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CALCULATION OF AVR PARAMETERS USING NEURAL NETWORK TO ENHANCE THE POWER SYSTEM STABILITY

Dr. Basim Talib Kadhem
University of Basrah
Collage of Engineering
Department of Electrical Engineering
basim72_sh@yahoo.com

MSc. student Yasir Flayyih Hasan
University of Basrah
Collage of Engineering
Department of Electrical Engineering
eng.yasir.flaih@gmail.com

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Abstract

In this paper a parameter optimization method using a neural network is suggested for finding the optimum control gains of a proportional deferential (PD) controller which it is used to control the excitation of the synchronous generator. In this work one PD controller and three D controllers has been used which it is mean five gains to be found which it is a very hard work to find it manually. The neural network has been used to automate the way in inding this gains which it was manually calculated until the desired plant output has been obtained. The controller gains which it is manually calculated has been compared with that calculated with neural network with MATLAB program and the performance has been simulated and compared.

Keywords: Power System Stability, Excitation Current Control, Neural Network.

حساب معاملات منظم الفولتية التلقائي بأستخدام الشبكة العصبية لتحسين استقرارية منظومة القدرة الكهربائية

م.د.باسم طالب كاظم
جامعة البصرة / كلية الهندسة / قسم الكهرباء

المهندس ياسر فليح حسن
جامعة البصرة / كلية الهندسة / قسم الكهرباء

الخلاصة

في هذه الدراسة تم استخدام الشبكة العصبية في حساب افضل معاملات للمسيطر من نوع تناسبي تفاضلي الذي تم استخدامه للسيطرة على تيار الاثارة في المولد التزامني. في هذا العمل تم استخدام مسيطرين من نوع تناسبي تفاضلي و مسيطر واحد من نوع تفاضلي وهذا يعني ان هناك خمسة معاملات لحسابها والتي هي عملية صعبة جدا للقيام بها يدويا. تم استخدام الشبكة العصبية ليعمل اوتوماتيكيا على ايجاد هذه المعاملات التي كانت تولف يدويا حتى يتم الحصول على الخرج المطلوب من المولد. تم مقارنة النتائج التي تم الحصول عليها باستخدام الشبكات العصبية مع تلك التي تم الحصول عليها عن طريق توليف المعاملات يدويا باستخدام برنامج الماتلاب ولقد تم عن طريق هذا البرنامج محاكات اداء كلا النظامين ومقارنتها.

الكلمات الرئيسية: استقرارية منظومة القدرة, السيطرة على تيار الاثارة, الشبكة العصبية.

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1. Introduction

A need for reliable and economic operation of power system led to interconnect the synchronous generator in the same plant or among plants in a wide area. The oscillation existed as soon as the synchronous generator has been connected together in the electrical network. The oscillation of small frequency topically of (1-3) Hz is described as hunting of synchronous machine **(Bikash Pal & Balarko Chaudhuri 2005).** The oscillation of the electromechanical coupling between the rotor and the rest of the system can be described as the pendulum motion which it is suffers from oscillatory acting following any disturbance from its nominal state **(John J. Grainger & W.D. Stevenson 1994).** The oscillations were found to be due to lack of damping of mechanical mode of the interconnected systems **(Bikash Pal & Balarko Chaudhuri 2005).** The additional damping can be provided by controlling the excitation system by adding an automatic voltage regulator (AVR).The fast evolution in the excitation techniques (like static excitation with power electronic devices) and its control ways (like P, PD, PID, and etc) helps the power system to enhance its stability **(Dr. J. Kumar, P. Pavan Kumar, A. Mahesh & A. shrivastava 2011).** The new excitation systems and controllers still suffer from the need to specify its gains by an efficient way because the deviations in these gains from the optimum value by a specific range may make the AVR to enhance the system instability **(IEEE guide 1990).** So the gains of the AVR should be specified by an automatic way rather than manual or mathematical calculation ways like Ziegler and Nichols method for tuning the control gains of PID controller **(K. Ogata 1997).**many researches have been made to automate the gain selection problem and many algorithms have been proposed. In **(M.G McArdle, D.J. Morrow & P.A.J. Calvert 2001)** fuzzy PID controller was proposed but the fuzzy algorithm need rules to be defined and membership functions to be selected. In (**S.H. Hosseini, R. Rohnavart & H. Kharratti 2009)** genetic algorithm was proposed to tune the PID controller but genetic need a fitness function to be defined and this is not easy job. Neural network has been used also to tune PID controller either combined with fuzzy like in **(Ms.M. Uma Vani, Dr.G.S. Raju & Mr.K.R.L Prasad 2009)** or alone like in **(V.S. Sundaram & Dr.T. Jayabarathi 2011)** but first one still suffers from the problems of fuzzy controller and in second one only one PID controller has been tuned. The finding of a set (5 gains here) of control gains of many controllers acts together and gives acceptable results may be impossible by the manual methods. A neural network has been used here to automate this process. The paper is ordered as follows: Section 2 describes the system model and the study objective, Section 3 gives a brief introduction to the neural network, the design procedures are given in section 4 and section 5 is dedicated to the evaluation of controller performance.

