems, to get the local solution of the least square problem.

3.1.1 Algorithm

when the Micro processor is initialized it checks all the input output ports to initialize them then it checks for the open or closed condition of the circuit breaker if it is in open circuit condition the it keeps checking for closed condition, then it sends the signal to the multiplexer to switch on S1 to get the current in the line. Then it starts conversing the signal to ADC till the conversion is completed after the completion of conversion it reads the value of the line current. Now if the value of the current value is less than zero then it calls for the delay time for relay to operate and after the delay time it sends the signal to relay to trip. Otherwise it sends the signal to multiplexer to switch S2. The above process keeps on continuing. After the whole process is completed the Microprocessor jumps again to third step and checks for the Relay condition.

3.1.1 Gauss Newton method [10]

Steps of Gauss-Newton method

- set $x_c = x_0$.
- While $\nabla f(x_c) > \tau_r \tau_0 + \tau_a$ & iteration < iteration_max. ($\tau = (\tau_r, \tau_a)$ is the termination criteria)

(a) Compute the step s

(b) $x_t = x_c + s$

(c) Compute $\nabla f(x)$

The Gauss-Newton(GN) algorithm computes the step s as

$$s = -(R'(x_c)^T R'(x_c))^{-1} \nabla f(x_c) = -(R'(x_c)^T R'(x_c))^{-1} R'(x_c)^T R(x_c)$$

where R' is the Jacobian of R.

3.1.2 Damped Gauss-Newton method

The Gauss-Newton (GN) direction is a descent direction, but the GN method do not have a good global convergence performance. When the initial iteration is near the solution, it dose not suffer from poor scaling of f and converges rapidly. However, when far away from the solution, the Hessian of GN may not be positive definite and the method will fail. To apply the Gauss-Newton method to a global convergence problem, the combination of Gauss-Newton direction with Armijo rule is made, which is called damped Gauss-Newton.

Steps of Damped Gauss-Newton method

1 $x_c = x_0$.

2 While $\nabla f(x_c) > \tau_r \tau_0 + \tau_a$ & iteration < iteration_max. ($\tau = (\tau_r, \tau_a)$ is the termination criteria)

3.5 Levenberg-Marquardt Method

The damped Gauss Newton algorithm is effective when used for solving zero residual and small residual problems. But it may fail when the condition number of the matrix is to small. Therefore, for the medial residual problems, Levenberg- Marquardt method is chosen. The Levenberg-Marquardt methods add a regularization parameter $v > 0$ to $\{R'(x_c)^T R'(x_c)\}$ in determining the step s $s = -(v_c I + R'(x_c)^T R'(x_c))^{-1} R'(x_c)^T R(x_c)$ where I is the $N \times N$ identity matrix. The matrix $v_c I + R'(x_c)^T R'(x_c)$ is positive definite. And again, if combining the Levenberg-Marquardt with Armijo rule, it become a globally convergent method for the over determined least squares problems.

4.0 Results

Bump test result from progress energy

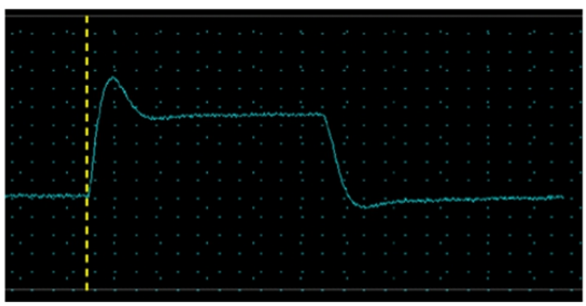

Fig 4 : Data plot of responses of bump test from Progress Energy

the Matlab PE Toolbox has been used to estimate the parameters based on the bump test results given in Fig. 4. (Blue line) The robust option has been used for the solution. Cost function shows the difference between the simulation output and measured output. And the step size shows convergence speed. As shown in the figure, the optimization terminated for the step size is too small, which means the program cannot find a good enough solution before it converged.

