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A Real Time Simulation Of A Controller For Synchronous Generator Excitation Using Artificial Neural Network Trained By Genetic Algorithm (Rt-Lab Benchmark)

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Abstract

This paper presents A New Methodology for Controlling excitation voltage of a synchronous generator Using Intelligent Controller. This controller depends on Genetic Neural Networks Using Single Phase Semi-converter, To investigate the Effectiveness of the Proposed Controller on the excitation of the synchronous generator, It Was Compared with AC1A Excitation System, The Proposed Controller Processes the angular velocity signal and the terminal voltage signal of the synchronous generator in order to control voltage fed to the excitation circuit of the synchronous generator itself, Finally the model was applied on real time simulator in order to ensure the validity of the results.

Keywords: Electrical Machines, Synchronous Machines, Genetic Neural Network /NeuroGen/, Artificial Intelligence (AI), Single Phase Semi-Converter, Excitation System, Electric Power System.

المحاكاة في الزمن الحقيقي لمتحكم دارة تهييج المولد المتزامن باستخدام شبكة عصبونية اصطناعية مدربة بواسطة الخوارزمية الجينية (منصة RT-LAB)

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الملخص:

يقدم البحث منهجية جديدة للتحكم بجهد التهييج المطبق على المولد التزامني عن طريق متحكم يعتمد في على الشبكات العصبونية الجينية، وذلك باستخدام دارة تقويم جسريه نصف مقادة / Single Phase Semi-converter /، لمعرفة فاعلية المتحكم المقترح في التحكم بتهييج المولد التزامني، تم مقارنته نظام التهييج AC1A Excitation System ، يعتمد المتحكم المقترح على شبكة عصبونية مصممة بالخوارزمية الجينية تعالج إشارة السرعة الزاوية واشارة الجهد الطرفي للمولد التزامني وذلك للتحكم بالجهد المغذى لدارة التهييج للمولد التزامني نفسه، ومن ثم تطبيق الموديل في الزمن الحقيقي من أجل الحصول على معلومات شبيهة بالواقع.

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الكلمات المفتاحية: الآلات الكهربائية، الآلات التزامنية، الشبكات العصبونية الجينية، الذكاء الصنعي، دارة تقويم جسريه نصف مقادة، نظام التهييج، نظام القدرة الكهربائية.

1- Introduction:

There are many sources of energy conversion in the world but most of the energy is converted by the Synchronous generator. (H. Chow & J. Sanchez-Gasca, 2020).

The Synchronous Generator is also known as an alternator; it converts Mechanical Power into Electrical, the electric energy we used in our homes or industries is mostly produced by the synchronous generator.

The Synchronous Generators used in our industries are constructed by a static or rotating Magnetic Field, it built by the static field is like the DC Generator.

The Excitation control of the Synchronous Generator is considered one of the most important and necessary issues for effective performance. The most frequent case that the generator is exposed to disconnecting and connecting the loads, which causes and may impose a change in the generator speed and a change in the output voltage of the synchronous generator. From this point of view, lies the importance of controlling the excitation voltage of synchronous generators.

The use of artificial intelligence in the field of control is one of the new and modern methods, and it increases reliability and speed of processing and reduces human error, for this reason, in this research, a controller designed on genetic neural networks aims to improve the response of the generator, and it is controlled by the voltage applied to the excitation system. The controller is trained on values based on the experience of an expert system and is taken from the most common values to control irritation (Jain, 1998).

Nevertheless, real-time simulation is known as reproducing the behavior of a physical system by running its computer-based model at the same rate as actual live clock time (ALNASSEIR, ALCHAREA, & ALMAGHOUT, 2021). In other words, in real-time simulation, when the simulation clock reaches a certain time, the same amount of time has passed in the real world, also it provides a virtual environment of the systems in which new control strategies or technologies can be tested ex-ante before implementing in the real world system providing trustable real-like information on impacts and benefits (Missaoui', Warkozek, Ploix, & Bacha, 2012).

2- Aims of the Research:

This research deals with the behavior of the Synchronous Generator, and analyze the response of Sync. Generator to load changes [ex: electrical loads that may be applied to the generator in order to carry out multiple and different tasks, and how to maintain the continuity of the electrical supply provided by the generator with high quality and reliability]. therefore, this research aims to:

1- demonstrating the principle of neural networks and the genetic algorithm, their modeling methods.

