Cumhuriyet Üniversitesi Fen Fakültesi
Fen Bilimleri Dergisi (CFD), Cilt:36, No: 3 Özel Sayı (2015)
ISSN: 1300-1949

Cumhuriyet University Faculty of Science
Science Journal (CSJ), Vol. 36, No: 3 Special Issue (2015)
ISSN: 1300-1949

Diagnosis and remedy of fault in a gas turbine with neural network and adaptive control

Meisam FATAHİ[1,*], Hamed KHODADADİ[2]

[1]*Department of Electrical, Abarkouh Branch, Islamic Azad University, Abarkouh, Iran*

[2]*Department of Electrical Egineering, Khomeini Shahr Branch, Islamic Azad University, Khomeini Shahr, Iran*

Received: 01.02.2015; Accepted: 05.05.2015

Abstract. This article is based on a design method of (neural network) in two different modes with the development and application of artificial neural network technique to diagnose (identifying and modeling) using an levenberg-marquardt algorithm and 4 conmon fault applied to gas turbine and then an exact detailed model of the procurement process and its control units provided and by comparing the output with the same variables in the nerrous pulsing estimates set the modeling and simulation of extraction and the difference they can be identified as residual .And in the next step using the remedy instrument (control instrument maker ADRS) to reach on optimal response in a sensitive , complex and nonlinear gas turbines in order to protect it against the fault progress of gas turbine that leads to adverse events and occurrence of break down that be great deal . the result of simulation of optimum performance shows the proper function of proposed controller

Keywords: Gas turbine, fault diagnosis , levenberg-marquardt algorithm, compensation ADRC

1. INTRODUCTION

Since the 1960 years the impact of automation on the operation and design of industrial processes increased gradually and from the beginning of the year 1970 with in creasingcomplexity and control system development and use gas turbine in filled and sensitive environment , like jet motorsnuclear and chemical centers and their important role's of it in the aviation industry, the production of electricity in modern industry need to develop reliable and accurate models and do the recogniation fault process at the same time and try to compensate those fault and disclosing them based on the operator'sperformance is absolutely impossible, furthermore, to prevent a huge irreparable and heavy costs for repair and maintenance is a basic and it is important, during recent decades, artificial intelligence as a powerful and reliable tool for indentification of nonlinear systems with success it used as official refinery pattern. In Ⅱ part phase fault diagnosis and it's different methods and in Ⅲ part the principle of gas turbine function and modeling gas turbine in Ⅳpart by using ANN and feed-forward training model and levenberg-marquardt algorithm with number of neurons and leading to arrange 10,15,20, reviews the results-based on performance measurement of norm (MSE) function error between the output model and the output software system as a criterion for distinguishing the appropriate structure and the best combination of transfer function between them are chased and network education in two mood without error and the presence of error by residual has been simulated and in phase part by using ADRC compensating as signal tracking referencestep for gas turbine error can be done in part the results and suggestion offered .

*Corresponding author. *Email address: meısam.fatahı19@yahoo.com*

Special Issue: The Second National Conference on Applied Research in Science and Technology

2. FAULT DIAGNOSIS

In, fact fault diagnosis is the result of a comparison, and this comparison in diagnosis should be between faulty system and healthy system, if a system turns out to be healthy, so any unexpected deviation of it reveal the fault .

Fault; it is an illegal deviation from at least one defiant attribute (feathers) of a system from standard mood to another that called core engine performance deterioration. [1]