2. System Model and Study Objective:

When generating station transmitting power over long distance to a load center then the system can be simplified in to a single machine connected to an infinite bus throw transformer and transmission line (SMIB) as shown in **Figure 1** if and only if the attention to be paid to the local mode of oscillation **(Dr. J. Kumar, P. Pavan Kumar, A. Mahesh & A. shrivastava 2011).**

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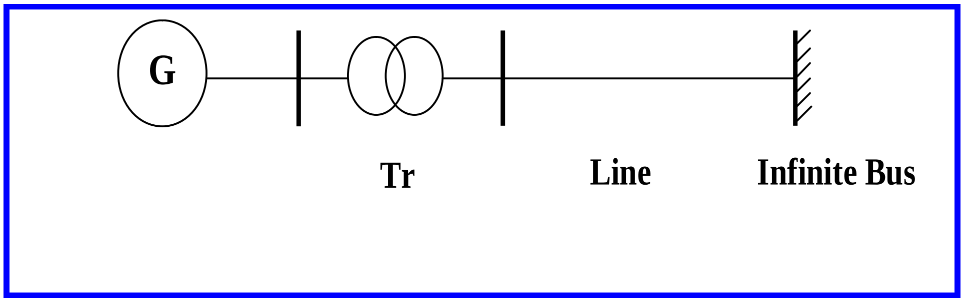

Fig.1 : System Configuration.

The synchronous machine considered her has three windings as stator windings and has one field winding and two damper windings. The excitation considered her is extracted from IEEE STA1 type and provided with an AVR known as strong action regulator as shown in following block diagram **(Figure 2).** The objective of the work is to design a multilayer neural network to give the gains (K_{ou}, K_{1u}, K_{ow}, K_{1w} & K_{if}) of the excitation PD controllers to enhance the static and dynamic stability of the power system. Note that **Figure 2** contains another variable (K_w) which it is constant and equal 1(K_w =1).

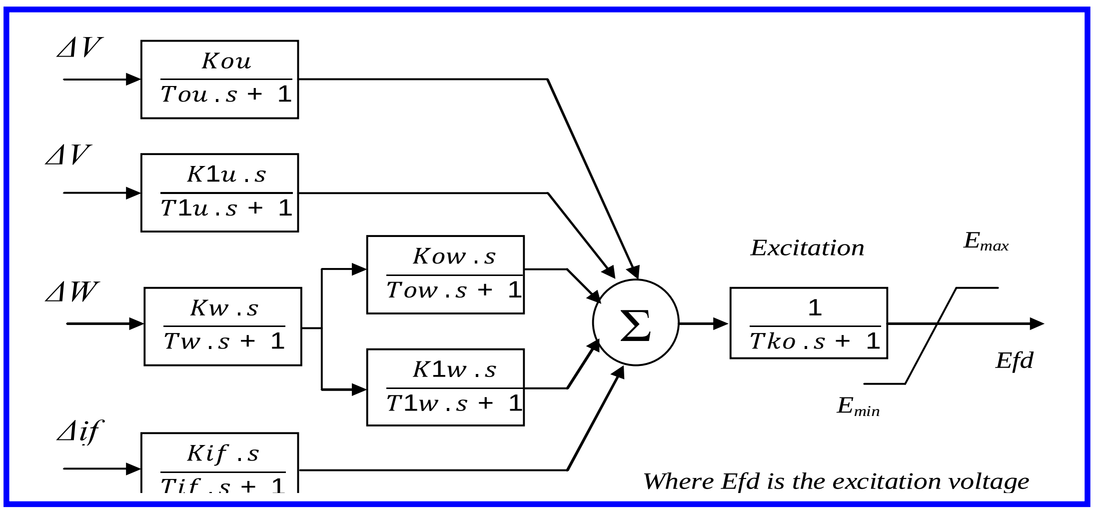

Fig.2: A block Diagram of AVR and Excitation Systems.

Where $T_{ou}, T_{1u}, T_w, T_{ow}, T_{1w}, T_{if}$ & T_{ko} are a time constants and $\Delta V, \Delta W$ & Δi_f are the change in voltage, frequency and excitation current respectively. The power system is highly nonlinear system but it can be linearized around an operating point which it is called the nominal operating point **(Li Yan 2011).** And the linearized system of equations will be expressed in state-space (SS) representation as (A_0, B_0, C_0 and D_0) with the following two equations:

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$x^{\cdot} = A_O.x + B_O.u$..eq.(1)

$y = C_O.x + D_O.u$..eq.(2)

Where:

x = state vector, u = input vector & y = output of the system.