2-Using a genetic controller to control the excitation voltage applied to the synchronous generator.

3- Compare the control of the AC1A Excitation System and the proposed controller to choose the best method between them. (H. Chow & J. Sanchez-Gasca, 2020)

3- Research Materials and Methods:

In this research we adopted the method of modeling and Real time simulation of a synchronous generator using the SIMULINK environment in the MATLAB program and RT-Lab hardware in the Loop unit. The genetic neural network was designed to deal with the angular velocity signal and the terminal voltage signal of the synchronous generator to process them for control, Finally, the proposed network training process was done using the MATLAB program, then we applied it to RT-Lab Programed for the real time simulation.

3-1- Studied System Model:

in Figure (1) a box diagram of the system shown below, Which will be explained in the course of this research

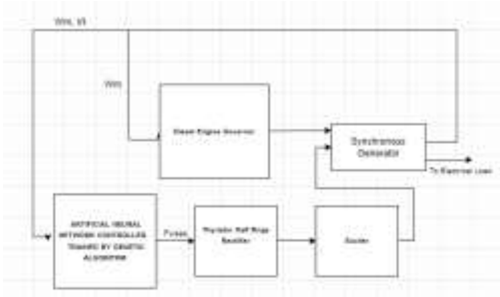

Figure (1): System Box Diagram

Figure (2) shows a synchronous generator, in a synchronous generator, a DC current is applied to the rotor winding. The rotor is then turned by a turbine to produce a rotating magnetic field, which induces 3-phase voltages within the stator windings.
Field winding: winding producing the rotor magnetic field (rotor winding). Armature windings: are the windings where the stator voltages are induced (stator windings).

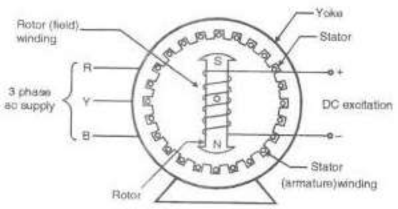

Figure (2): Synchronous Generator

As shown in Figure (3), the equivalent circuit of the synchronous generator:

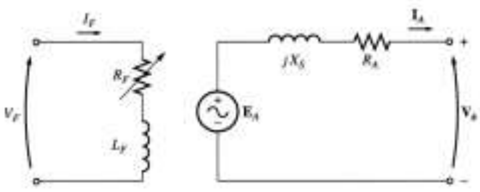

Figure (3): The Equivalent Circuit Of The Synchronous Generator

Where:

R_A	stator resistance	R_F	field resistance
X_S	series inductance	L_F	field inductance
E_A	Internal Generated Voltage	V_F	field voltage
I_A	Load Current	I_F	field current
V_ϕ	Total Voltage		

in this work, the synchronous generator block from simulink environment in matlab program was applied, as shown in figure (4):

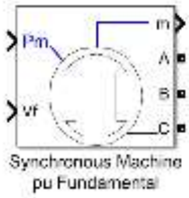

Figure (4): The Synchronous Generator Block In Simulink Environment

then a salient-pole synchronous generator; with the following Parameters was used:

Parameter	value	unite
P	4	KW
V	380	volt
fn	50	Hz
N	1500	rpm
J	0.2224	kg.m^2
p	2	pole pairs

3-2- Single Phase Semi-Converter:

Single Phase Semi Converter /is also known as a half-controlled converter/
utilizes SCRs(thyristor) and diodes to convert AC power to DC power (Rashid, 2018).
Due to the utilization of diodes and thyristors, it provides limited control over the level of DC output voltages، as shown in Figure (5):

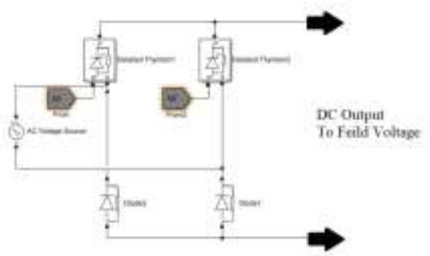

Figure (5): Single Phase Semi-Converter

Consist of 2 thyristors, 2 Diodes &
Ac Voltage Source.