3. GAS TURBINE AND ITS COMPONENTS

A gas turbine is a periodical engine and by controling the hat gases pass flow by inhibiting the production of energy. This engine has three major part includes compressor, combustion chamber and the turbine. At the first stage of gas turbine work, a starter which has been coupled to compressor and during the start process turns the compressor air through compressor's suction can be entered, and at the bottom it is compressed so increased temperature and pressure, then this hot and compressed air enters the combustion chamber .This place is combined with air and fuel combustion takesplace, the higer the temperature, and the mixture can be ignited quickly expanded. Hot gases resulting from the combustion turbine in the next stage will be entered into with the turbine blades would deal with the fan turbine due to low total.Compressor with this rotating moved and no need to ballast suction and rotating air continues and this cycle will continue, the path through the air inside the turbine and it can be combined with fuel to be turned into the path of the hot gases called pass gas .due to the importance role of the passing by gas through the path inside the main components, this path's analysis can be an an important performance status and health outcome of turbine at the discretion of the user . [2]

3.1. Simulated fault conditions

In gas turbine four fault include compressor contamination Fs(t), thermocouple sensor fault (output sensor failure), fy(t), high pressure turbine seal damage (core engine performance deterioration), fs(t), fuel actuator friction wear (controller fault),fc(t),Note that in real industrial application it is commonplace for each of the above fault to develop slowly over a decade or months for the purpose of this simulation In order to avoid excessively long duration simulations occur over periods of seconds-a factor which must be taken account of in any FDI algorithm design, it is amazed to know low small fault has been making.

4. IDENTIFICATION

4.1. Artificial neural network

Artificial neural network is a date driven model. ANN is a group of interconnected artificial units (neurons)with linear or nonlinear transfer faunctions, like system identification, moderate fuanction and control have been applied.

4.2. forming levenberg-marquardtalgoritm

Consider the following equation:

$$x_{k+1} = x_k [J^T(x_k) J(x_k) + \mu_k I]^{-1} J^T(x_k) v(x_k) \tag{1}$$

or:

$$\Delta x_k = -[J^T(x_k)J(x_k) + \mu_k I]^{-1} J^T(x_k) v(x_k) \quad (2)$$

This algorithm has the main priority that by increasing the amount of algorithm μ_k algorithm change to the must decreasing algorithm and the amount of learning being smaller

In fact, we have big μ_k

$$x_{k+1} \cong x_k - \frac{1}{\mu_k} J^T(x_k) v(x_k) = x_k - \frac{1}{2\mu_k} \nabla F(x) \quad (3)$$

$$F(x) = \sum_{q=1}^{Q} (t_q - a_q)^T (t_q) = \sum_{q=1}^{Q} e_q^T e_q = \sum_{q=1}^{Q} \sum_{j=1}^{Q} (e_{j,q})^2 = \sum_{i=1}^{N} (v_i)^2 \quad 4)$$

So ,q,ei,j is a member of vector error about q entrance couple that is goal vector [3] the ARX model always has been used for dynamic system, linear ARX can not display input and output model. In such case we can use nonlinear ARX for system identification. This model expressed system output according to system input and former output.

$$y(t) = f\big(y(t-1), \dots, y(t-n_a), u(t-d), \dots, u(t-n_b-d)\big) \quad (5)$$

Function 4 appeared an a nonlinear mapping 4 compared to the linear model ARX the relationship between the input and output of system will allow access to proper nonlinear function for modeling and identification system is not an easy job, one of policy that can be chose for this function .

It's placement with a neural network and then trained it as anonlinear ARX model and is expressed by this and 4 relationship between input and output with lowest estimated error does established. In this paper, the feed forward network has used for modeling and evaluating network and for training using the levenberg-marquardtalgorithm .[3-4]

4.3. The stricter of neural network in nonlinear model ARX

Doing a lot of simulation, indicate that the best structure for this network was feed forward which has 3 hidden layers with some neurons by this order 20,15 and 10. For this network hidden layers the verity of function has been used which is provided in table (I). and for training network levenberg-marquardt algorithm has been used . [5]

Table 1. Ten different mood for transfer function which is used in different neural network layers.