A_0, B_0, C_0 & D_0 matrices describing the system performance (see appendix for more detail about x, y, A_0, B_0, C_0 & D_0). For more information about the driving of SS form of power system the reader referred to one of the very good references on this objective **((P. Kundur 1994)**, **(P.M. Anderson 1994) & (Chee-Mun Ong 1998))**. The state-space (SS) is a modern control method which states that if the nonlinear system can be expressed in a form of differential equations then the state space theory can linearize it around an operating point and represent it by four matrices (A, B, C & D) **(U. A. Bakasi 2008).** As mentioned above the aim of this paper to design a multilayer neural network to give the gains (Kou, K1u, Kow, K1w & Kif) of the excitation PD controllers.

3. Neural Network Introduction

A neural network NN is a computational network taking from a biological model consisting of many computational units called neurons **(Howard Demuth & Mark Beale 1998).** The NN has many advantages like adapting itself, and learning with part of data and generalized it to all data ranges and other practical properties. The NN arranged in layer form first layer is called the input layer the last layer is called the output layer any layer in between these two layers is called hidden layer. Each neuron can perform a function like sigmoid and pure line. The experiment shows that a NN with one sigmoid function as a hidden layer and an output layer with pure line function can approximate any function **(Howard Demuth & Mark Beale 1998).** In this paper the work will be divided into three steps first train the NN to approximate the plant work second connect the controller with the trained NN and train the controller alone. At the end separate the controller and take its average output.

Controller design:

First step:

As said above that the experiment shows that a NN with one sigmoid function as hidden layer and an output layer with pure line function can approximate any function **(Howard Demuth & Mark Beale 1998).** Here the same structure will be used with 5 neurons in the hidden layer and one neuron in the output layer to approximate the step response of the plant as can be seen in **Figure 3**.

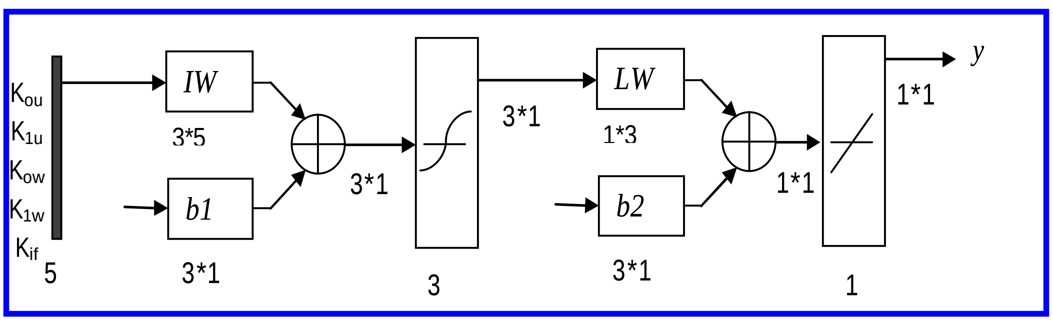

Fig.3: A Block Diagram of the NN (Plant)

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Where *IW & LW* are the input and hidden layer weight matrix respectively and b1 & b2 are the input and hidden layer base vectors respectively. The neural network will be trained by Fletcher-Reeves method with hybrid bisection- cubic line search (for more details see reference **(Howard Demuth & Mark Beale 1998)). Figure 4** shows the step response of the original plant function red line and its approximation by neural network the blue line.

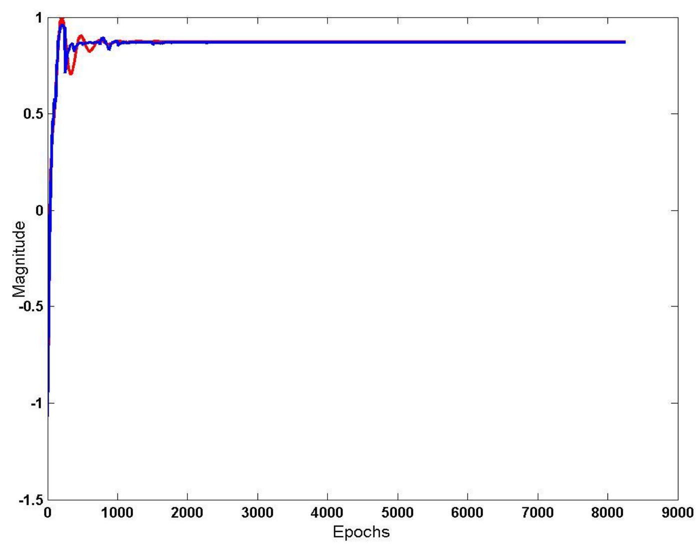

Fig.4: the NN Tracking (Blue Line) to the Step Response of the Plant (Red Line).