3-3- Diesel Engine and Governor:

To supply the suitable rotation torque from the generator axe, a Diesel engine was coupled on the same rotation axes. (Ong, 1998). As shown in Figure (6), 1st and 2nd inputs: Desired and

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actual speed (pu) while the Output is: Diesel Engine Mechanical Power Motor

The diesel generator governor was controlled by a Controller with transfer function according to equation below (M. Elsherbiny, S. Nada, & Kamal, 2019):

Controller transfer function (HC):

$$Hc = K * \frac{(1 + T3.s)}{(1 + T1 * s + T1 * T2 * s^2)}$$

Actuator transfer function (Ha), & its equation:

$$Ha = \frac{(1 + T4 * s)}{[\,(s * (1 + T5 * s) * (1 + T6 * s)\,]`)}$$

Where:

Regulator time constants	
T1	0.01
T2	0.02
T3	0.2
Actuator time constants	
T4	0.25
T5	0.009
T6	0.0384

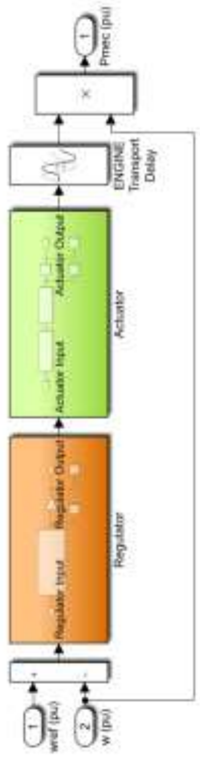

Figure (6): Diesel Engine and Governor

3-4- Artificial Neural Networks:

Artificial neural network is a machine or model that is designed to simulate the way the brain works in accomplishing a specific task. It can be a set of electronic components or a set of programs on a digital computer.

These neural networks perform useful calculations through the learning process, and therefore, to achieve a good achievement, a large number of internal connections are used between simple computational cells called neurons or processing units. Thus, a neural network can be defined as follows:

It collects a large number of computational elements called neurons or nodes distributed in a row and has a neurological property in storing experimental information and making it available for use. It is similar to the brain in two things:

1- You gain information during the training process.

2- Storing information using connecting forces inside neurons called synaptic weights.

The procedure used to accomplish the learning process is called the learning algorithm and it is meant to modify the lattice weights and offsets of the lattice in a specific way so that a desired design objective is achieved.

Neural networks derive their computational power from two points:

1- Its structure is highly distributed.

2- Their ability to learn and then generalize.

Generalization means the ability of the network to produce a reasonable output for an input that you have not trained on, and this is what makes neural networks able to solve complex problems.

neuron model

The neuron is the basic information processing unit in the construction of the ANN. The neuron consists of four basic elements: /Figure (7), Figure (8)/

1- A group of connections (synapses) or connecting lines, each of which is described by its own weight or force w.

2- Adder collector to collect the signals in the weighted input.

3- The conversion function or the activation function (f) that limits the output of the neuron, also called the damping function, as it makes the output within a specific range, often within the range of [0, 1] or [1-, 1].

4- Bias applied externally (Bias), this bias increases or decreases the net income of the activation function, according to its value, which can be positive or negative. Where:
p - represents the input at the link entrance.
w - lattice weight.
b - Bias.
n – is the product of the adder $n = p * w, n = p * w + b$.
f – is the activation function.

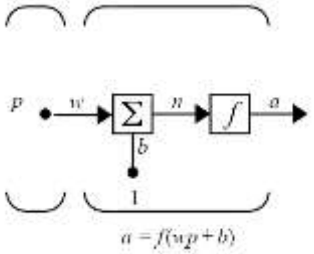

Figure (7): Representation of a Simple Neuron with a Shift.

-Representation of a neuron with an input beam:
The input ray is:

$$p_1, p_2, \dots, p_R$$

here R represents the number of elements of the input ray, and the weights ray are:

$$w_{1,1}, w_{1,2}, \dots, w_{1,R}$$

and here we represent the input ray by (p) and it is a vertical matrix, and the weights radius are in (W) and it is a line matrix, Figure (8)

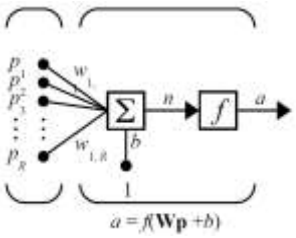

Figure (8): Representation of Neuron with several income values.

Here, (n) is:

$$n = w_{1,1} * p_1 + w_{1,2} * p_2 + \dots + w_{1,R} * p_R + b$$

It is written in MATLAB format:

$$n = w\,p + b$$

The previous model is represented by Matlab in Figure (9), because when we have a lot of inputs, it is difficult to represent them like the previous model, so this representation comes to the flexibility of dealing with a single neuron.