Mood	Layer1	Layer2	Layer3	mood	Layer1	Layer2	Layer3
1	Purelin	tansig	Logsig	6	hardlim	Tansig	Hardlim
2	Hardlim	purelin	Logsig	7	purelin	Satlin	Logsig
3	Tansig	tansig	Tansig	8	Satlin	purelin	Purelin
4	Logsig	hardlim	Purelin	9	purelin	Logsig	Radbas
5	Radbas	radbas	Radbas	10	Radbas	purelin	Tansig

At first, we consider any mood at table I and train the network. Then by putting input system in nonlinear ARX, approaching the desired out pouts in order to find the best combine in transform function in 10 mood we choose the mean square error (MSE) between output model and output system .

Table II indicates the best performance it should be noted that the necessary date for training network, for simulation the gas turbine system for 80 second a period of time and 0.01 second fixed time is obtained. As well as the singles used in available linear function have been chosen to the following:

$$\Psi = [y(t-2) \quad y(t-1) \quad F_f(t-2) \quad F_f(t-3) \quad a_v(t-2) \quad a_v(t-3)] \tag{6}$$

The errors norm between output model with my out of the sestem is measured by y is show in table 2,in a stste of 9 is very small in comparsion to the rest of scenarios.if the input to the ARX model of nonlinear that neural network layers which are includes 9 transfer function, and we applied this,the output of the network will be the shape (1.a).the output of this two different error will be zero and this shows the high difference accuracy identification.

Table 2. Output error estimation in 10 different mood for neural network transfer functional.

mood	$\|y - y_m\|$	**mood**	$\|y - y_m\|$
1	**2.4473 e4**	**6**	**1.7451**
2	**1.1729 e4**	**7**	**1.8596 e4**
3	**0.3890 e4**	**8**	**0.0161 e4**
4	**0.4292 e4**	**9**	**0.0002 e4**
5	**0.1400 e4**	**10**	**0.9018 e4**

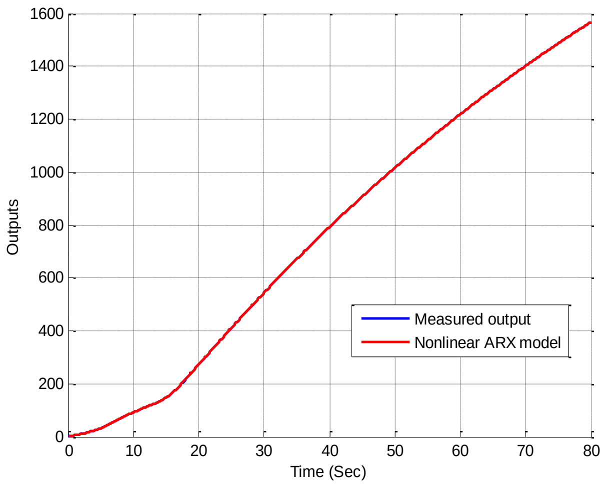


Figure (1.a). Error between output measurement and model identification

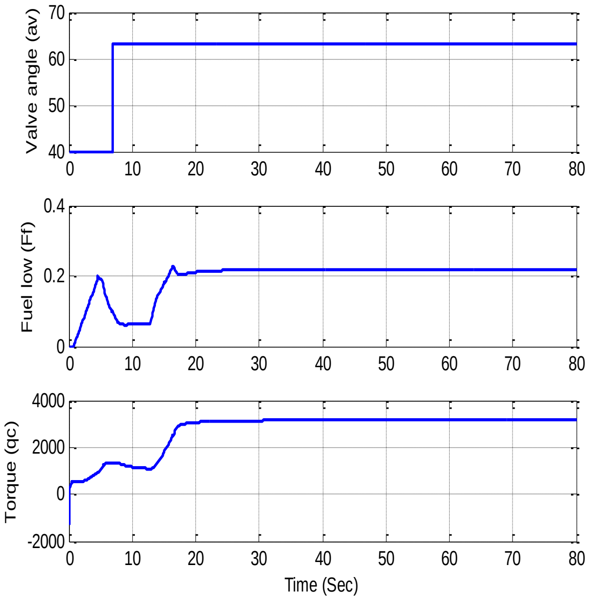
4.4. Simulation

For 4 different model of possible failure at a single gas turbine system, there is, an operation failure diagnosis . failure diagnosis has been alone by this two models [6] :