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4.1 AC1A excitation system result

The response with typical parameters of AC1A excitation system is obtained as

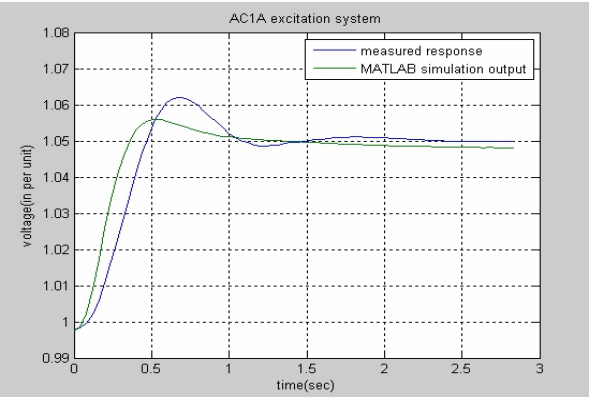

Fig 5: Model response with typical parameters of AC1A excitation system

4.1.1 Parameter Estimation Using Matlab PE Toolbox

The Matlab PE Toolbox has been used to estimate the parameters based on the bump test results given in Fig. 5. (Blue line) The robust option has been used for the solution.

Figure 6, shows the iterations that were taken

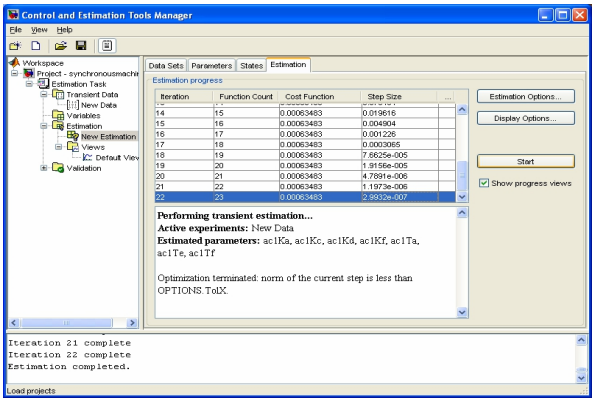

Fig 6: Cost function and step size of each iteration with typical parameters of AC1A excitation system

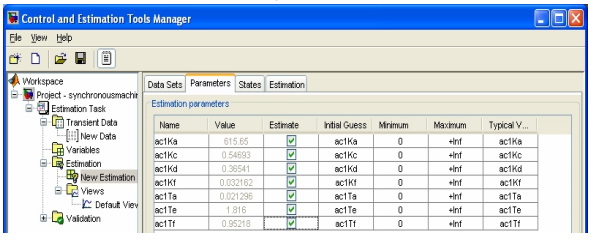

Fig 7: Estimated parameters of AC1A excitation system starting from typical parameters

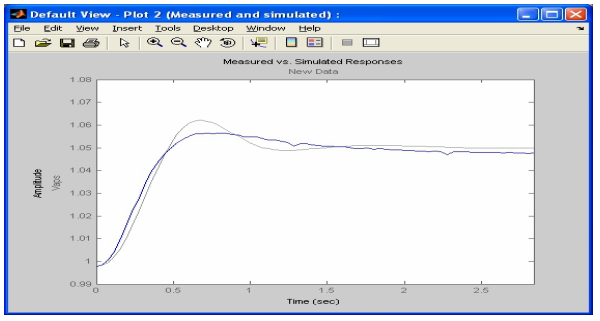

Fig 8: Final terminal output of generator with typical parameters of AC1A excitation system