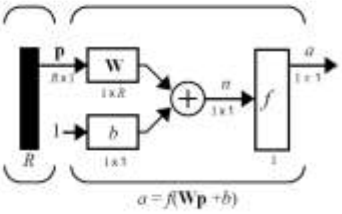

Figure (9): Representation of a Neuron in a MATLAB Architecture

3-5- Genetic neural network architecture:

Genetic Algorithms definition are a class of stochastic search algorithms based on biological evolution. Given a clearly defined problem to be solved and a binary string representation for candidate solutions.
A Genetic Neural Network is a combination of artificial neural networks and a genetic algorithm. A genetic algorithm is used to generate a neural network based on the data of a genetic algorithm.
The input of the network in this research is a two input, which is the angular velocity signal and the terminal voltage signal, while the output is Phase Angle Firing of the thyristors of the Single Phase Semi-Converter.
We collect Generator operational data from various load and processing states are collected by AC1A Excitation System.
- System Design Algorithm:
To design this system in the MATLAB environment, we write the genetic algorithm, which consists of several steps (Negnevitsky, 2005):
1- We choose the size of the chromosome group, the probabilities of crossover and mutation, and determine the number of training times
2- Determine the fitness function in order to know the performance of the chromosome.
3- Create an initial set of chromosomes randomly.
4- Decode each chromosome into a neural network, then train by the program with random weights and random network shifts.
5- We repeat step 4 to include all chromosomes.
6- We select a pair of chromosomes for mating, we choose them with an appropriate fitness function for our case.

7- We apply the property of crossing over and mutation, each of which is performed randomly on the chromosome.

8- We apply the chromosomes resulting from the previous step and see the fitness function for each of them.

9- If the fitness function is not suitable, we repeat the steps back from step 6.

3-6 Training

Before using a neural network, it must be trained according to valid data, so the training data is placed in a matrix consisting of three columns, the first column is angular velocity signal, the second column is terminal voltage signal & the third column is Phase Angle Firing of the Single Phase Semi-converter.

Then we write the previous algorithm program with a Matlab program (Abdalla, Elfaki, & AlMurtadha, 2014).

A genotype is a series of pairs (0 or 1), each genotype corresponds to a unique chromosome. In this research, a chromosome of 5 binary numbers was adopted (Ahmed, Nordin, Sulaiman, & Fatimah, 2009).

Figure (10) shows the method of representing the design parameters by binary coding

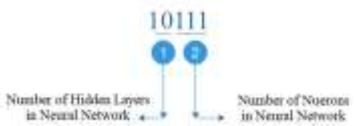

Figure (10): Representation of design parameters of a neural network through binary coding

Here is a table showing the number of layers and the number of neurons mentioned in the above figure(10):

Table (1) The number of binary encoded hidden layers

Binary Number Sequence	Hidden Layers Number in a Neural Network
00	1
01	2
10	3
11	4

Table 2: The number of binary encoding neurons

Binary Number Sequence	Neurons Number in a Hidden Layer
000	1
001	2
010	3
011	4
100	5
101	6
110	7
111	8

We did not set a Zero value for each of the number of hidden layers number and neurons numbers, because it must have values, for example the values in the figure(10) number are interpreted as follows:

1- (10) has 3 hidden layers.

2- (111 The number of neurons in one hidden layer is 8.

Using the newff function to train the neural network based on the data taken into account from the number of hidden layers and the number of neurons in the hidden layer, with training data and signal processing, and it has the following form in the MATLAB program:

net=newff(P,T,N);

Where:

P: The input of the neural network, which is taken from the expert system's experience, is the angular velocity signal and the terminal voltage signal.

T: the desired neural network output, also taken from the expert system's experience, triggered thyristor angle.

N: is an array containing the number of hidden layers and the number of neurons in the hidden layer.

net: is the generated neural network

Then we use the /train/ function, which is trains the neural network:

net=train(net,P,T)

Then we apply the /sim/ statment , which gives the simulation result of the network after training:

Y = sim(net, P);

Where:

Y: is the simulated result of the network after training.

Then we find the fitness function, which is the square of the error between the desired output T and the output obtained after the training process Y.