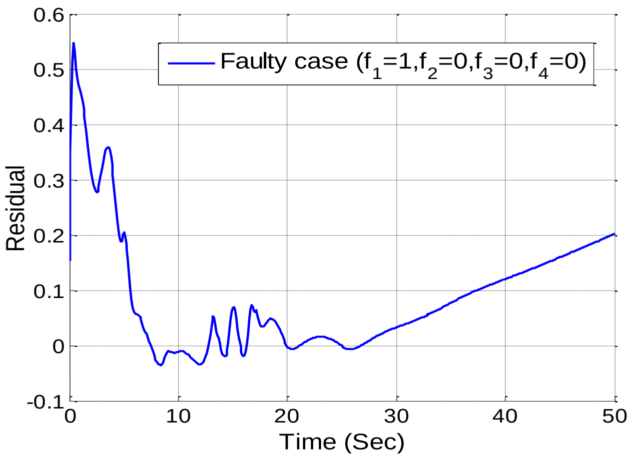
1) Training network at without fault mood and diagnosis failure the residual was not zero
2) Training network at the presence of failure and diagnosis failure the residual is zero

4.4.1. Failure number 1

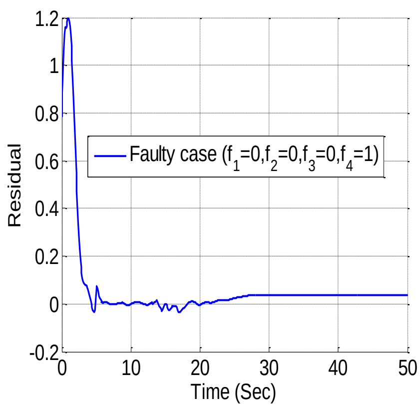
Failure number 1 representent the model that neural network fuel flow and valve angle are inputs and output is the rate of moment qc(t). figures (2.a) and (2.b) in order are systems output and input, due to failure which has happened on output qc(t) it has been displayed. This figure is against zero result shows the moment of failure, and indicate the ability of neural network model at diagnosis failure figure (2.a) the recordered input and output for figure (2.b). and the amount of training neural network that has remained when failure case1 has happened.

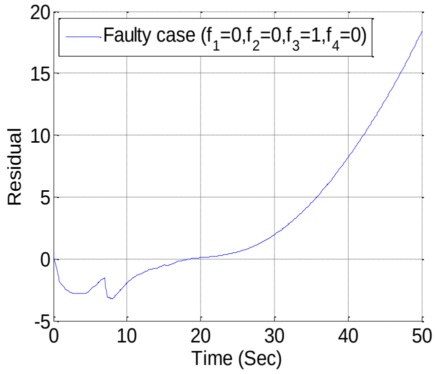


Figure(2.a). The recorded input and output for training neural network at failure case 1



Figure(2.b). Value residual at failure case 1 has happend





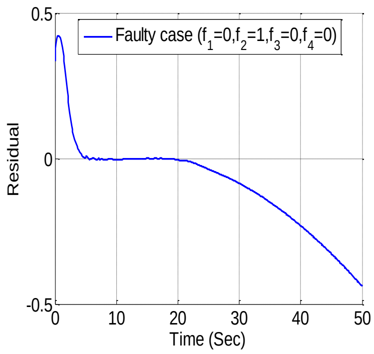


Figure 3. Happened errors

4.4.2. Fault diagnosis by using case 2

In this case, by doing failure on each output gas turbine, the remain of it was identified for all four case and was calculate in former part.

All remain except case 1 are not equal to zero .