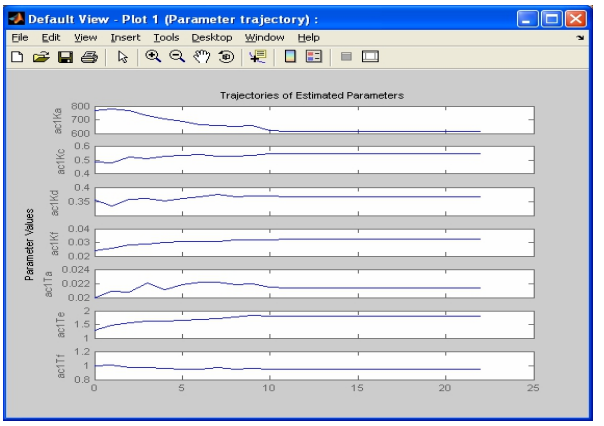

Fig 9: Parameter trajectory when estimating parameters of AC1A excitation system

4.2 AC8B excitation system result

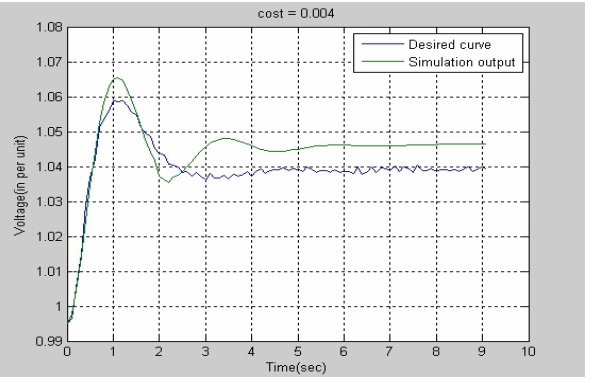

Fig 8: Model response with good parameters of AC8B excitation system (Data Unit 1)

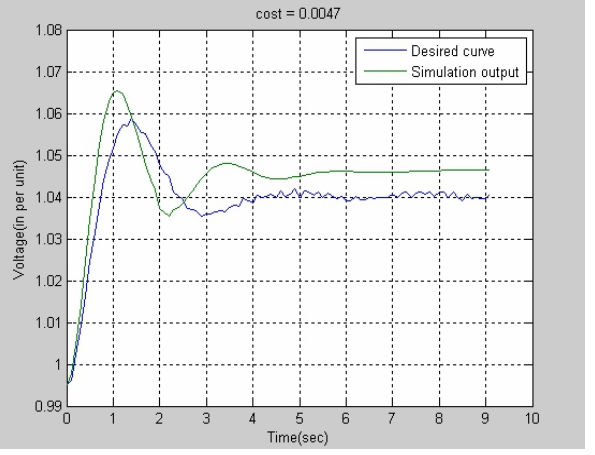

Fig 9: Model response with good parameters of AC8B excitation system (Data Unit 2)

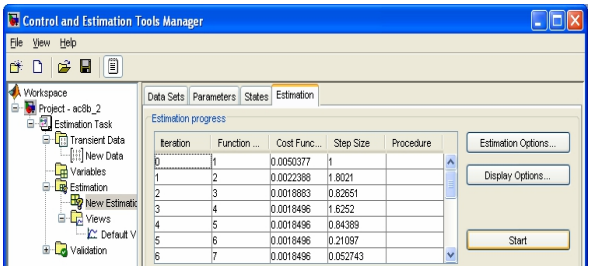

Fig 10: Iterations, cost function and step size of each iteration

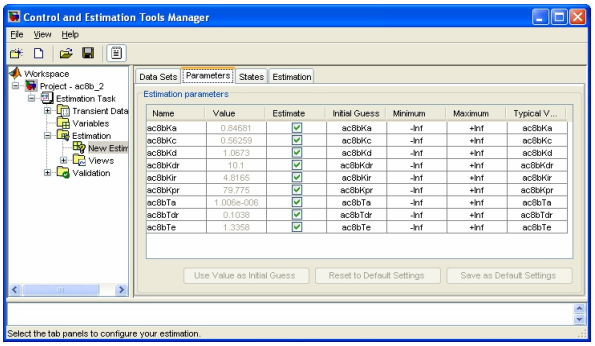

Fig 11: Estimated parameters of AC8B excitation system(Unit 1)