In the above Figure **(Figure 4)** the blue line represents the output (y) of **(Figure 3)** and shows the good tracking performance of the neural network.

Second step:

The previously trained NN will be connected with a new NN as shown in **Figure 5**. The new NN will be consisted of input layer, one hidden layer with sigmoid function and output layer with linear function as shown in **Figure 5**.

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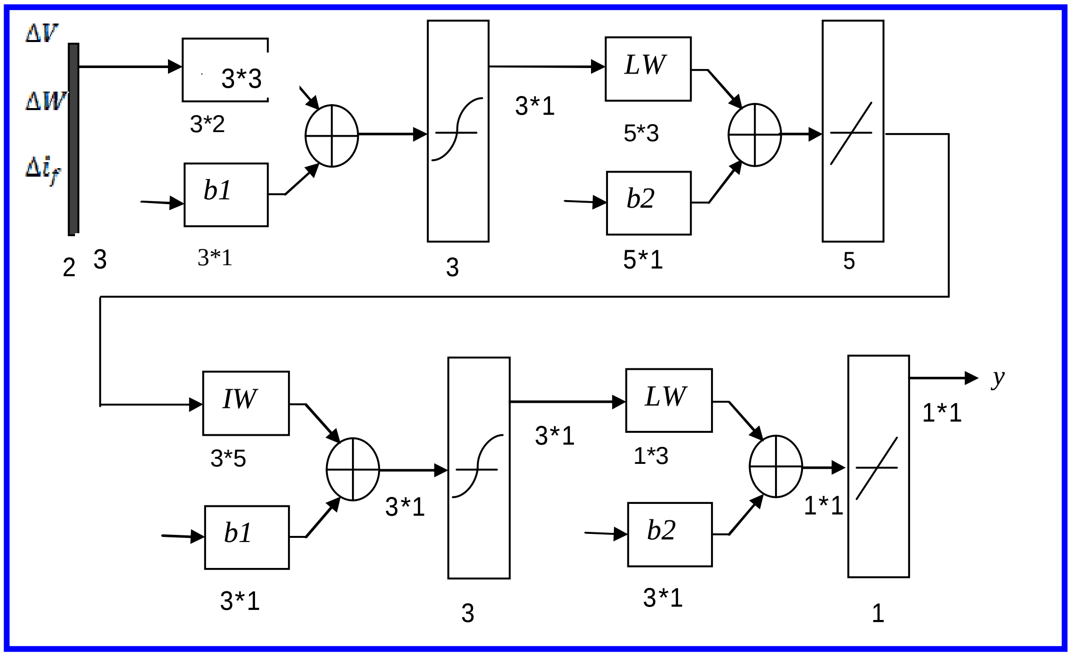

Fig.5: A Block Diagram of the Complete NN (Plant+ Controller).

Where the three inputs to the new neural network are assumed to be the range of change in the terminal voltage, frequency and excitation current which are defined by the following ranges.

$\Delta V = [-0.5, 0.5]$
$\Delta W = [-1, 1]$
$\Delta i_f = [-0.3, 0.3]$

Which they are decided from simulating the machine under normal and abnormal conditions. The new NN will be trained to perform the controller work. The same function will be used for training and line search function to train the network. The response of the overall NN can be seen in **Figure 6** which shows good tracking performance for the step response of the real system. Some error can be seen in the first few epochs but after that the two lines can be considered identical to some extent tolerance as it clearly can be seen in **Figure 6**.

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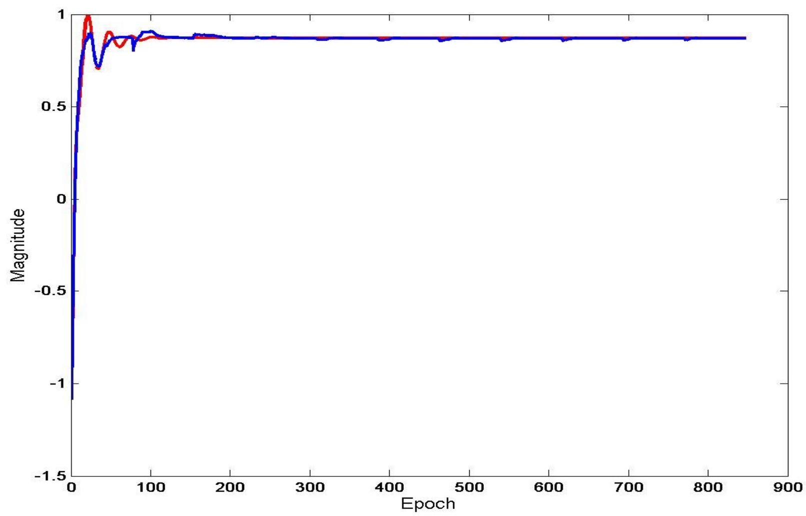

Fig.6 : NN Tracking with the Controller to the Step Response of the Plant.

