Improving the Performance of Gas Turbine based on Rowen Model Using Type-2 Fuzzy Controller

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Abstract – According to the crucial role of gas turbines in electricity production without significant harmful effects on the environment, this paper is aimed at the modeling and simulation of a particular type of these systems known as V94.2. Gas turbine is an instrument for power generation, which is capable of producing a vast amount of energy by considering its size and weight. Despite all the advantages and applications of gas turbines, the use of these systems is not free of difficulties because of their remote controls in such a way that it is estimated that about a quarter of turbine price is spent on its launching. To tackle this problem, a mathematical model has been proposed for V94.2 gas turbines as a result of the review of the pieces of research done on the modelling of gas turbines in the past few years and on the basis of Rowen model. In the following, the capability of fuzzy type-2 controllers has been used to ensure the system stability. The results of the simulation in MATLAB software clearly shows that the output variables of V94.2 gas turbine reach a specific situation and place after applying the inputs at the right time.

Keywords: Gas Turbine, V94.2 Gas Turbine, Rowen Model, Type-2 Fuzzy Control

1. Introduction

Population growth, urban and rural development, and development of industrial and commercial centers have led to the increasing need for clean energy. Due to increased air emissions, very high cost of the development of traditional networks with possession of wind energy, solar energy, steam, and hot gas pressure, it is no longer effective to use traditional networks for energy production. Thus, in the last three decades, dispersed energy sources, especially renewable energy sources that are more appropriate both economically and in terms of producing emissions have been used. According to a report issued by the International Energy Agency (IEA) in 2009, 1.3 billion people worldwide do not have access to energy resources. Living in remote areas and lack of access to the main networks of energy production constitute the reason for this lack of energy. To meet this challenge, small-scaled energy sources, such as diesel generators and gas turbines have been used that can provide local loads [1].

Turbines are devices that use kinetic energy of the fluids and produce mechanical energy. The energy fluid used may generally be water, wind, steam, and hot exhaust gases resulting from combustion. It is noteworthy that hydro, wind, steam, and gas turbines have been designed based on the type of the fluid used. Steam and combustion gases are two energetic fluids that contribute to the production of mechanical work in steam and gas turbines [2].

Since 70 years ago, gas turbines have been used for power generation; however, production of these types of turbines has increased as large as twenty times in the last twenty years. The first gas turbine similar to today's gas turbines was founded by "John Pier" in 1791. Then, following numerous studies, the first gas turbine was produced from a multi-stage reactive turbine and an axial multi-stage compressor until the early twentieth century. The first gas turbine device was utilized in 1933 at a factory in Germany. The advancement of technology related to gas turbines was such that gas turbine with 212.2 MW is also used today [2].

Gas turbine technology has expanded greatly over the past thirty years until its efficiency has increased by 15 percent to about 45 percent. In addition to the above-

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mentioned reasons, long life is among the other factors for the increasing use of this type of turbine. From among all the drivers, gas turbine takes advantage of the lowest initial cost, the lowest maintenance cost, and the fastest time to reach the rated conditions [3].

Mechanical energy produced in turbines is rotational; therefore, it is used in industry to rotate various devices. For example, wind and water turbines are often used to spin generators and produce electricity in wind and water power plants. Gas turbine generators are widely used for power generation. This type of generator is a perfect choice in remote areas where grid connection is not possible. In the same way, these generators are used to increase network reliability where load changes or power outages occur as usual [4].

Gas turbines are used as drive engines; generator drives, compressors, and pumps; and as generator drives in aviation industries, oil and gas and petrochemical industries, and thermal power plants, respectively. Gas turbines were first used in aviation industries; however, the use of gas turbines in other industries, especially in power industry experienced an increasing growth with the increasing demand for electrical energy and the need for the use of machines with small volume, low initial capital, and short setup time to convert thermal energy into mechanical work [5].

Gas turbine modelling has become one of the topics of interest to designers since the second half of the twentieth century. In addition to the usage in diagnosis of gas turbine error, modelling is of considerable importance in simulator construction, control logic design, system analysis for testing in different power conditions, and aerospace applications. In Table 1, the most important proposed gas turbine models along with their specifications have been presented.