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3-7- Computer simulation:

The circuit has been modeled in Matlab-Simulink, it consists of Synchronous Generator, Single Phase Semi-Converter, Diesel Engine and Governor, load, Circuit Breaker, as shown in figure (11)

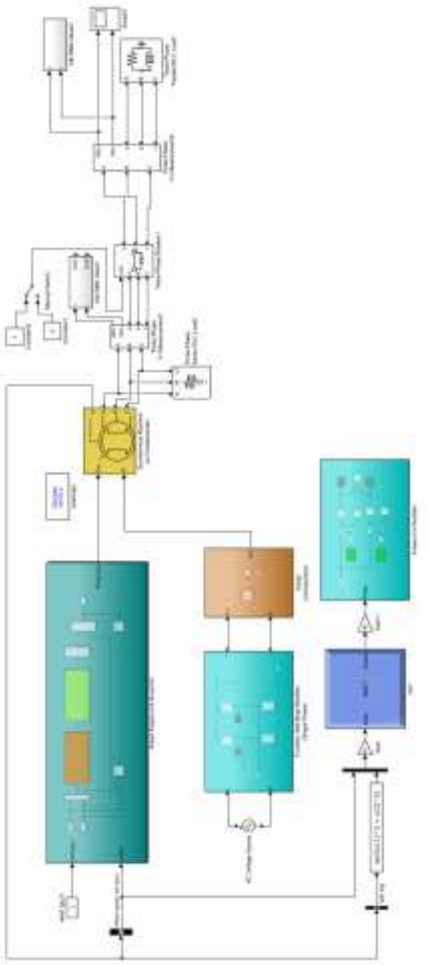

Figure (11): Full Circuit in Matlab

Figure (12) Shows The Pulse Generating Circuit and Its Components (Alhazory & Warkozek, 2020):

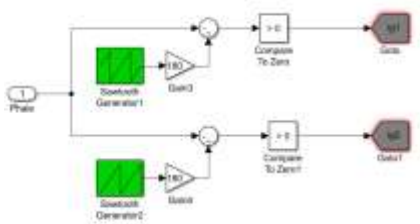

Figure (12): Pulse Generating Circuit

The neural network that we had from the output of the genetic algorithm was applied, which is in the form of net (cell), (Figure (13)), with all its parameters like weights, basis & transfer Functions, it has the form in the Matlab-Simulink program:

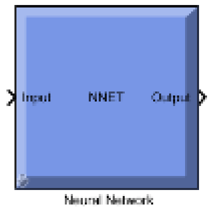

Figure (13): Neural network block in MATLAB program, Simulink environment

The network consists of 4 layers: an input layer, two hidden layers, and an output layer, as shown in Figure (14):

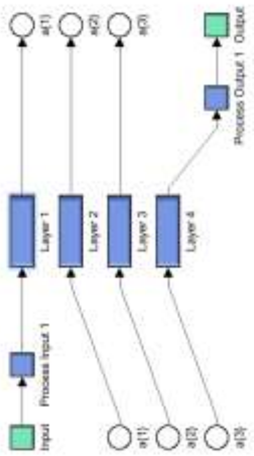

Figure (14): Block structure of a neural network

Each layer consists of four neurons except for the output layer which consists of one neuron, and the activation functions used are of type /tansig/ except for the output layer which is of type /purelin/.

figure (15) shows the Synchronous Generator model with AC1A Excitation System.

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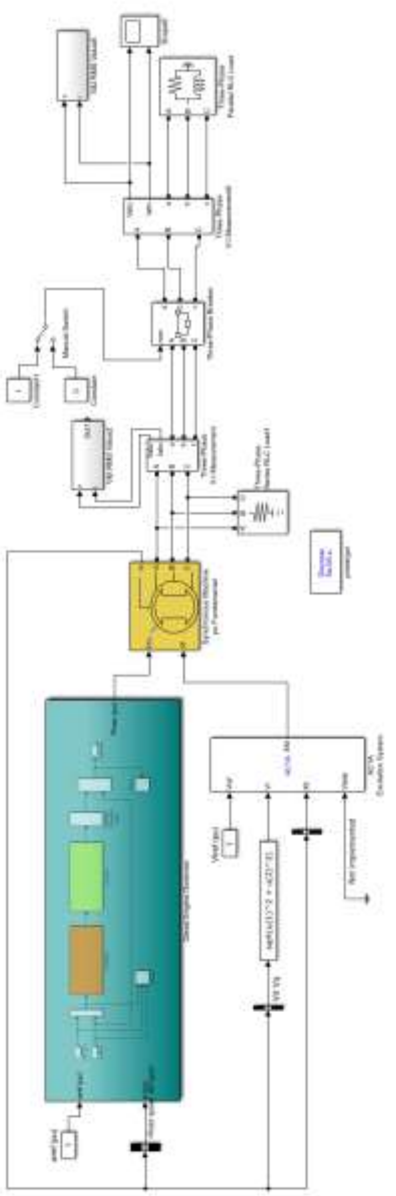