Where the blue line in **Figure 6** represents the output (y) of **Figure 5.**

Third step:

Disconnect the controller NN and gate its outputs. The outputs of this NN will be the gains of the PD controller of the synchronous generator exciter. The gains will be as can be seen in **Table 1**.

Table 1: PD controller New Gains.

K_{ou}	K_{1u}	K_{ow}	K_{1w}	K_{if}
-14.856	-3.4305	0.73572	0.72383	-0.61202

4. Results and Discussion

Here the static and dynamic stability will be studied. The static stability will be studied from the location of the Eigen values and the damping ratio (ζ) point of view. The damping ratio (ζ) is used to measure the rate of decay of the signal's oscillation.

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$$\varepsilon = \frac{\sigma}{\sqrt{(\sigma^2 + \varpi^2)}} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq.(3)$$

σ = is the real part of the Eigen value.
ω = is the imaginary of the Eigen value.

The damping ratio for the system with the PD gains calculated with the analytical method will be compared by that which it is gotten by NN.The comparison has been listed below in **Table 2**. Our concern is the eigen value with a frequency less than or equal (10 rad). (For more information about the PD gains values see appendix of this paper).

Table 2 The Eigen Values and its Damping Ratio.

Eigen value		Damping ratio	
analytic	NN	analytic	NN
-10.87± 9.9614i	-11.295 ±6.5391i	73.72%	86.54%
-1.2786 ± 6.3476i	-2.3096 ±1.9225i	19.75%	76.86%

For the dynamic stability of the plant, the response of the plant to a 3 phase fault and a duration 0f (0.2 sec) in the machine terminal will be studied here.

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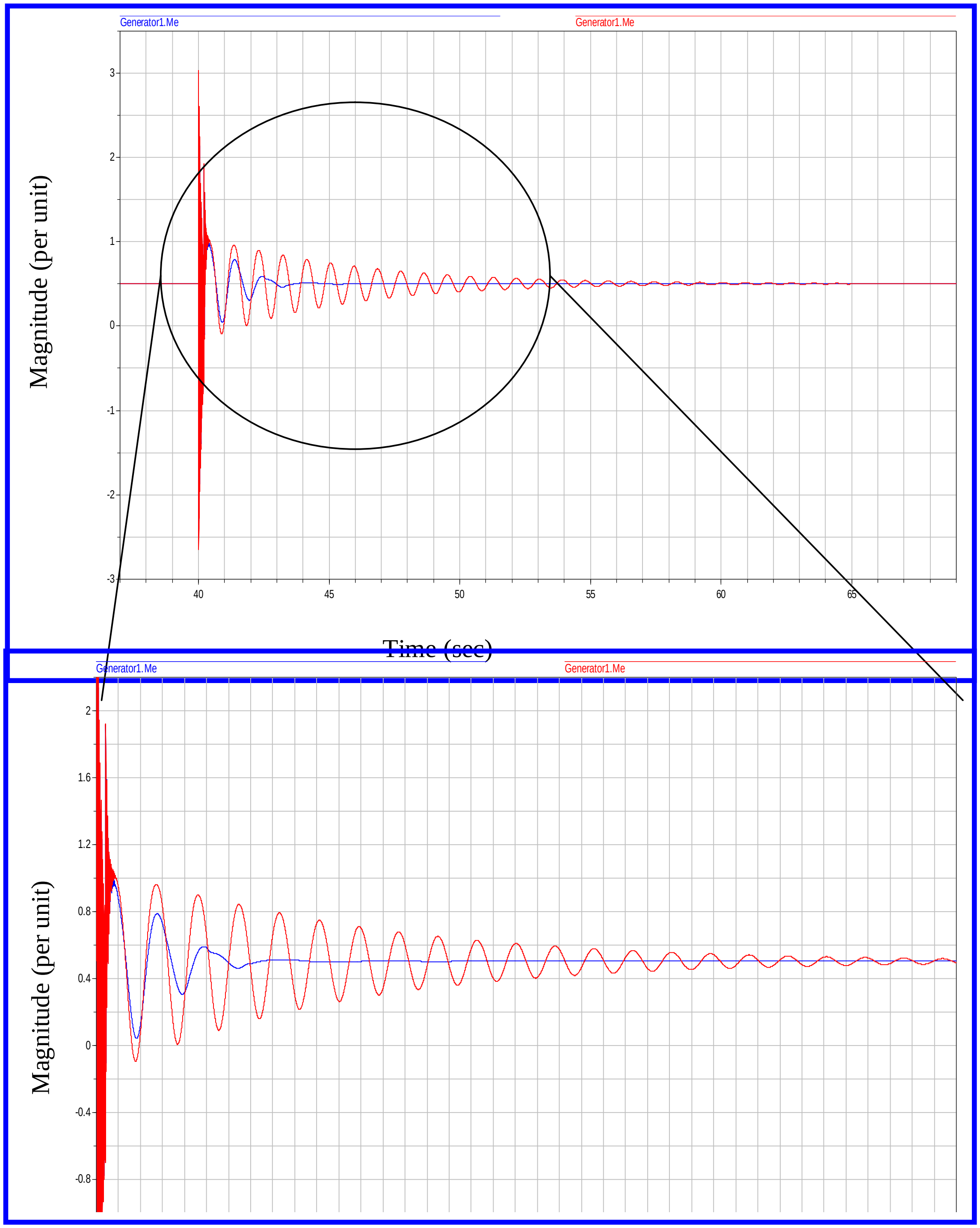