In terms of control engineering, numerous studies have been published in respect to the stabilization of the gas turbines available in industry. In[9], an overview of adaptive control techniques applied to gas turbines has been proposed. Then, a comparative optimized method has been proposed to control these systems. Next, derivatives of optimal controllers have been somewhat modified for turbines by means of Pontryagin's minimum principle. As mentioned in this reference, one of the problems of adaptive controls is their severe sensitivity to the model in such a way that these controllers lose their effectiveness with small changes in the model. For this reason, these controllers are not used to control parameters of gas turbines.

Table 1: The main models proposed for gas turbine along with their specifications

Model name	Modelled system	Main features of the model
CIGRE [6]	Gas turbine used in combined cycle power plant	Consisting of an external control loop to maintain the output power constant at a pre-defined level; Gas turbine in this model has been modeled with a second-degree block.
Silvio Simani[7]	Laboratory model of a gas turbine	The desired gas turbine is a uniaxial gas turbine that includes air inlet chamber, 11-stage compressor, annular combustion chamber, one-stage turbine, and a valve for fluid exit; It is a comprehensive model in which further turbine details, such as ambient temperature and pressure, fuel mass flow rate, compressor size, and combustion chamber volume are considered and it is superior to previous models in this respect. This model belongs to an MW5 gas turbine laboratory that does not include some of the main components of a true gas turbine and is not connected to any external system. Thus, it is not simply possible to reconcile this model with a true gas turbine that is connected to the generator in the power plant wherein the changes in the grid frequency and load have a direct effect on it, and the existence of IGV blades, load controller, and temperature controller is essential in its structure.
Rowen [8]	High power gas turbine	Rowen model is among the first and most famous gas turbine models with high power; Turbine control system has been composed of three control loops, including speed control, temperature control, and acceleration control. Gas turbines have been modeled with a first-order block in this model. In addition to accuracy, it does not suffer from any computational problems as in CIGRE model; Considering IGV blades as one of the system state variables, applying its impacts to turbine outlet temperature, and not ignoring the loading conditions are among the benefits of this model that are not available in Simani model.

In [10], intelligent control of neural networks has been used to control gas turbines. In this reference, turbines are available in practice and black box technique and neural network method are used to identify them. In this reference, the system controller has been trained in off-line mode by using modified back-propagation based on conjugate gradients. However, the algorithm used in this reference only belongs to a particular system the desirable results obtained for this system may not be achieved in implementing this controller on other systems since no model has been proposed here.

In [11], sliding mode controllers on gas turbines have been checked. These controllers ensure system stability in non-linear models and, thereby, they are widely used in industry. One of the objections leveled against this reference is the model considered for gas turbine. In this reference, there no distinction has been made between system parameters and it is merely to show the proper functioning of sliding mode controllers for nonlinear systems.

In [12], PI or PID controllers with a constant quotient rate has been used to control the velocity of gas turbines. This method is effective when the system is active only in one point. Moreover, this method does not have the ability to concurrently adjust the speed and eliminate disturbance. To tackle this problem, the generalized PID controller is used wherein controller parameters are updated based on the operating point [13]. To meet the need for the system model and its parameters, the mixed PI-Fuzzy is used to control the system[14]. Thereafter, in [15], PI-Fuzzy method along with quotient table has been used to increase efficiency. In [16] and [17], neural network method and fuzzy method have been respectively used to model the system in black box mode. Fuzzy control for nonlinear systems is presented in [18].

In this paper, the previous studies on modeling of gas turbines in the past few years were first reviewed and, accordingly, the model of a specific type of these turbines, entitled V94.2 based on the structure of Rowen model was selected. The following constitute the reasons for this selection: accessibility to performance data and real data of the turbine as well as benefits such as the possibility of startup and fast loading due to the presence of rotor with a very low thermal response time, high efficiency during periodic functions because of the existence of some components with the capability of handling different situations, easy installation of HRSG Boiler because of the horizontal placement of the turbine exhaust, replacement of most fixed and moving blades of the turbine on the site without the need for rotor movement, and easy and quick inspection of all parts of turbine hot track due to large and appropriate valves. Following the model presentation, type-2 fuzzy controllers are used to ensure system stability.

This paper has been organized in five sections. In the second section, Rowen model is considered as the foundation and a nonlinear model is extracted for gas turbine V94.2 according to the available data. In the third section, the structure of the proposed controller has been investigated. Then, in the fourth section, the simulation results of the type-2 fuzzy controller on the model of gas turbine V94.2 has been presented. Last but not least, the fifth section has been dedicated to the conclusion.

