Analyzing the behavior of a Reheat Gas Turbine cycle by using Adaptive Neuro-Fuzzy Inference System

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Abstract

The gas turbines holds a very important role in many industrial applications like power generation, food processing industry and many more. Testing the behavior of the whole system before implementing and during the operations plays an important role economically and for overall optimization of the system. There are many techniques to check the behavior of the gas turbines. In the present study the technique used for the optimization of the gas turbine is Adaptive Neuro Fuzzy Inference System (ANFIS). The work is devoted to analysis and optimization of reheat cycle of the gas turbine engines to obtain the optimum design point in accordance with the demand of maximum thermal efficiency or maximum specific output. The optimization of criteria such as thermal efficiency and specific output can be formulated as a Neuro-Fuzzy Problem and is hence solved using Adaptive Neuro Fuzzy Inference System (ANFIS) in Matlab software. This technique is used for solving constrained optimization problems with objective and constraint function. The gas turbine system is divided into a number of sub-systems and operating state is expressed by design variables that govern such system. The results obtained are quite satisfactory. ANFIS is quite accurate, efficient and fast as it gets adapted to the prevailing conditions under real circumstances. The results obtained are compared with those obtained by multiplier method to establish the validity of optimization procedure.

Keywords.*Adaptive Neuro Fuzzy Inference System, Optimization*

1. Introduction

The gas turbines are enormously used for Power generation which is one of an important issue today. Demand is outweighing supply because of lack of initiatives by the industries to build their own Co-generation plants for their energy needs. As such the current power plants can be used for their full strength by predicting the need of power utilization and optimizing the current power production systems. Electronic revolutions in the fields of computers equipped with the intelligent techniques can prove to be role changer to overcome the problems of the power needs.The power requirements can only be met by optimizing the existing power plants so that the power generation can be increased to its fullest strength. Due to this the thermodynamics engineers especially in the fields of power generation and those who are well well acquainted with the gas turbine cycles such as Brayton Cycle, will be in high demand.It is the backbone of power generation. Tsujikawa et al.[1]devoted their study to the analysis and optimization of simple and sophisticated cycles, particularly for various gas turbines engines and aero-engines (including ramjet engine) to achieve maximum performance. The optimization of factors such as thermal efficiency, specific output and total performance for gas turbine engines and overall efficiency, non-dimensional thrust and specific impulse for aero-engines has been performed by optimization procedure with the multiplier method. Mallinsonet al. investigated the part load performance of various gas turbine engine schemes and conventional three group notation given by them has been adopted here also.In the present study the optimization of Reheat Cycle of gas turbine is done using the intelligent technique Adaptive Neuro Fuzzy Inference System (ANFIS). The architecture and learning procedure of ANFIS (Adaptive Neuro Fuzzy Inference System), which is a fuzzy inference system implemented in the framework of adaptive networks is explained in the study of (JyhShing Roger Jang). In this technique firstly learning of the Neural system of the technique is done so that the technique gets adapted to the behaviour of the system to be optimized.Maryam et al.[3] used the ANFIS technique for calculating the demand of biological oxygen (BOD) for the Surma River of Bangladesh. Abdorreza et al.[4] used the ANFIS technique is used for calculating the soil properties like Pedotransfer functions, geometric mean diameter and mean weight diameter.Amir et al.[5] estimated the placement of well for oil and gas production in the reservoir is estimated by using the ANFIS. The technique used genetic algorithms for populating the ANFIS. ANFIS is used for evaluating the discharge co-efficient of triangular labyrinths weirs. The results were compared with those of Multilayer Perceptron (MLP) methods, which showed that the ANFIS results are more optimal. As far from the above said researches this technique is used for every field like economics for analysing the exchange rate and GDP,[6] meteorologyfor predicting the wind speed ,[7] automobile for fault diagnostics in the gearbox.[8]

2. Mathematical modelling of the problem

As the area of application of gas turbine is extended, the thermodynamic cycle of gas turbine becomes more sophisticated. The gas turbine basically consists of compressor, combustor and a turbine. By the inclusion of heat exchangers such as regenerator the amount of fuel required can be reduced which increases the thermal efficiency. The increase in the number of components, however, requires more elaborate analysis to determine the conditions for the cycle. In the present study, the cycle is divided into a number of sub-system or components. The operating state is expressed by parameters that govern such sub-systems. Thefactor of optimization are thermal efficiency and specific work done. The optimization of above mentioned criteria is done with the help of Adaptive Neuro Fuzzy Inference System. This method can be employed for simple and sophisticated cycles as well as for giving the optimum values of parameters in short time. This is an artificial intelligent method which can further predict the values of optimum parameters for different configurations. This is one of the latest technique developed recently.