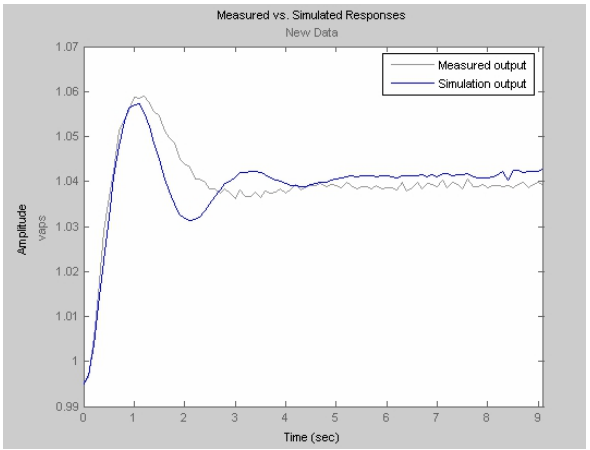

Fig 12: Final terminal output of generator when estimating AC8B excitation system (Grey - Desired curve, Blue - Simulation output)

4.3 Optimization result

4.3.1 Damped Gauss Newton Method

The damped Gauss Newton Method which has been implemented in MATLAB has been used to estimate the parameters, using the same initial parameter values which yielded the following values

Norm(gc)	fc	Armijo Iter.	Iterations
74.8970	0.0040	0	0
64.3266	0.0022	0	1
58.5847	0.0015	1.0000	2
254.7465	0.0008	0	3
212.7478	0.0008	0	4
4.2138	0.0001	0	5
9.9908	0.0001	0	6
17.6911	0.0001	3.0000	7

Fig 13: Iteration history of parameter estimation of AC8B starting from good initial parameters using DGN

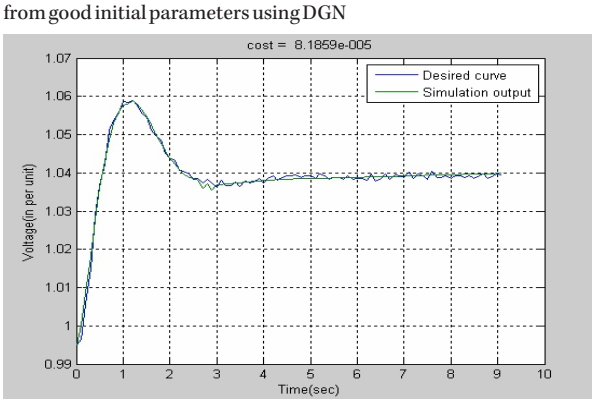

Fig 14: Final terminal output of generator when estimating AC8B excitation system with DGN parameters

4.3.2 Levernberg Marquardt method

Table below shows the history of the iteration when using Levenberg Marquardt

Norm(gc)	fc	Trust region test itr.	Iterations
0.0114	0.0096	1.0000	6
0.0114	0.0046	2.0000	7
0.0114	0.0046	1.0000	8
0.0312	0.0046	1.0000	9
0.0312	0.0046	1.0000	10
0.0312	0.0046	1.0000	11
0.0312	0.0046	1.0000	12
0.0312	0.0042	5.0000	13
0.0312	0.0042	1.0000	14
0.0312	0.0042	1.0000	15
0.0065	0.0042	1.0000	16
0.0065	0.0042	1.0000	17
0.0065	0.0042	1.0000	18
0.0065	0.0042	1.0000	19
0.0065	0.0034	2.0000	20

Fig 15: Iteration history of parameter estimation of AC1A starting from high parameters using LM

The results obtained are:

Xmodel_LM =

ac1Ka	ac1Kf	ac1Te	ac1Tf	ac1Ta	ac1Kc	ac1Kd
751.1027	0.0266	2.7584	1.3613	0.0262	0.6049	0.4179