2- Representation of V94.2 gas turbine model based on the structure of Rowen model

In this paper, gas turbine V94.2 has been specified using actual data measured in plant as well as the data belonging to equipment producing companies based on structure of Rowen model. This model has been extracted according Figure 1(with certificate obtained directly from the manufacturer).

In Figure 1, the system inputs are marked with orange color and the system outputs are specified with blue color. The number of system states equals the number of $(\frac{1}{s})$ blocks. In **Error! Reference source not found.**, the inputs, outputs, and system states have been shown.

Table 2: inputs, states and outputs of V94.2 gas turbine system

		Parameter	Symbol
System inputs	u_1	Fuel valve control signal	FV_{cs}
	u_2	IGV control signal	IGV_{cs}
System states	x_1	Fuel valve angel	θ
	x_2	Fuel flow	q_f
	x_3	Air flow	q
	x_4	Temperature inside the radiation shield	T_{sh}
	x_5	Measured temperature	T
	x_6	The outlet of the IGV	$ligv$
System outputs	y_1	Exhust temperature	T
	y_2	Mechanical power	P_m

According to **Error! Reference source not found.**,V94.2 gas turbine model has six state variable that state space equation relating to the variables can be seen from Figure 1. In (1) the state space system equations:

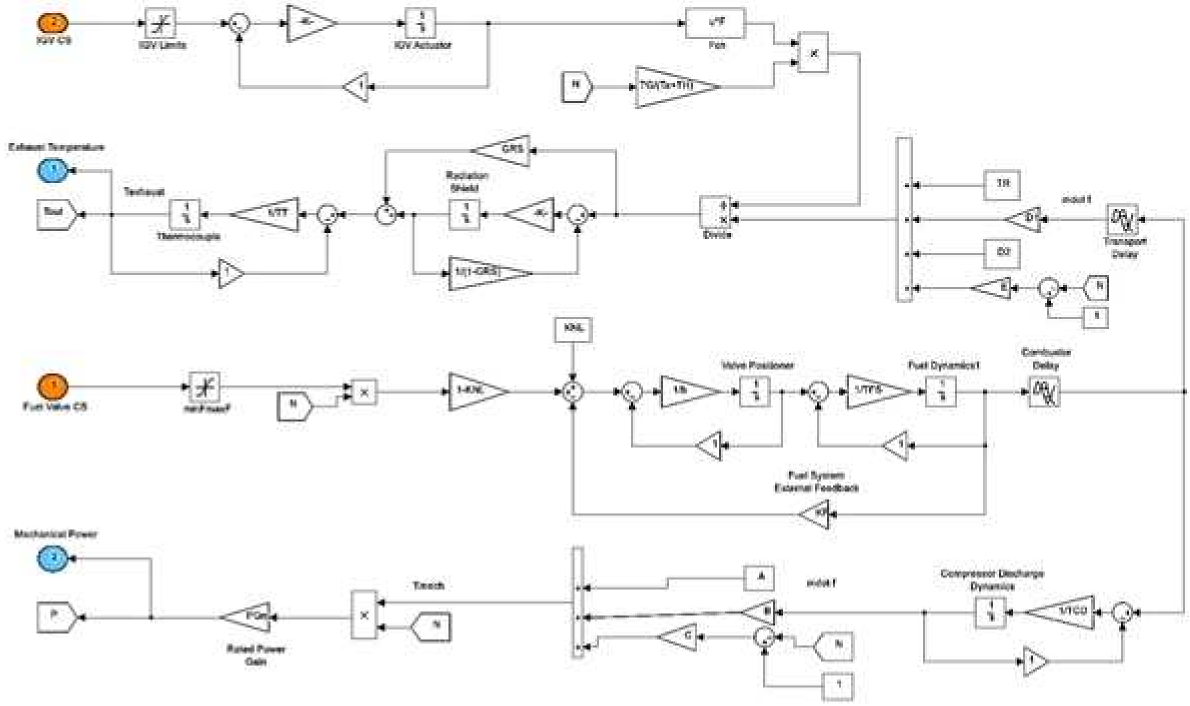

Figure 1: schematic diagram of V94.2 gas turbine model

$$
\begin{aligned}
\dot{x}_1 &= \frac{1}{b}(u_{1s} \times N \times (1 - KNL) + KNL - K_F - x_1)\\
\dot{x}_2 &= \frac{1}{T_{FS}}(x_1 - x_2)\\
\dot{x}_3 &= \frac{1}{T_{CD}}(x_2(t - T_{CR}) - x_3)\\
\dot{x}_4 &= \frac{1 - G_{RS}}{T_{RS}}\left(\frac{T_m}{K_{IGV}} - \frac{1}{1 - G_{RS}} \times x_4\right)\\
\dot{x}_5 &= \frac{1}{T_T}\left(G_{RS} \times \frac{T_m}{K_{IGV}} + x_4 - x_5\right)\\
\dot{x}_6 &= \frac{1}{T_{IGV}}(u_{2s} - x_6)
\end{aligned} \tag{1}
$$