The arrangement and block diagram for the 1/LP is shown in Figure 4.5 and Figure 4.6 respectively. There occurs a pressure loss in the combustion chamber only. The configuration has a compressor, combustion chamber and two turbines, one designated as HP (high pressure) turbine and other as LP (low pressure) turbine. High pressure turbine drives the compressor and low pressure turbine gives network output.

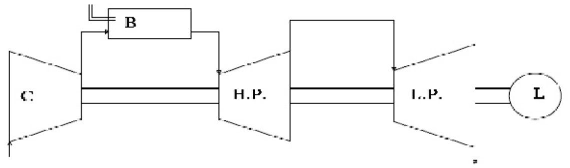


Figure 1. Schematic Diagram of 1/LP Configuration

$$\theta_C = \frac{T_{out}}{T_{in}} = \frac{Temperature\ at\ compressor\ outlet}{Temperature\ at\ compressor\ inlet}$$

$$\theta_E = \frac{T_{EX}}{T_{out}} = \frac{Temperature\ at\ regenerator\ outlet}{Temperature\ of\ air\ at\ the\ inlet\ of\ regenrator}$$

$$\theta_T = \frac{T_E}{T_{max}} = \frac{Temperature\ at\ exhaust\ of\ turbine}{Maximum\ temperature\ of\ cycle}$$

2.1.Constraints

There are three input variables. θ_{HT} is temperature ratio of high pressure turbine. θ_{LT} is the temperature ratio of the low pressure turbine and θ_C is temperature ratio in the compressor.

$$\theta_{HT} = \frac{Temperature\ at\ outlet\ of\ the\ high\ pressure\ turbine}{Temperature\ at\ inlet\ to\ the\ high\ pressure\ turbine} = \frac{T_{E1}}{T_{max}}$$

$$\theta_{LT} = \frac{Temperature\ at\ outlet\ of\ the\ low\ pressure\ turbine}{Temperature\ at\ inlet\ to\ the\ low\ pressure\ tubine} = \frac{T_e}{T_{E1}}$$

1. Temperature at compressor outlet, T_{out} $\geq$ Temperature at compressor inlet, T_{in}

$$0 \leq \theta_C \leq 1$$

2. Temperature at outlet of high pressure turbine, $T_{E1} \leq$ Temperature at inlet to the low pressure turbine, T_{max}

$$T_{E1} \leq T_{max}$$

$$\frac{T_{E1}}{T_{max}} \leq 1$$

$$0 \leq \theta_{HT} \leq 1$$

3. Temperature at outlet of low pressure turbine, $T_e \leq$ Temperature at inlet to the low pressure turbine, T_{E1}

$$T_e \leq T_{E1}$$

$$\frac{T_e}{T_{E1}} \leq 1$$

$$0 \leq \theta_{LT} \leq 1$$

2.2.Non-dimensional specific output

Non-dimensional Specific Output, I = $\frac{l}{C_p T_{in}}$

$$I = \frac{C_P(T_{E1} - T_e)}{C_p T_{in}}$$

$$I = \frac{(T_{E1} - T_e)}{T_{in}}$$

$$I = \frac{T_{E1}}{T_{in}}\left(1 - \frac{T_e}{T_{E1}}\right)$$

$$I = \frac{T_{max}}{T_{in}}\frac{T_{E1}}{T_{max}}\left(1 - \frac{T_e}{T_{E1}}\right)$$

$$I = \theta\ \theta_{HT}(1 - \theta_{LT})$$

2.3.Thermal efficiency

Thermal Efficiency,

$$\eta_{th} = \frac{work\ output\ of\ L.P.turbine}{Energy\ supplied}$$

Work output of L.P. turbine = $C_P(T_{E1} - T_e)$

Energy supplied to the compressor = $\frac{heat\ supplied\ in\ combustion\ chamber}{efficiency\ of\ combustion\ chamber}$

$$= \frac{C_p(T_{max} - T_{out})}{\eta_B}$$

Thermal efficiency, η_{th}

$$= \frac{C_P(T_{E1} - T_e)}{\frac{C_p(T_{max} - T_{out})}{\eta_B}}$$

$$= \frac{\eta_B(T_{E1} - T_e)}{(T_{max} - T_{out})}$$

$$= \eta_B \frac{T_{E1}(1 - \frac{T_e}{T_{E1}})}{(T_{max} - T_{out})}$$

$$= \eta_B \frac{\frac{T_{E1}}{T_{in}}\frac{T_{max}}{T_{max}}(1 - \frac{T_e}{T_{E1}})}{\frac{T_{max}}{T_{in}} - \frac{T_{out}}{T_{in}}}$$

