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THERMODYNAMIC PERFORMANCE ANALYSIS OF A 500MWE SUPERCRITICAL POWER PLANT BASED ON PARAMETRIC AND NEURO-GENETIC OPTIMIZATION TECHNIQUES

Ritesh Ranjan, Sujit Karmakar*

Department of Mechanical engineering, National Institute of technology Durgapur, West Bengal, India

*Corresponding Author Email: sujitkarmakar@yahoo.com

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ABSTRACT

The thermal power plant efficiency depends on many parameters, which includes main steam pressure and temperature, intermediate turbine steam inlet (reheat) pressure, reheat temperature, deaerator pressure, low-pressure turbine steam inlet pressure to mention a few. An ANN-GA (neuro-genetics), parametric based optimization tools are performed to optimize chosen parameters of a 500 MWe super-critical high ash Indian coal fired power plant in this study for getting the best possible net plant efficiency. The net efficiency values of this base plant for random data generated between the ranges of all the chosen parameters is obtained using Fortran based commercially available software called 'Cycle-Tempo'. Levenberg-Marquardt feed forward back propagation technique is used to train the data using Neural network modeling in MATLAB 2018a. Parametric optimization of the plant yielded 7.3% rise in the net plant energy efficiency, 7.32% rise in net exergy efficiency compared to that of base plant whereas neuro-genetic tool resulted in enhancement of energy, exergy efficiencies by 7.8% and 7.82% respectively. Further, a comparative study is made between the results obtained through ANN-GA methodology and parametric optimization technique.

KEYWORDS

coal fired power plant, supercritical, exergy, artificial neural network, genetic algorithm.

1. INTRODUCTION

A developing country like India needs electricity for fastening the growth and economic development. Currently the coal reserve in India is about 319 billion tonnes which is about 10% of world reserve (Ministry of Coal, 2019). In India, coal fired thermal power plant contributes about 54.2% of total installed capacity (Ministry of Power, 2019). The current scenario of sub-critical and supercritical Thermal power plant is as, around 88.65% is based on sub-critical technology and just around 11.35% is based on super-critical technology.

Almost every coal based thermal power plant that uses coal consisting of high ash (HA) have net plant efficiency below 35% on HHV basis. Due to depletion of fossil fuel resources at a faster rate and increase in the emission of CO₂ draws attention for the installation of more efficient thermal power plant so that emission of CO₂ is less. As the number of super-critical thermal power plant is less in number and the present super-critical plant is working in low range and this allow researchers to optimise the various parameters in order to improve the net plant efficiencies as much as possible.

The power plant efficiency depends on so many parameters like main steam pressure and temperature, deaerator pressure, reheat pressure and temperature and condenser pressure. Simultaneous optimization of these parameters is difficult task so the artificial intelligence tool like Artificial neural network (ANN) along with the Genetic algorithm (GA) is used to solve such complex problem. ANN is broadly applied in various field like

optimization, forecasting, image and voice recognition. Suresh, Reddy and Kolar worked on neuro-genetic optimization of high ash coal-fired super-critical power plant (Suresh et al., 2011). Rajarshi, Jitendra and Tarun modelled a Thermal power plant using neural network and regression technique (Dixit et al., 2015).

Genetic Algorithm is used for solving both unconstrained and constrained problems based on natural selection process that is inspired by biological evolution such as mutation, crossover and selection. Wagner, Pereira, Pius and Roberto applied genetic algorithm (GA) for optimising turbine extraction of a pressurized-water reactor (Sacco et al., 2002). In previous study, author have taken three different thermal power plants i.e. subcritical, supercritical and Ultra-supercritical based for optimisation of steam extraction pressure which will helps in enhancing the net plant efficiency along with decrease in specific fuel consumptions (Kumar et al. 2016).

The study presented here used a neuro-genetic optimization technique consisting artificial neural network coupled with genetic algorithm for determining the maximum possible plant net efficiency. This power plant is based on the high ash coal-fired with super-critical steam condition. A 500 MWe super-critical power plant is used for optimization using ANN-GA technique. Also, in this study a comparison is done for energy and exergy analysis of optimised plant based on ANN-GA technique, Parametric optimization technique and further compare the base plant efficiency with parametric optimised plant and neuro-genetic optimised plant.

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Nomenclature

A	$\dot{m}$ = mass flow rate (kg s^{-1})
B	$\dot{N}$ = molar flow rate (kmol s^{-1})
C	$\dot{Q}$ = heat transfer rate (kW)
D	H = specific enthalpy (kJ kg^{-1})
E	ψ = exergy (kJ s^{-1})
F	I = irreversibility rate (kW)

2. METHODOLOGY

As power plant is a complex network, having number of components and each component are connected by various interconnected circuits. A computer software named 'Cycle-Tempo' used for both modelling and simulation of power plant circuit. 'Cycle-Tempo' software used for steady state thermodynamic modelling and analysis of systems is done for production of electricity, heat and refrigeration (Delft University, 2008). Training of neural network (ANN) is done by first generating the random numbers between the fixed ranges of parameters and simulate it in the ANN toolbox included in the MATLAB.