In equations (1), u_{1s} and u_{2s} are linked to the u_1 and u_2 according the two equations in (2):

$$
\begin{aligned}
u_{1s} &= saturat\ (u_1, minF, maxF)\\
u_{2s} &= saturat\ (u_2, minIGV, maxIGV)
\end{aligned} \tag{2}
$$

Such, from Figure 1,T_m and k_{IGV} are calculated with regard to equations (3):

$$
\begin{aligned}
T_m &= T_R + D_1 x_2\big(t - (T_{CR} + T_{TD})\big) + D_2 + E(1 - N)\\
k_{IGV} &= N \times \frac{T_G}{T_a + T_H} \times x_6^F
\end{aligned} \tag{3}
$$

System outputs also are:

$$
\begin{aligned}
y_1 &= x_5\\
y_2 &= P_{Gn} \times N \times \big(A + Bx_3 + C(1 - N)\big)
\end{aligned} \tag{4}
$$

3- Control Structure of Type-2 Fuzzy Controller

The control structure proposed in this paper is the intelligent fuzzy control optimized by genetic algorithm. The first step in implementing this control structure is fussy control design. The high flexibility of the controller is the main reason for the selection of this controller since control signals are not limited to absolute mathematical values. For this purpose, fuzzy controller has been considered in the form of two-input/one-output system as an initial hypothesis according to article [18]. Their membership functions have been shown in Figure 2.

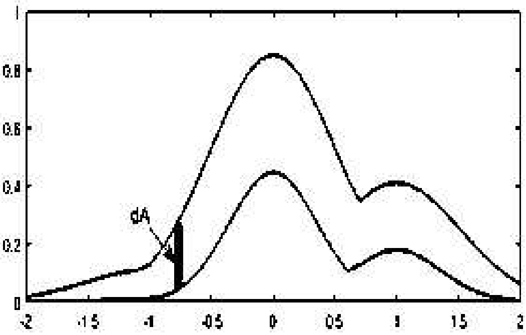

Figure 2: membership functions of the input and output variables in designed fuzzy control

Despite the favorable impact of fuzzy control on the stabilization of industrial processes, fuzzy controller does not work alone for the systems wherein access to expert opinion is not possible. The proposed solution for dealing with this problem in this study is to add optimization genetic algorithm to fuzzy control structure. The purpose of the employment of genetic algorithms in this paper is to determine the optimal parameters of fuzzy controller in such a way that this controller does not need expert opinion.

According to Figure 2, the number of 7 membership functions has been considered for each of the error inputs and its derivative in the control structure. For the optimization of fuzzy control by means of genetic algorithm, these membership functions are converted to binary numbers presented in equation (5).

$$\begin{aligned} \bar{\mu}_B(y) &= \cup_{k=1}^{M} \left(\bar{f}^k \times \mu_{G^k}(y)\right) \\ &= \cup_{k=1}^{M} \left(\bar{\mu}_{\tilde{F}_1^i}(x_1) \times \bar{\mu}_{\tilde{F}_2^j}(x_2) \times \mu_{G^k}(y)\right) \\ \underline{\mu}_B(y) &= \cup_{k=1}^{M} \left(\underline{f}^k \times \mu_{G^k}(y)\right) \\ &= \cup_{k=1}^{M} \left(\underline{\mu}_{\tilde{F}_1^i}(x_1) \times \underline{\mu}_{\tilde{F}_2^j}(x_2) \times \mu_{G^k}(y)\right) \end{aligned} \tag{5}$$

As it can be observed, all membership functions of the fuzzy controller have been replaced4-bitbinary numbers. It is necessary to mention that the first bit in these numbers represent the sign; indeed, if it equals one, it will be a negative number; and if it is zero, it will be a positive number. In the following structure, this model has been shown for one of the membership functions of fuzzy control.