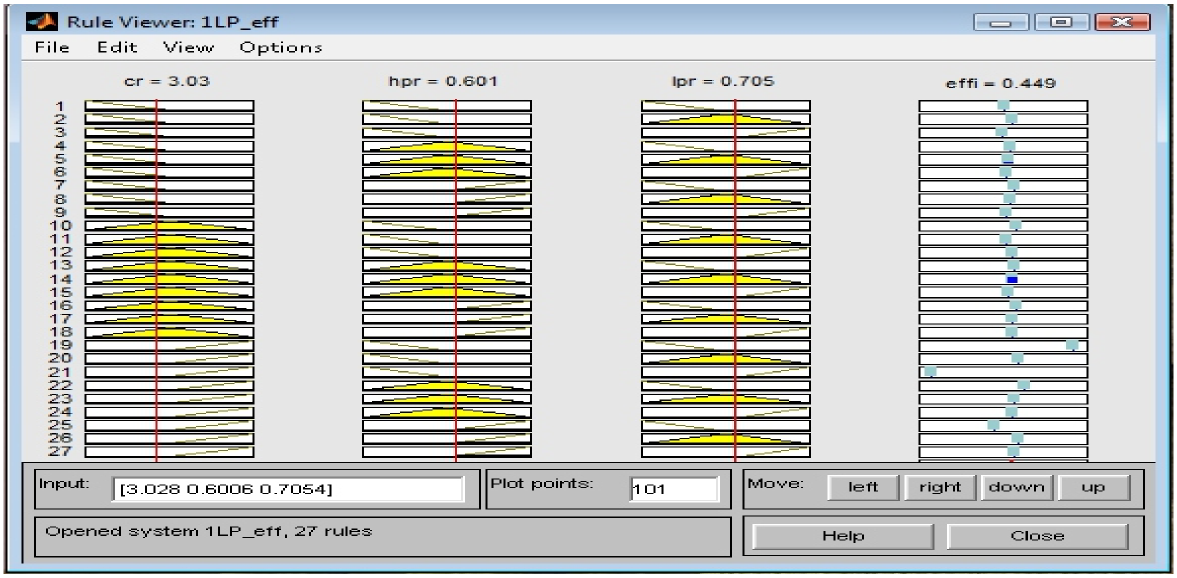
$$\eta_{th} = \eta_B \frac{\theta\theta_{HT}(1 - \theta_{LT})}{\theta - \theta_C}$$

3. Results and discussions

The results for the 1/LP configuration is shown in Figure 2 and Figure 3 in which the results are obtained for the efficiency and specific work done for the two same inputs. In the Figure 2 and Figure 3 the value of efficiency and specific work done are obtained for $\theta_C = 3.028$ (cr=compression ratio), $\theta_{HT} = 0.6006$ (hpr=high pressure turbine ratio) and $\theta_{LT} = 0.7054$ (lpr=low pressure turbine ratio). The output efficiency (effi.=efficiency), $\eta_{th} = 0.449$ and specific work done (swd=specific work done), l = 286 KW/kg sec.

For 1/LP configuration, a higher value of $\theta_{HT}$and a lower value of θ_{LT} results in both increased specific work done and thermal efficiency. A higher value of θ_C results in increased thermal efficiency. So the optimum values of the efficiency and specific work done should be higher at the higher values of θ_{HT} and θ_{LT} as they directly proportional. By the induction a second turbine the energy that we loosing gets recovered hence the thermal efficiency gets enhanced. The table showing the comparison of the results of the Multiplier Method and the ANFIS are shown in Table 1.

For 1/LP configuration, the value of specific output falls as value of $\theta_C$and θ_T increases. The value of thermal efficiency increases as the value of θ_C and θ_E increases and there occurs a fall in the value of θ_T. More compressor work is compensated by the increase in the turbine work output and more heat is transferred to the air entering into combustion chamber by the hot gases in the regenerator.