Time (sec)

Fig. 7: The Electromagnetic Torque.

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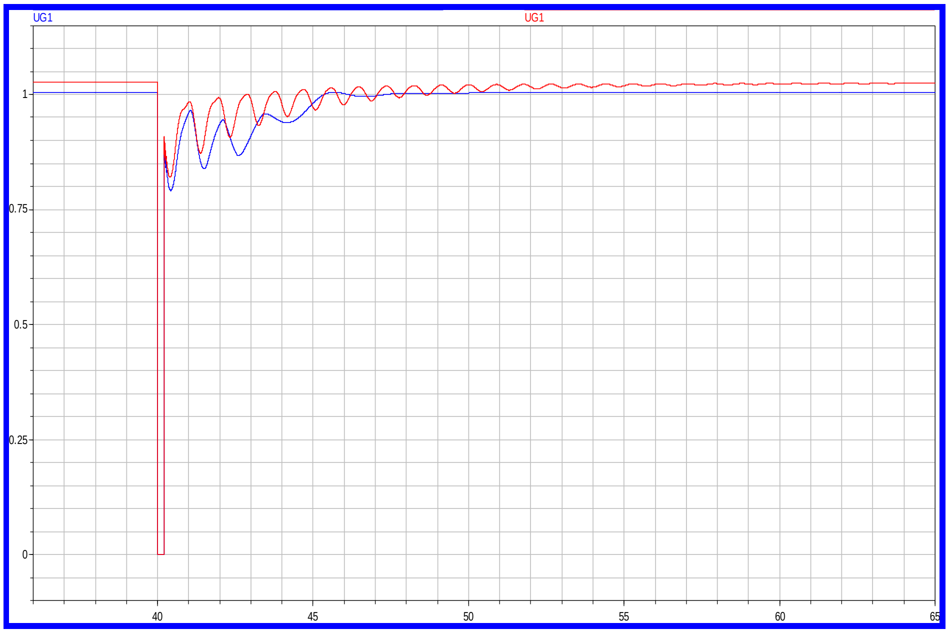
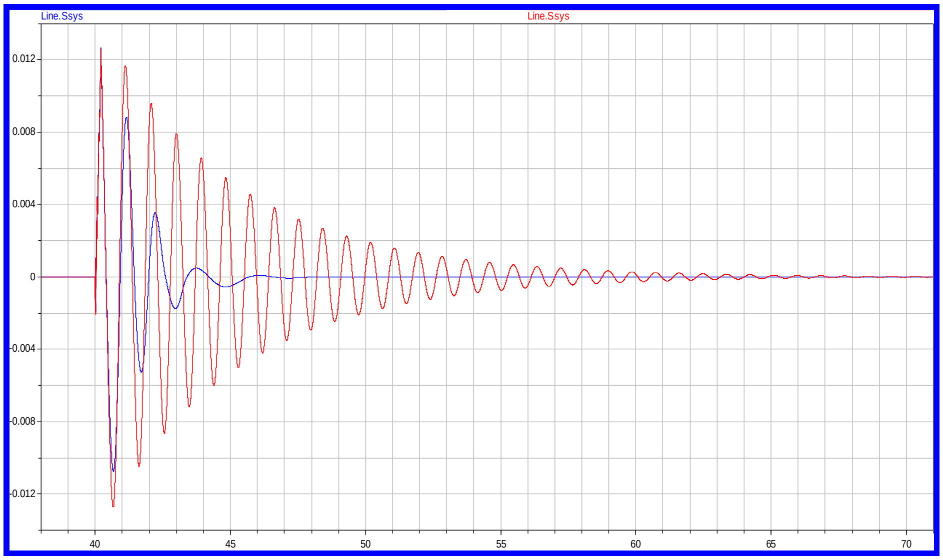
Magnitude (per unit)



Time (sec)

Magnitude (per unit)



Time (sec)

Fig.9 : Slip of the Synchronous Generator.