Figure (15): Synchronous Generator model with AC1A Excitation System.

While figure (16) illustrates Synchronous Generator model with a neural network controller That designed with genetic algorithm.

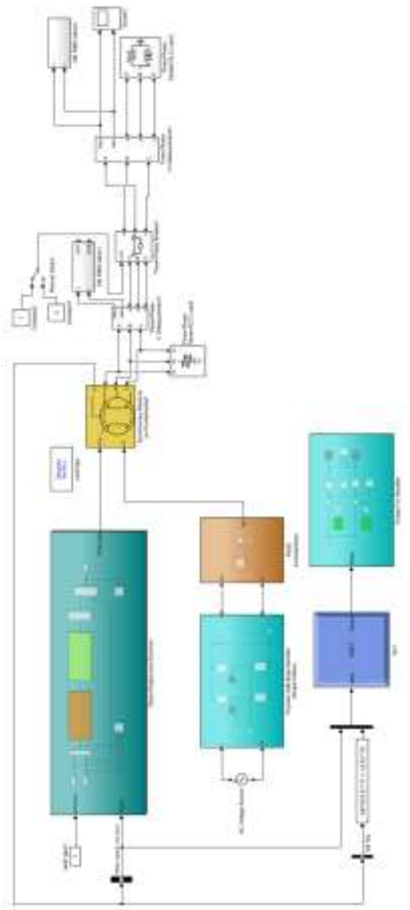

Figure (16): Synchronous Generator model with a neural network controller

4- Real Time Simulation using RT-LAb:

for the real-time simulation, we bring the circuit from the MATLAB program and upload it from the RT-LAB program, as shown in the figure (17):

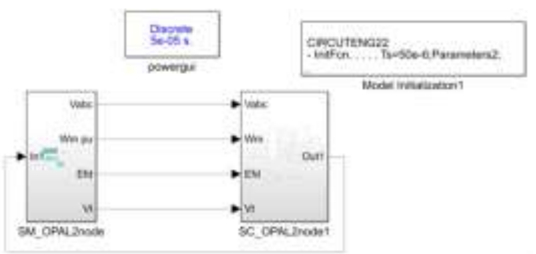

Figure (17): Circuit in RT-LAB program

Then we compile the model within the RTLAB program, after compiling it, we will have new interface as show in figure (18):

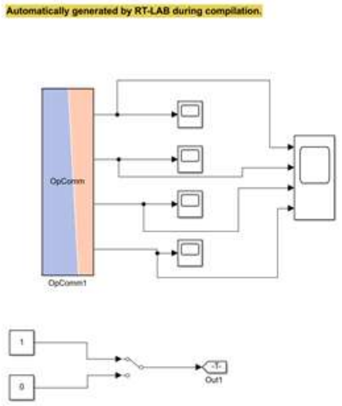

Figure (18): Circuit After Compiling

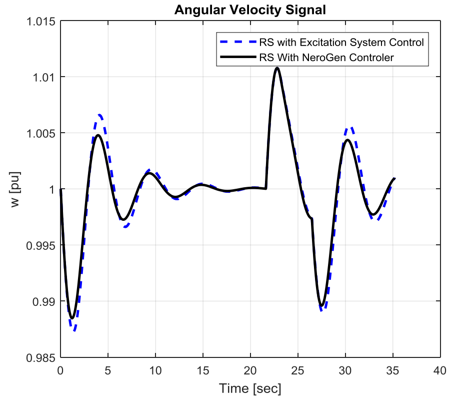

Figure (20): W Curve

5- Results and discussion:

The time response of the Angular Velocity Signal & Terminal voltage of Synchronous generator resulting from the model using the proposed controller was compared with the same response generated from the model using AC1A Excitation System control.