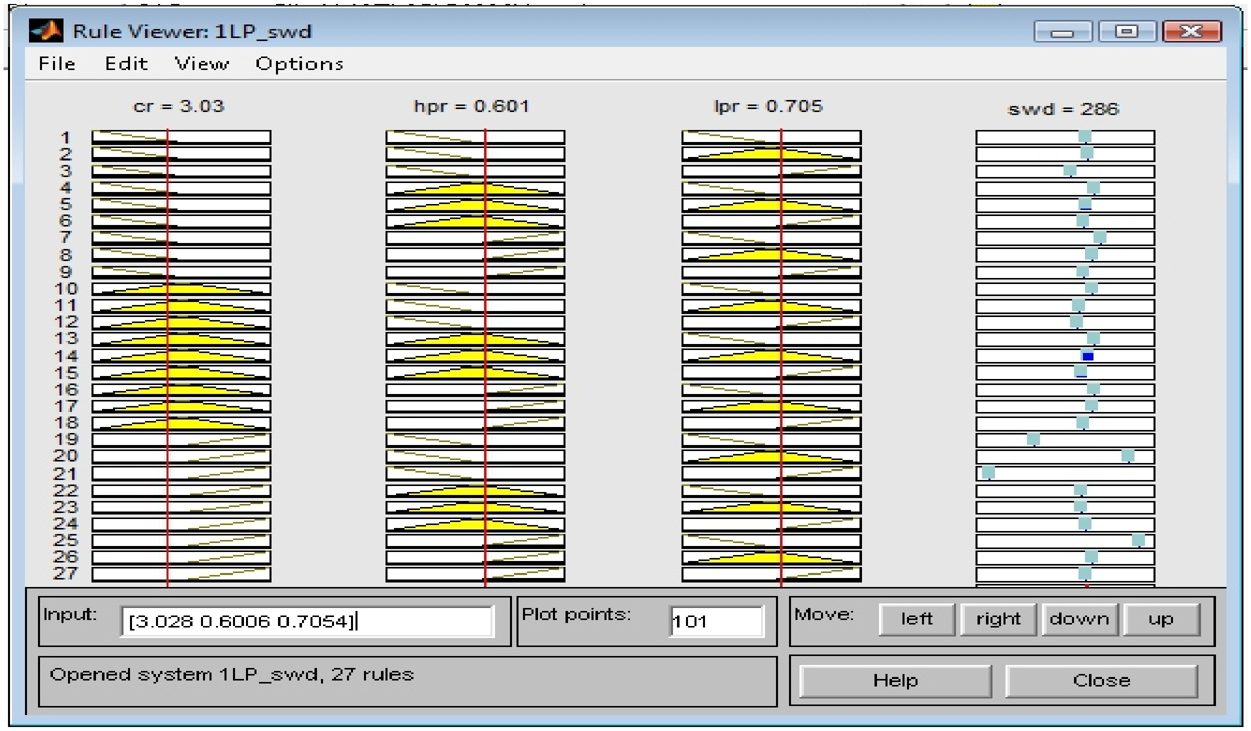


cr = 3.03
hpr = 0.601
lpr = 0.705
effi = 0.449

Input: [3.028 0.6006 0.7054]
Plot points: 101

Opened system 1LP_eff, 27 rules

Figure 2.Result for Efficiency for 1/LP Configuration



cr = 3.03
hpr = 0.601
lpr = 0.705
swd = 286

Input: [3.028 0.6006 0.7054]
Plot points: 101

Opened system 1LP_swd, 27 rules

Figure 3. Result for Specific Work Done for 1/LP Configuration

Values of Various Parameters			Objective Function			
			ANFIS		Multiplier Method	
θ_C	θ_{HT}	θ_{LT}	η_{th}	I(KW/kg s)	η_{th}	I(KW/kg s)
3.028	0.6006	0.7054	44.90%	286	43.97%	288.4
2.187	0.7678	0.715	39.50%	360	38.12%	359
2.497	0.7065	0.6992	40.80%	345	41.59%	347.8

Table 1.Comparison of the Results Obtained with those of Multiplier Method for 1/LP Configuration