Table 3. Values residual obtained for different errors.

residual / Fault type	r_1	r_2	r_3	r_4
f_1	0	Against 0	Against 0	Against 0
f_2	Against 0	0	Against 0	Against 0
f_3	Against 0	Against 0	0	Against 0
f_4	Against 0	Against 0	Against 0	0

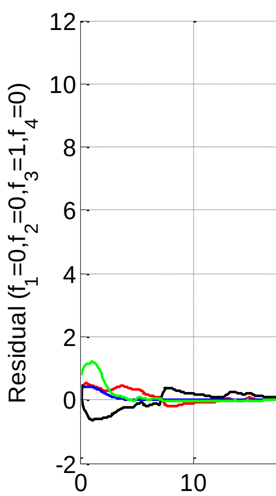


Figure (3.a). the residual of identification models of 3 fault occur.

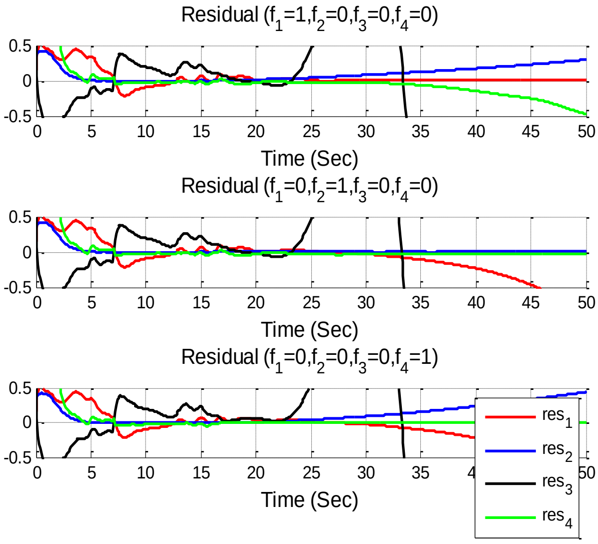


Figure (3.b). Other residuals.

5. ACTIVE DISTURBANCE REJECTION CONTROL (ADRC)

In this article the results relation to the compensation of gas turbine for uniaxial has been offered. The method that has been used for compensation was called the active disturbance rejection control which is part of adaptive robust method, this method applicable to dynamic systems , which has a cononical form of state space are displayed. First we introduce method and then we show that it is a workable method for gas turbine systems .the goal of controller device is to reach output system to desirable point .therefore, the actual value of the output of the device controller in order to make the desired amount comparied with the reference input, and will determine its deviation and a control signal to deliver zero offset buildup with small quantities. Set the controller on the basis of expectations we have on control ring has done .then the simulation results are present and the efficiency of the proposed method will be proof. To check this thread first, entry and exist system should be specified. Therefore. In order to reach this approach take system independent Tinlet input temperature and output system are taken any signal that can be important for the design .here output take equal to qco and suppose that the goal of control by input Tinlet variance. To check the veracity of the matter .by using the mean square we find the transfer function between this two variables if it's a deal that the transfer function has a cononical mode space, it must be displayed by this forms

$$q_{co}(k) = a_1 q_{co}(k-1) + a_2 q_{co}(k-2) + \cdots + a_n q_{co}(k-n) + bT_{inlet}(k-1) \quad (7)$$

So the transfer function system is equal to:

$$G(z^{-1}) = \frac{bz^{-1}}{a_1 z^{-1} + a_2 z^{-2} + \cdots + a_n z^{-n}} \quad (8)$$

Now if we explain system mode like this,

$$x_1 = y(k-n), x_2 = y(k-n+1), \ldots, x_n = y(k-1) \tag{9}$$

We have,

$$\begin{cases} x_1(k+1) = x_2(k) \\ x_2(k+1) = x_3(k) \\ \vdots \\ x_n(k+1) = a_n x_1(k) + a_{n-1} x_2(k) + \cdots + a_1 x_n(k) + bu(k-1) \end{cases} \tag{10}$$