at the beginning the load was applied on the generator then it has been disconnected, to simulate a normal On/Off loading case. and the response was as shown in the following figures / Figure 19,20 and 21 /:

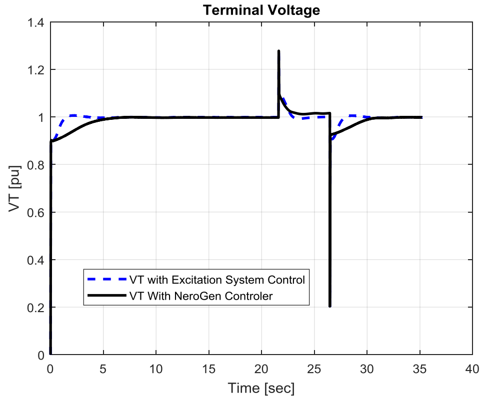

Figure (21): Vt Curve

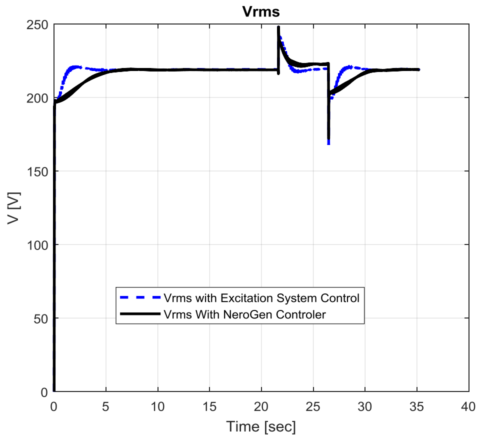

Figure (19): Vrms Curve

It is noted in the time response diagram for changing the angular velocity and terminal voltage shown in Figure (19,20) that the proposed controller /NureoGen/ makes the angular velocity curve close to 1 pu in other word to made to reduce amplitude, the Vrms Curve shift is gradual rather than jumpy, It can be a bit unpleasant but good for keeping frequency oscillation in a good range for the Synchronous Generator.

In Figure (21) we see the terminal voltage output from the generator, and we note that it is Streamlined and gradual way more in the case of applying the proposed controller.

- After that stage, we applied the model on the Opal platform (Figure (22)) that supports real-time simulation through the RT-Lab program, and we performed same procedures explained previously. The figure (22) shows the platform connected with a computer for simulation application. The figure (23,24) shows the Results after applying on the platform, Vrms, W & Vt Curves.

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Figure (22): Opal platform

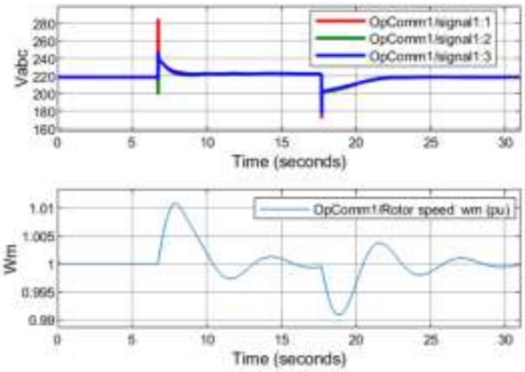

Figure (23): Vrms Curve, W curve.

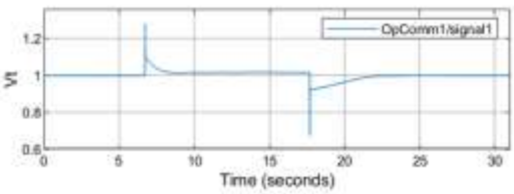

Figure (24): VT Curve.

The Results in fig (23,24) have fast and good response to load changes in real-time when we connect and disconnect loads via RT-Lab.

6- Conclusions and Recommendations:

We conclude from the results we obtained:

1-The controller based on its work on genetic neural networks has the ability to improve the performance of the generator when the load changes applied to it.

2-The controller designed on artificial intelligence can learn continuously by expanding the database used for training and applying different work situations, which makes it more adaptable and easier to handle than other controllers.

3- The performance of the designed controller is better than the traditional one because it reaches the reference values in different working conditions.

Recommendations:

1- Completing the research by studying the response of the artificial intelligence controller to the changes of faults on generators in industrial facilities and electrical systems.

2- Benefiting from research in linking artificial intelligence with other areas of control.

3-Comparison between different RT simulation platforms (ie, RTDS, PLEX, OpalRT).

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