$$dA = \left(\bar{\mu}_{\tilde{B}}(y) - \underline{\mu}_{\tilde{B}}(y)\right).dy \tag{6}$$

It is obvious that fuzzy rules are created as a result of the combination of the membership functions of fuzzy control. For example, the first rule of fuzzy control can be defined as follows:

$$\frac{\int_{-\infty}^{\infty} y.\left(\bar{\mu}_{\tilde{B}}(y)\right).dy - \int_{-\infty}^{\infty} y.\left(\underline{\mu}_B(y)\right).dy}{\int_{-\infty}^{\infty}\left(\bar{\mu}_{\tilde{B}}(y)\right).dy - \int_{-\infty}^{\infty}\left(\underline{\mu}_{\tilde{B}}(y)\right).dy} = \frac{C_u A_u - C_l A_l}{A_u - A_l} \tag{7}$$

Equivalently, each of the fuzzy rules can be expressed as the binary numbers attributed to them. For example, fuzzy rule(7) goes as follows:

$$CoA(\tilde{B}) = \frac{\sum_{i=1}^{n} y_i.\mu_{\tilde{B}}(y_i)}{\sum_{i=1}^{n} \mu_{\tilde{B}}(y_i)} \tag{8}$$

In this paper, each of the fuzzy rules expressible in the design of fuzzy-genetic control is defined in the form of a chromosome in order to design the intelligent genetic algorithm. In this way, the number of $7 \times 7 \times 7 = 343$is defined as follows:

$$y_{Crisp} = \frac{\sum_{k=1}^{M} b_k \left(\bar{\mu}_{\tilde{F}_1^i}(x_1).\bar{\mu}_{\tilde{F}_2^j}(x_2)\right) - \sum_{k=1}^{M} b_k (\underline{\mu}_{\tilde{F}_1^i}(x_1).\underline{\mu}_{\tilde{F}_2^j}(x_2)}{\sum_{k=1}^{M} \bar{\mu}_{\tilde{F}_1^i}(x_1).\bar{\mu}_{\tilde{F}_2^j}(x_2) - \sum_{k=1}^{M} \underline{\mu}_{\tilde{F}_1^i}(x_1).\underline{\mu}_{\tilde{F}_2^j}(x_2)} \tag{9}$$

According to equation (9), there are three binary numbers in each 12-bitchromosome which mutually represent the input-output modes.

In this paper, for the conduct of optimization by genetic algorithm, the objective function has been selected out of fitness functions and the main goal is the minimization of these functions. The objective functions used in this paper are as follows:

$$\mu_{F^i}(x) = exp(-\frac{1}{2}(\frac{x - m_i}{\sigma_i})^2) \tag{10}$$

The performance of genetic algorithms in simulation is such that, after the determination of the results for each chromosome in each stage, the best one which includes the chromosome with the fastest response is transferred to the next generation as the elite and the remaining ones are integrated together using mutation and crossover methods and produce the next generation.

4-Results from Simulation

MATLAB software has been used to apply the fuzzy controller optimized by genetic algorithm to the gas turbine V94.2 model. In simulations, the values of a sample turbine V94.2 in article[19] have been used in the form of Table 3in order to identify the model parameters of this type of turbine in Figure 1.