Note: the blue line is the response of the system after modifying the gains of the PD controller and the red line before modifying the gains.

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5. Conclusion:

The design of a PD controller with a NN for gains calculation of the PD controller has been proposed here. The proposed controller has the same structure of the PD controller but with a NN to calculate the gains of the PD controller in off line mode. The structure of the NN has been proposed. The stability of a single machine infinite bus bar (SMIB) has been discussed and compared with the conventional PD controller (the parameters were selected by analytic calculation) from the point of view of damping ratio, the location of Eigen values and the dynamic simulation of the SMIB system. The NN parameter estimation was found to give optimal parameters to the PD controller which enhances the response of the PD controller which in turn enhances the static and dynamic stability of the system.

Appendix

$\dot{x} = A_0.x + B_0.u$

$Y = C_0.x + D_0.u$

The synchronous generator SS form

$$\begin{pmatrix} \dot{\psi d} \\ \dot{\psi q} \\ \dot{\psi f} \\ \dot{\psi kd} \\ \dot{\psi kq} \\ \dot{s} \\ \dot{\delta} \end{pmatrix} = \begin{pmatrix} x_1 & -\omega & x_2 & x_3 & 0 & 0 & 0 \\ \omega & x_4 & 0 & 0 & x_5 & 0 & 0 \\ x_6 & 0 & x_7 & x_8 & 0 & 0 & 0 \\ x_9 & 0 & x_{10} & x_{11} & 0 & 0 & 0 \\ 0 & x_{12} & 0 & 0 & x_{13} & 0 & 0 \\ -\frac{iq}{2H} & \frac{id}{2H} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \omega & 0 \end{pmatrix} \times$$

$$\begin{pmatrix} \psi d \\ \psi q \\ \psi f \\ \psi kd \\ \psi kq \\ s \\ \delta \end{pmatrix} + \begin{pmatrix} -\omega * v_d \\ \omega * v_q \\ \omega * E_{fd} \\ 0 \\ 0 \\ \frac{1}{2H} * Tmech \\ 0 \end{pmatrix}$$

Where: $x_1 = \frac{Rs}{xs+Xt}(1 - \frac{Kdd}{xs+xt})$, $x_2 = -\frac{Rs*Kdd}{xsf(xs+xt)}$, $x_3 = -\frac{Rs*Kdd}{xs1d(xs+xt)}$

$x_4 = \frac{Rs}{xs+Xt}(1 - \frac{Kqq}{xs+xt})$, $x_5 = -\frac{Rs*Kqq}{xs1q(xs+xt)}$, $x_6 = -\frac{Rsf*Kdd}{xsf(xs+xt)}$

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$$x_7 = \frac{Rsf}{xsf}\left(1 - \frac{Kdd}{xsf}\right) \quad , \quad x_8 = -\frac{Rsf * Kdd}{xsf * xs1d} \quad , \quad x_9 = -\frac{R1d * Kdd}{xs1d(xs+xt)}$$

$$x_{10} = -\frac{R1d * Kdd}{xsf * xs1d} \quad , \quad x_{11} = \frac{R1d}{xs1d}\left(1 - \frac{Kdd}{xs1d}\right) \quad , \quad x_{12} = -\frac{R1q * Kqq}{xs1q(xs+xt)}$$

$$x_{13} = \frac{R1q}{xs1q}\left(1 - \frac{Kqq}{xs1q}\right) \quad , \quad K_{dd} = \frac{Xad}{1 + Xad * \left(\frac{1}{Xs+Xt} + \frac{1}{Xsf} + \frac{1}{Xs1d}\right)}$$

$$K_{qq} = \frac{Xaq}{1 + Xaq * \left(\frac{1}{xs+xt} + \frac{1}{xs1q}\right)} \quad , \quad Xaq = xq - xs \quad , \quad Xad = xd - xs$$