The number of data are taken such that network properly detect the complex relationship between dependent and independent variables and predicts the result having error as minimum as possible. Then the fitness function predicted by the ANN is coupled with GA for optimization of various parameters and getting the maximum plant efficiency corresponding to optimised parameters. Also, the error between the efficiency predicted by the neuro-genetic optimization and the Cycle-Tempo is noted for showing the results.

3. POWER PLANT SIMULATION

This study is done for 500MWe super-critical coal fired thermal power plant as shown in Figure 1. Modeling & simulation of this plant is done on the Cycle-Tempo software and the operating parameters such as pressures, temperatures and efficiencies for each component are specified. Table 1 shows the assumptions made during the simulation (Suresh et al., 2011).

The base plant used here has main steam pressure and temperature of 242.2 bar and 537 °C and having the single reheat at pressure of 42 bar and temperature of reheated steam is 565 °C. An auxiliary power consumption of around 7% is assumed in the base plant and optimized plant which consists of lightening and heating loss, steam turbine auxiliaries, transformer losses. The characteristics of reference high ash Indian coal used here for simulation in Cycle-Tempo is shown in Table 2 (Suresh et al., 2011).

Figure 1: Schematic diagram of 500MWe super-critical power plant

3.1 Performance parameters

The power plant performance is calculated by plant energy and exergy efficiency i.e. η & ϵ .

$$\eta = \frac{\text{net work output rate}}{\text{mass flow rate of fuel} \times \text{LHV of fuel}} \quad (1)$$

$$\epsilon = \frac{\text{net work output}}{\text{mass flow rate of fuel} \times \text{specific exergy of the fuel}} \quad (2)$$

Table 1: Super-critical power plant assumptions

Ambient pressure	1.013 bar
Ambient temperature	33 °C
Relative humidity of the air	60%
Chemical compositions: (mole fraction)	
N ₂	0.7562
O ₂	0.2030
H ₂ O	0.0312
CO ₂	0.0003
Others	0.0093
Ash compositions	
SiO ₂	70
Al ₂ O ₃	30
Condenser pressure (kPa)	10.3
Isentropic efficiencies (%)	
HP turbine	90
IP turbine	92
LP turbine	90
Generator efficiency	98.7
BFP	80
Fans	80

Table 2: Characteristics of Indian coal

High ash coal (HA)	As-received (wt. %)	
	Dry (wt. %)	
Proximate analysis		
Fixed carbon	24.00	27.27
Volatile matter	21.00	23.86
Ash	43.00	48.87
Moisture	12.00	
Ultimate analysis		
C	34.46	39.16
H	2.43	2.76
O	6.97	7.92
N	0.69	0.78
S	0.45	0.51
Ash	43.00	48.87
Moisture	12.00	--
LHV (MJ/kg)	13.96	15.83
Exergy (MJ/kg)	15.26	17.30

4. NEURO-GENETIC OPTIMIZATION

Prior to the training of neural network, the range of chosen parameters must be fixed. In this study, the range of all the six chosen parameters i.e. Main steam pressure and temperature, de-aerator pressure, reheat (IP inlet) pressure as well as its temperature and LP turbine steam inlet pressure are chosen based on the parametric optimization done by the author. Figure 2 represents the ANN schematics with all the six parameters.

Table 3 represents the range of all six parameters. Figure 3 shows the neuro-genetic methodology by using block diagram. The random data which is generated between these range for all the parameters is used for training the network for the prediction of the fitness function. The fitness function obtained after training of neural network is then optimised using genetic algorithm (GA). For this study, the toolbox which is included in the MATLAB for ANN and GA is used.

The Levenberg-Marquardt backpropagation algorithm, with seven number of neurons in the hidden layer, is used for training of the neural network. Neuron independent study is also taken into consideration for reducing the complexity of the network. For optimization, the population size is taken as 300 with the elite count is 2 and crossover fraction as 0.8 respectively.

The regression chart obtained after training and testing of neural network shows that the model is predicting output close to actual value and hence genetic algorithm can be applied over the ANN predicted fitness function to obtain the optimised set of parameters which gives the maximum net plant efficiency. The Figure 4 shows the performance curve after training of the network. The regression fit obtained after training between ANN model and Cycle-Tempo simulation of power plant is shown in Figure 5.

Figure 2: Flow diagram of neural network

Figure 3: ANN-GA based methodology

Table 3: Ranges of different parameters for training and optimization

Parameter	Range
Main steam inlet pressure (bar)	230-300
Main steam inlet temperature (°C)	530-580
Reheat pressure (IP turbine steam inlet) (bar)	30-80
Reheat temperature (°C)	570-620
Deaerator pressure (bar)	7-15
Low pressure turbine inlet pressure (bar)	2-6

Figure 4: Performance curve for ANN model

A comparison of neuro-genetic optimization technique and parametric optimization is done as is represented in Table 4. There is a little change in the value of optimised parameters obtained after the ANN-GA and parametric optimization. One of the main advantages of neuro-genetic optimization is that this process reduces the computational effort in comparison to parametric optimization. With the optimised parameters the plant energy and exergy balance are observed and it is represented

in Table 5 and 6. It is also perceived that the error between the results predicted by the ANN-GA model and the Cycle-Tempo with the same optimised parameters is under the acceptable range and is less than 1%.