Table 3: Values of V94.2 gas turbine model parameters

Parameter	Value	Parameter	Value
Gas electrical output (P_{Gn})	162.1	Fuel system time constant (T_{FS})	**0.398**
Nominal frequency (f)	50	Delay of combustion system (T_{CR})	**0.005**
Turbine speed (RPM)	3000	Transport delay of turbine and exhaust system (T_{TD})	**0.04**
No load mass flow ($\dot{m}_{nl}$)	104.3	Compressor discharge lag time constant (T_{CD})	**0.1**
Fuel flow at IGV opening point ($\dot{m}_{fo}$)	5.372	Gas turbine torque block parameters	**A=-0.2197**
Mass flow at IGV opening point ($\dot{m}_{o}$)	286.8		**B=1.2197**
Fuel flow ($\dot{m}_{fn}$)	9.326		**C=0.5**
Exhaust mass flow ($\dot{m}_{n}$)	521.5	Gas turbine exhaust temperature block parameters	**D1=613.6848**
Exhaust gas temperature (T_R)	518.9		**D2=-355.082**
Pressure Ratio (PR)	11.6945		**E=311.34**
Ambient temperature (T_a)	15	Radiation shield parameter (G_{SH})	**0.8533**
Compressor irreversible adiabatic efficiency (η_c)	72.45	Radiation shield time constant (T_{SH})	**12.256**
Turbine irreversible adiabatic efficiency (η_t)	92.47	Thermocouple time constant (T_{TR})	**1.7**
Temperature change at IGV operation (D_{IGV})	2	Rated exhaust temperature (T_R)	**518.9**
Temperature change at OTC operation (D_{OTC})	5	IGV demand signal max limit (maxIGV)	**3.5534**
No load fuel consumption (KNL)	0.1978	IGV demand signal min limit (minIGV)	**0.7081**
Fuel demand signal max limit (maxF)	1.5	IGV loop constant (c_{igv})	**0.7081**
Fuel demand signal min limit (minF)	-0.0761	IGV loop gain (k_{igv})	**5.0232**
Speed controller set point (f_{set})	50	IGV actuator time constant (T_{igv})	**3.1**
Valve positioner time constant (b)	0.082		

Sue to the connection of the gas turbine to the national electricity network and few changes in the network frequency, turbine speed in this paper has been assumed equal to 1pu. The substitution of the numerical values existing in Table 3, the equations (1) to (4) are obtained in the form of the relations (11) to (13):

$$\begin{aligned} T_m &= 613.6848 \times x_2(t-0.045) + 258.6028 \\ &\quad + 311.34(1-N) \\ k_{IGV} &= N \times \frac{519}{T_a + 460} \times x_6^{0.2567} \end{aligned} \tag{11}$$

$$\begin{aligned} \dot{x}_1 &= -12.195\, x_1 + 9.78\, u_{1s} + 2.41 \\ \dot{x}_2 &= 2.5126\, x_1 - 2.5126\, x_2 \\ \dot{x}_3 &= 10\, x_2(t-0.005) - 10\, x_3 \\ \dot{x}_4 &= [(6.74 \times x_2(t-0.045) + 2.84) \\ &\quad \times x_6^{-0.2567}] - 0.0818\, x_4 \\ \dot{x}_5 &= 0.5882\, x_4 - 0.5882\, x_5 \\ &\quad + 41.83\, [(6.74 \\ &\quad \times x_2(t-0.045) + 2.84) \\ &\quad \times x_6^{-0.2567}] \\ \dot{x}_6 &= 0.3226\, u_{2s} - 0.3226\, x_6 \end{aligned} \tag{12}$$

$$\begin{aligned} y_1 &= x_5 \\ y_2 &= 197.71\, x_3 - 35.61 \end{aligned} \tag{13}$$

The general form of the state-space equations of the gas turbine model is as the relationship given in (14):

$$\begin{cases} \dot{X} = AX + A_d X(t-d) + BU + Dw \\ Y = CX \end{cases} \tag{14}$$

In model (14), X, X (t-d), U, and w represent the system state variables, delays in system states, system inputs, disturbances in the system, respectively. According to the equations (11) to (14), the numerical value of the matrix describing the system is as the following equation (15) in state-space form:

$$A = \begin{bmatrix} -12.195 & 0 & 0 & 0 & 0 & 0 \\ 2.5126 & -2.5126 & 0 & 0 & 0 & 0 \\ 0 & 0 & -10 & 0 & 0 & 0 \\ 0 & 0 & 0 & -0.0818 & 0 & 0 \\ 0 & 0 & 0 & 0.5882 & -0.5882 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0.3226 \end{bmatrix}$$

$$B = \begin{bmatrix} 9.78 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0.3226 \end{bmatrix}$$

$$A_d = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 10 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (15)$$

$$C = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 197.71 & 0 & 0 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 41.83 \\ 0 \end{bmatrix}$$

It is to be noted that:

$$U = \begin{bmatrix} u_{1s} + 0.246 \\ u_{2s} \end{bmatrix}$$

$$Y = \begin{bmatrix} y_1 \\ y_2 + 35.61 \end{bmatrix} \quad (16)$$

$$d = 0.005$$

$$w = [(6.74 \times x_2(t - 0.045) + 2.84) \times x_6^{-0.2567}]$$

In the following, the design parameters for the genetic algorithm have been shown in the following table.