Therefore, first we have tried to take randomly entry to Tinlet input and measuring qco output, and we obtain transfer function to form(8) for system. If by using this transfer function the threat of input and output system has been modeled well so, the result is we have the input and output system by cononical form model . it should be noted that this experiment is just to secure of this matter that open loop system can be modeled by transfer function (8) form firt , random entry figure (4.b) to apply the system , and the output measurement of system will be in figure (4.a). Now assuming that the system is to the level 2 and system parameters with respect to the method of least squares was obtained as follows :

$$a_1 = 0.9350 , a_2 = 0.0552 , b = 0.1084 \tag{11}$$

With respect to obtained result we can apply ADRC method in gas turbine system Because , it has been shown that open loop system thread complies with transfer function which has cononical farm displayed .

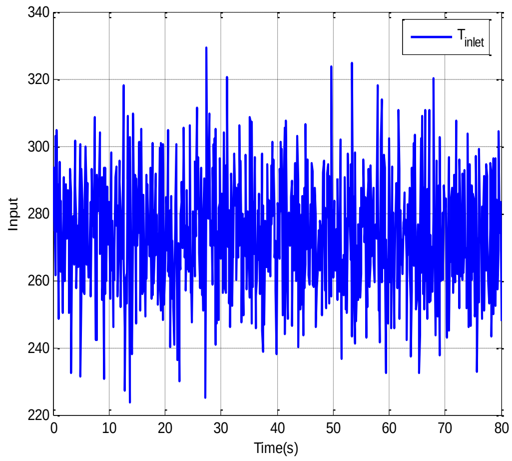


Figure (4.b). Applied random input to system In order to Identification model.

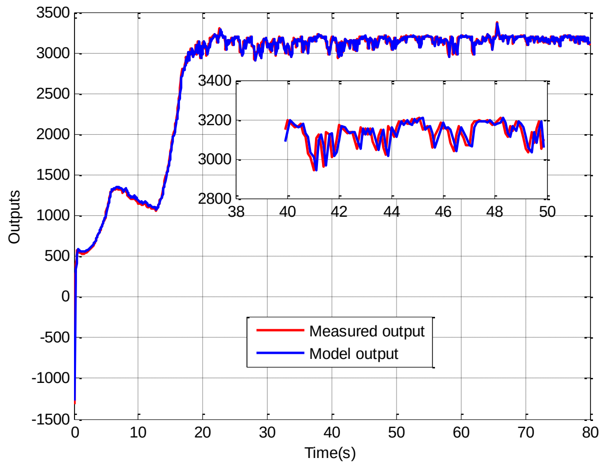


Figure (4.a). Measuring output of gas turbine system and ouyput of Identification model.

5.1. Compensation first case fault at gas turbine system

According to being 2 grade of this system, ADRC controller which has a 3 grade cursor estimater has been design to check the performance of the close-loop system and ability to remove the errors occured in the controller on the output of the system we consider to both simulation mode, in the first case the reference signal tracking step in the presence of error and in the absence of the error take place .

5.2. Tracking signal reference step at the second fault mode

In the first case of simulation assume that purpose of the tracking step reference signal is3000 demine. The controller bandwidth and observer in order is equal to wc=1 ,wo=4 . the desire aim is eliminating the fault onthe output system which is a kind of slope and at themoment of td=60 occurs, at the figure (5.b) and the reaction of controller can be seen clearly at the moment of occurs, it should be noted that above results in the case comes as no information was available on system, and all the signals needed to control the system , by aobserver has been generalized at the discretion of the controller[7-10]