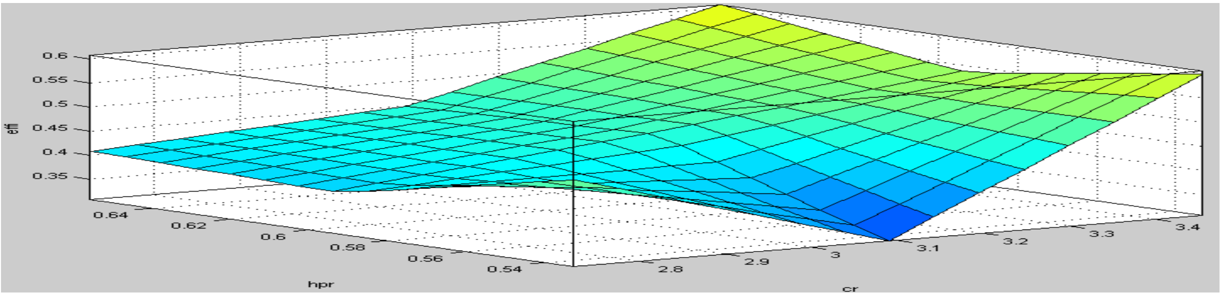


Figure 4. Surface for 1/LP Configuration for Efficiency

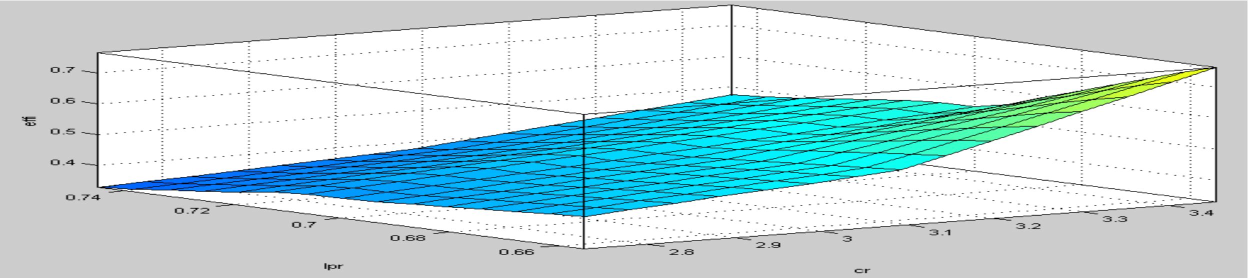


Figure 5.Surface for 1/LP Configuration for Specific Work Done

From the Figure 4 and Figure 5 it is clear that the specific work output increases as θ_T falls because much more work will be obtained from the turbine. In addition , work input required for the compressor also increases; however, the former predominates over the latter, resulting in increasing the work output. The thermal efficiency falls due to increased value of work input to the compressor, less heat is transferred to the air going to the combustion chamber from regenerator as indicated by fall in the value of θ_E and lower value of turbine exhaust temperature resulting in more fuel consumption.

4. Conclusion

The solution of the optimization problem has been obtained with help of Adaptive Neuro Fuzzy Inference System (ANFIS) in Matlab Software. The training data which is used to train the network is given in Appendix-A. The conclusion drawn from the thesis work is given in the following points:

1. The gas turbine system is considered to be made up of a number of sub-systems and the operating state is expressed by design variables that control such subsystems. These design variables are temperature ratios across the compressor, turbine and regenerator which are used to optimize to achieve maximum performance. These temperature ratios are given certain initial values which should satisfy the constraints.
2. The criteria for optimization are thermal efficiency and non-dimensional specific output. The temperature ratio that gives maximum specific output and thermal efficiency are different.
3. The problem of optimization of various gas turbine configurations has been treated as constrained optimization problem with differentiable objective and constraint functions which fully justifies the use of Artificial Neural Networks.
4. The optimum results are obtained with the help of data obtained from the results of Y. Tsujikawa and M. Nagaoka.[1]
5. In the design procedure of various gas turbine schemes, an optimum working cycle can be determined by the ANFIS in a short duration of time.
6. The results obtained by ANFIS technique are compared with those obtained by Multiplier Method to show the validity of ANFIS.

Nomenclature

Data assumed

θ = Maximum temperature ratio of cycle = 5

η_B = Burner efficiency = 0.98

C_P = Specific heat = 1.114 KJ/Kg K

T_{in} = Ambient temperature = 288.15 K

T_W = Temperature of water = 288.15 K

List of symbols

B = Combustion chamber

C = Compressor

C_P = Specific heat (KJ/kg K)

l = Specific output (KW/Kg sec)

I = Non-dimensional specific output

P_{out} = Pressure at inlet of the combustion chamber

T_{max} = Maximum temperature of the cycle

T_{in} = Temperature at inlet to the compressor

T_{out} = Temperature at outlet to the compressor

T_E = Temperature at outlet of the turbine

T_{EX} = Temperature at outlet of the regenerator

T_e = Temperature at outlet of the low pressure turbine

T_W = Temperature of the water

θ = Cycle maximum temperature ratio

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