Table 7 shows the net plant efficiency predicted by neuro-genetic optimization methodology and the Cycle-Tempo simulation software and its error which is below 1%. Figure 8 shows the comparison of the parametric optimization result and neuro-genetic result with the base plant efficiency by a chart.

Figure 5: Regression fit based on the ANN model

Figure 6: Fitness curve of optimised parameters of plant using GA

Table 4: Comparison of optimised parameters through neuro-genetic technique and parametric optimization technique

Parameters	Operating plant condition	Parametric optimization	Neuro-Genetic optimization
Main steam inlet pressure (bar)	242.2	295	288.63
Main steam inlet temperature (°C)	537	570	579.48
Reheat pressure (IP turbine inlet) (bar)	42	80	79.39
Reheat temperature (°C)	565	590	579.52
Deaerator pressure (bar)	11.94	11	11.38
Low pressure turbine steam inlet pressure (bar)	2.98	2	4.59

Table 5: Energy balance of the optimised plant

Components (%)	Parametric optimization	Neuro-Genetic optimization
Power (net efficiency)	40.96	41.15
Cooling water loss	47.96	48.17
Stack loss	4.83	4.83
Bottom ash heat loss	0.85	0.85
Other losses	5.40	5.00

Table 6: Comparison of exergy balance

Components (%)	Parametric optimization	Neuro-Genetics
Power (net efficiency)	36.07	36.24
Combustor loss	33.37	33.19
Steam generator loss (besides combustor)	18.06	18.06
Stack loss	3.84	3.85
Turbine loss	4.34	4.41
Condenser and cooling water loss	1.87	1.88
Feed water heaters loss	0.68	0.77
Loss through bottom ash	0.45	0.45
Other losses	1.32	1.15

Table 7: Comparison of ANN-GA predicted efficiency and Cycle-Tempo efficiency with the same optimised value obtained using GA

	Operating plant efficiency	ANN-GA predicted value	Cycle-Tempo (with optimised parameters)
Net plant efficiency (%)	38.17	41.32	41.15

Figure 7: Comparison of efficiency of two optimization tool with base plant efficiency

5. CONCLUSIONS

The optimization study conducted on a 500 MWe high ash Indian coal fired thermal power plant has shown that using ANN-GA methodology, the net plant energy efficiency increases by 7.8% whereas the exergy efficiency has increased by 7.82%, whereas the rise in net energy and exergy efficiencies are 7.3% and 7.32% using parametric optimization tool. The reason can be attributed to the rise in mean temperature of heat addition in the boiler with the rise in main steam inlet temperature. For the optimised parameters, the result predicted by the trained ANN-GA closely matches with that of the result obtained using Cycle-Tempo with an error percentage of 0.41%. The results obtained from both optimization tools clearly indicate the scope for efficiency enhancement of the base plant. This would eventually address the environmental concern as there will be a drop in specific CO₂ emission from the plant. The energy balance shows that for neuro-genetic methodology, there is little increase in cooling water loss but other losses decreases. The exergy balance clearly gives idea about the loss of exergy which is maximum in the steam generator dominated by irreversibility associated with coal combustion and heat transfer. So, the exergy analysis draws attention of the designers to focus on steam generators/combustors rather than condensers. Thus, the installation of power plant based on the optimized parameters is more helpful for adding capacity in future.

REFERENCES

- Delft University of Technology. Cycle-Tempo Release 5.0, Delft University of Technology, 2008. See also <http://www.tudelft.nl/live/pagina.jsp?id=8c53f82e-a500-41f1-971b-629e832bfef&lang=en>.
- Dixit, R., Kumar, J., Soota, T. 2015. Modeling of Thermal power plant using neural network and Regression technique. J. Sci. Res. Adv. Vol. 2, No. 4, 166-174.
- Kumar, P. R., Raju, V. R., Kumar, N. R., 2016. Simulation and parametric optimization of thermal power plant cycles", Elsevier, K304-306.
- Ministry of Coal (MOC), Government of India, 2019. Available from <https://www.coal.nic.in/>. Accessed on December 02, 2020.
- Ministry of Power (MOP), Installed generation capacity as on January 31, 2020, Government of India, 2019. Available from <https://powermin.nic.in/>. Accessed on December 02, 2020.
- Sacco, W.F., Claudio, M.N.A. Pereira, Soaresa, P.P.M., Schirru, R. 2002. Genetic algorithm applied to turbine extraction optimization of a pressurised-water reactor", Applied Energy 73, 217-222.
- Suresh, M.V.J.J., Reddy, K.S. and Kolar, A.K., 2011. ANN-GA based optimization of a high ash coal-fired supercritical power plant. Applied energy, 88(12), 4867-4873.