Table 3: designed parameters in type-2 fuzzy control

e-dot / e	NB	NS	Z	PS	PB
NB	b1	b2	b3	b4	b5
NS	b6	b7	b8	b9	b10
Z	b11	b12	b13	b14	b15
PS	b16	b17	b18	b19	b20
PB	b21	b22	b23	b24	b25

After the application of the optimal results obtained from the genetic algorithm in fuzzy control, the output variables of V94.2 gas turbine are as follows.

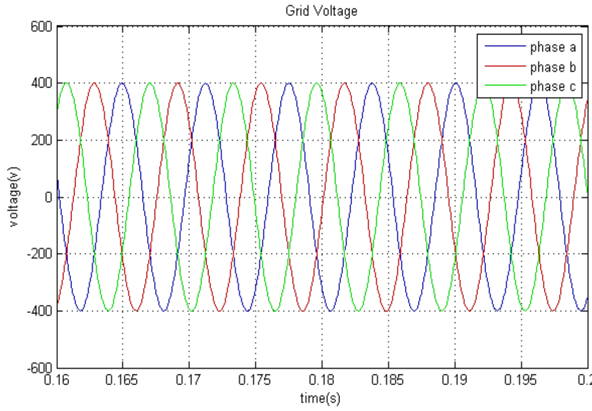

Figure 3: The temperature T output variable in presence Fuzzy Controller

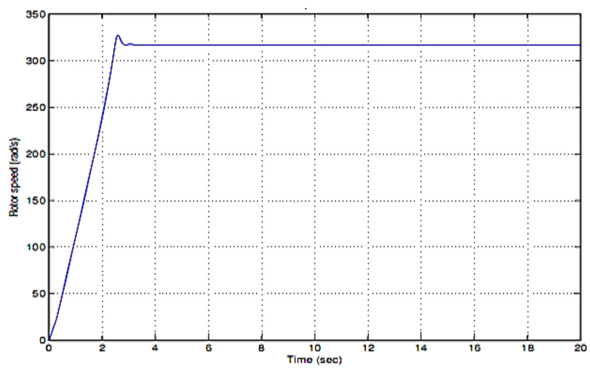

Figure 4: The mechanical powerP_m output variable in presence Fuzzy Controller

According to Figure 3andFigure 4, it is clear that the control structure applied in this paper has stabilized the output variables of the gas turbine V94.2 without the need for expert information about the system. The control signals applied to the system by the designed controller are represented as Figure 5 and Figure 6.