The Excitation SS Form

$$\begin{pmatrix} \dot{V}1 \\ \dot{V}2 \\ \dot{V}4 \\ \dot{V}5 \\ \dot{V}6 \\ \dot{V}7 \\ \dot{E}fd \end{pmatrix} = \begin{pmatrix} \frac{-1}{Tou} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T1u} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{-1}{Tw} & 0 & 0 & 0 & 0 \\ 0 & 0 & X1 & \frac{-1}{Tow} & 0 & 0 & 0 \\ 0 & 0 & X2 & 0 & \frac{-1}{T1w} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{-1}{Tif} & 0 \\ \frac{1}{Tkob} & \frac{1}{Tkob} & 0 & \frac{1}{Tkob} & \frac{1}{Tkob} & \frac{1}{Tkob} & \frac{-1}{Tkob} \end{pmatrix} \times$$

$$\begin{pmatrix} V1 \\ V2 \\ V4 \\ V5 \\ V6 \\ V7 \\ Efd \end{pmatrix} + \begin{pmatrix} \frac{Kou}{Tou}\Delta V \\ -\frac{K1u}{T1u^2}\Delta V \\ K * Ta \\ \frac{Kow}{Tow} K * Ta \\ \frac{K1w}{T1w} K * Ta \\ X3 \\ \frac{-K1u}{Tkop * T1u}\Delta V - \frac{1}{Tokp} Efdo \end{pmatrix}$$

Where: $X1 = \frac{-Kow}{Tow * Tw}$. $X2 = \frac{K1w}{T1w * Tw}$ $\quad Ta = T_{mech} - T_{em}$

$$K = \frac{50 * \pi * Kw}{Tw * H} \quad , \quad K_{dd} = \frac{Xad}{1 + Xad * \left(\frac{1}{Xs+Xt} + \frac{1}{Xsf} + \frac{1}{Xs1d}\right)}$$

$$X3 = \frac{Kif * (1 - Kdd) * wc}{Tif\ Xsf} Rf * ir + \frac{Kif * Kdd * wc}{Tif\ Xsf} * \left[\frac{-vd - Rs * id - (1+s) * \psi d}{Xsf * Xs} + \frac{-wc * R1d * ird}{Xs1d}\right]$$

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The above equations can be combined to give the full system state space representations.

Symbols

ψd , ψq = flux linkage in direct (d) & quadrature (q) axis respectively.
ψf = flux linkage in the field winding.
ψkd , ψkq = flux linkage in damper windings.
id, iq = current in d & q stator winding.
ir = current in excitation winding.
Rs = stator windings resistance.
Rsf = field winding resistance.
R1d, R1q = damper winding resistance.
x_s = stator winding self reactance.
x_{sf} = field winding self reactance.
X_{s1d}, X_{s1q} = damper windings self reactance.
X_t = transmission line reactance.
v_d , v_q = stator windings voltages.
E_{fd} = field winding voltage.
s = machine slip.
δ = load angle.
H = related inertia constant of the machine.
ω = synchronous speed.
T_{mech} = mechanical torque.
T_{em} = electro mechanical torque.

6. Reference

[1] Bikash Pal & Balarko Chaudhuri, "*Robust Control in Power Systems*", springer, 2005.

[2]Chee-Mun Ong, "Dynamic Simulation of Electric Machinery using MATLAB**/ simulink",** Prentice Hall, Upper Saddle River, New jersey 07458, 1998.

[3]Dr. J. Kumar, P. Pavan Kumar, A. Mahesh & A. shrivastava, "Power system stabilizer based on artificial neural network", IEEE, 2011.

[4] Howard Demuth & Mark Beale, "Neural network toolbox for use with MATLAB", Math Works, Inc, 1998.

[5] IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control System, IEEE, 1990.

[6] John J. Grainger & W. D. Stevenson, Jr, "Power system analysis", McGraw-Hill, Inc.1994.

[7] K. Ogata, "Modern Control Engineering 3rd Edition", Prentice Hall, Upper Saddle River, New jersey 07458, 1997.

[8] Li Yan, Wang Dongmei," Simulation of Synchronous Generator's Dynamic Operation Characteristics", IEEE, 2011.

[8] M.G McArdle, D.J. Morrow & P.A.J. Calvert, "A Hybrid PI and PD Type Fuzzy Logic Controller for Automatic Voltage Regulator of Small Alternator":, IEEE, 2001.

[9] Ms.M. Uma Vani, Dr.G.S. Raju & Mr.K.R.L,"Prasad, Robust supplementary controllers for AVR and PSS,IEEE, 2009.

[10] P.M. Anderson, A.A. Fouad, "Power System Control and Stability," Tshe lowa state university press, 1994.

[11] S.H. Hosseini, R. Rohnavart & H. Kharratti, "Application of Genetic Algorithm to Design PID Controller for Power System Stabilization", IEEE, 2009.

[12] Prabha Kundur, "Power System Stability and Control", McGraw-Hill, Inc.1994.

[13] U. A. Bakasi & M. V. Bakashi,"Modern control theory 1st edition",Technical publications Pune, 2008.

[14] V**.S. Sundaram & Dr.T. Jayabarathi,**"Load Frequency Control using PID Tuned ANN Controller in Power System",IEEE, 2011.