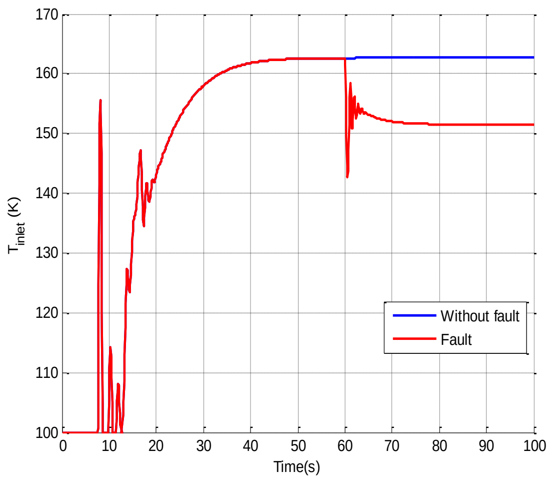


Figure (5.a). applying entry (input) without presence and with fault case 1 at following reference step signal

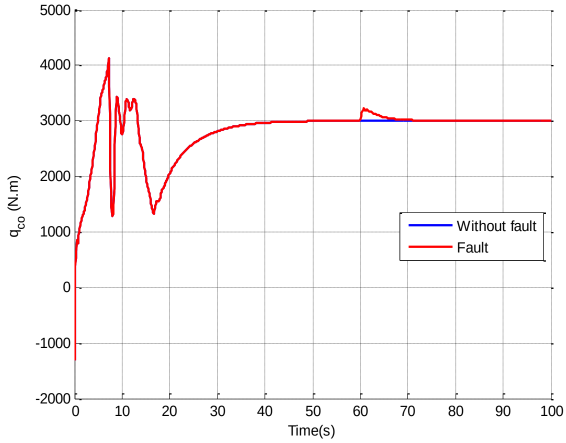


Figure (5.b). exist (output) system at close loop system at the presence and without presence of fault case one at tracking signal reference step .

6. CONCLUSION

Designing of a model by using neural network can recognized nonlinear behavior and control it so it is strong powerful and reliable techniques .Therefore, the main purpose of correct and on time diagnosis of fault is to prevent of it's progress. At the stage of making compensation while having the appropriate function, the fault can be detected well in such way that does not reduce the efficiency of the system and to reach the desire response .

The cases where they have ability to continue this work to offer, it can refer to solve the problem of neural network at the presence of disturbance ,also we can noted to the affect of exact modeling of fault diagnosis system in which at the simultaneously fault occer at second case diagnosis case, according to fault which has been trained.

REFRENCES

R. Isermann, "Fault-Diagnosis Applications,"springer Heidelberg Dordrecht London new York;library of congerss control number;2011926417.2011

Industrial gas turbines: Performance and operability, Robin Elder,2007.

Martin T.Hagan,HowardB.Dcmuth, Mark Beale: Neural Network Design ,2002

Ljung,L.,"system identification: theory for the user", (Prentice-Hall, Upper Saddle River, Nj),1999.

Asgari, H., Chen, X., Menhaj, M. B., &Sainudiin, R. "Artificial Neural Network–Based System Identification for a Single-Shaft Gas Turbine", Journal of Engineering for Gas Turbines and Power, 135(9), 092601, 2013.

Patton, R. J., et al. "Fault diagnosis of a simulated model of an industrial gas turbine prototype using identification techniques." Proceedings of the 4th IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes. 2000.

J.Q. Han, "From PID to active disturbance rejection control", IEEE Trans. Ind. Electron., 56, 900-906, 2009.

Z. Gao, "Active disturbance rejection control: A paradigm shift in feedback control system design," in Proc. Amer. Control Conf., pp. 2399–2405, 2006.

W. Zhou, S. Shao, Z. Gao, "A Stability Staudy of the Active Disturbance Rejection Control Problem by a Singular Perturbation Approach", Applied Mathematical Sciences, vol. 3, no, 10, 491-508, 2009.

Bao-Zhu Guo, Zhi-Liuang Zhao, Cui-Zhen Yao:"The Active Disturbance Rejection Control for Nonlinear System Using Time-Varying-Gaine"IEEE,2013.