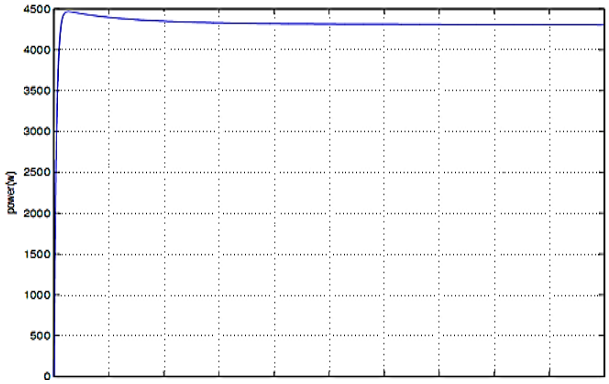

Figure 5: $u_1(t)$ control signal from Fuzzy Controller

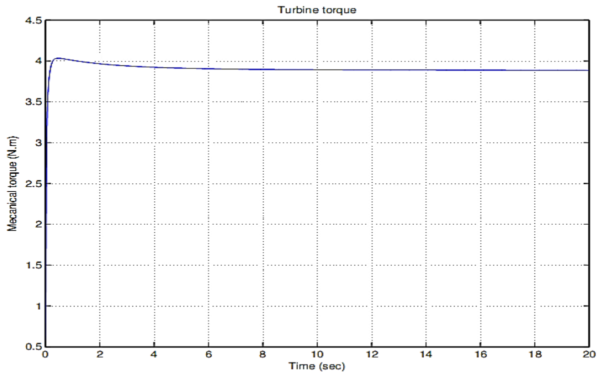

Figure 6: $u_2(t)$ control signal from Fuzzy Controller

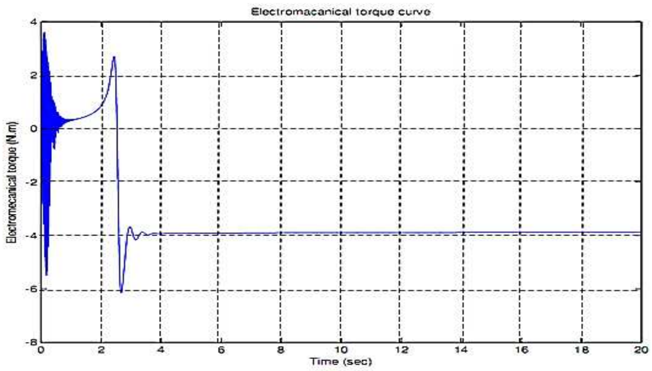

Figure 7: $u_1(t)$ control signal from Fuzzy Controller

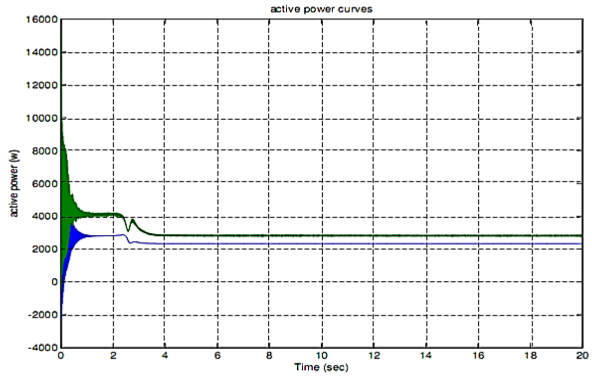

Figure 8: $u_2(t)$ control signal from Fuzzy Controller

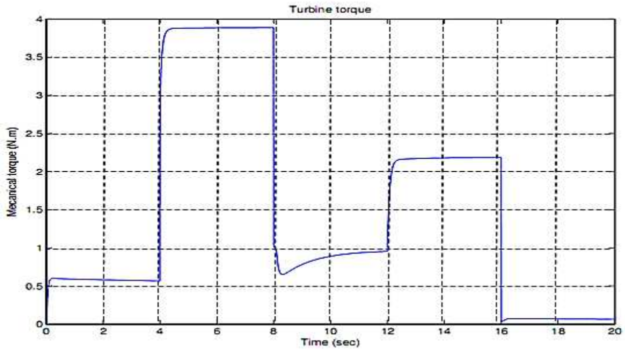

Figure 9: $u_1(t)$ control signal from Fuzzy Controller

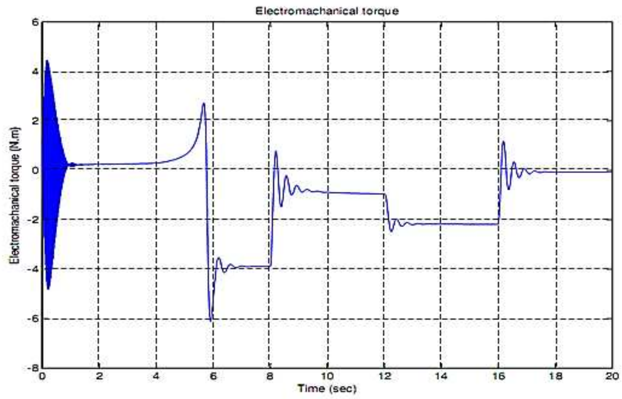

Figure 10: $u_2(t)$ control signal from Fuzzy Controller

4- Conclusion

In this paper, a nonlinear model was extracted for gas turbine V94.2 based on Rowen model and with regard to the accessibility of performance data and actual data measured in plant. This nonlinear model dynamically is an unstable system with nonlinear dynamical behaviors. In the following, the capability of combined fuzzy controllers was used to ensure system stability in the face of noise and disturbance. Given the weakness of fuzzy controllers for the systems that do not have access to expert information, genetic optimization algorithm has been added to the control structure in order to deal with this problem. The use of genetic algorithms in this paper was aimed at determining the optimal fuzzy control rules by minimizing a certain cost function. The results of the simulation revealed the proper functioning of the type-2 fuzzy controller in detecting the reference optimum signals by the variables of gas turbine V94.2. For the continuation of research in this domain, it is suggested to increase the accuracy of V94.2 model presented in this article by obtaining a more comprehensive model for each of the gas turbine components. For example, drive time delay, valve friction, and so on will also be considered in the valve model of fuel control. Similarly, it is possible to observe the impact of load disturbance and network frequency on the model and to increase the model consistency with the reality by obtaining the generator model and adding it to the existing gas turbine model.

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