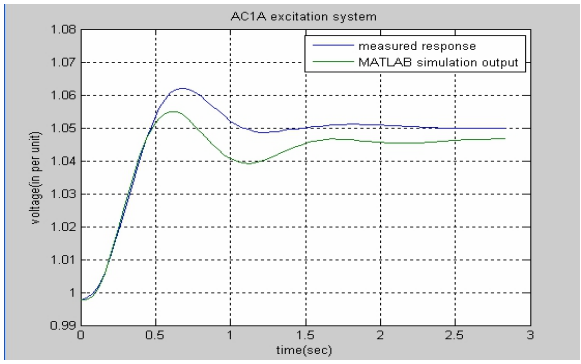

Fig 16: Final terminal output of generator starting from high parameters using LM

From the history, we can see the method did not totally settle down before it converge, so the solution will not be the best point. Fig. 4.21 tells us the settle points are different in both of the curve, which prove that the solution from LM is not good enough. Also, observed from the plot of each iteration, we found that, the simulation output become closer and closer to the measured one as it started, but after getting to some point, it will suddenly change back to a bad shape and try get closer again. We may improve our program by choosing the best solution in the iterations as the solution.

4.4 Final plot of AC1A and AC8B excitation system models

Here the simulations are performed in MATLAB and both the results of AC1A and AC8B are analyzed using MATLAB and they are presented above. There may the difference in the waveforms but the results matches with desired outputs i.e; the third peak in both the analysations is same.

The final plot of AC1A and AC8B excitation models is shown in figures 17, 18

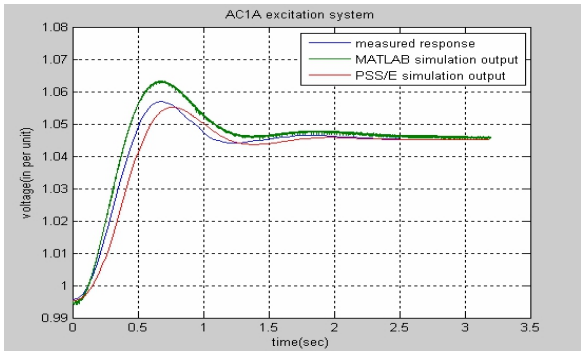

Fig 17: Simulation outputs of AC1A excitation system in MATLAB and PSS/E with the final optimum parameters

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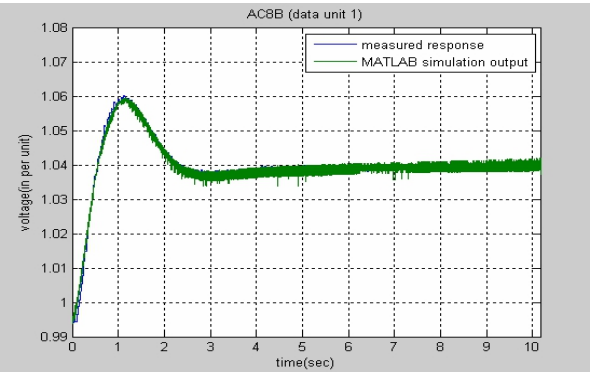

Fig 18: The final plot when estimating the parameters of AC8B excitation system

5. Conclusion

This thesis has laid out a new approach to estimate the parameters of AC excitation systems. The parameter estimations of AC1A and AC8B excitation system are presented as the application of the developed program. MATLAB/Simulink is used for providing the simulation output with certain parameters and the program of Damped Gauss-Newton and Levernberg-Marquardt is used to do the optimization and provide a new guess of parameter values to the simulation tool. The iteration of the program will stop when either the difference between simulation output curve and desired curve is less than the tolerance that has been set before or the number of iteration time has reached the decided maximum iteration time. There are two methods using in five different cases, MATLAB Parameter Toolbox and MATLAB proto type codes. The previous method is convenient and user-friendly. And by using the later one, we can choose different algorithms and make more advanced developments.

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