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Artificial Neural Network based Prediction Model for reduction of failure frequency in Thermal Power Plants

Om Prakash[1], T. Ravi Kiran[2] and Ajay Kumar Kaviti[1]

[1]Department of Mechanical Engineering, Sagar Institute of Science and Technology, Gandhi Nagar, Bhopal
[2]Department of Mechanical Engineering, Maulana Azad National Institute of Technology, Bhopal

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ABSTRACT

This paper describes a systematic approach to predict the water level in the drum of a steam boiler with the help of artificial neural networks (ANN). The parameters of the model can be obtained from the physical dimensions and characteristics of the boiler. The frequency of deviations and the degree of deviation of the water level in the drum can be significantly reduced by the ANN modeling of the water tube boiler water feed system to the drum. The ANN model to be applied for the boiler feed system in the power plant will not only increases the efficiency of the system but shall considerably reduce the tripping of the power plant. The model so developed can be used for synthesis of model-based control algorithms of boiler system.

Keywords: boiler model, power plant, ANN, training, prediction model.

INTRODUCTION

Boiler system is a**n** important integral part of thermal power plant. The dynamic performance of boiler will mainly determine the performance of power unit. A number of dynamic models which are used to predict the behavior of boilers can be found in literature [14]. These models are used for controller synthesis and real-time evaluation of controller performance. In general, a ordinary Water tube Boiler system, as shown in figure 1, the foremost difficulty is the fluctuation of water level in the Boiler drum. The boiler needs very precise control and measurement for its efficient operation. On one hand, a sudden decrease in the water level may uncover boiler tubes, allowing them to become overheated and there are possibilities of damage. On the other hand, increase in this level may interfere with the process of separating moisture from steam within the Boiler drum, thus reducing boiler efficiency and carrying moisture into the process or turbine. Therefore, it would be an ideal condition if before hand the opening of the pneumatic valves at scoop and at the feed control station can be predicted and transfer this signal to the controller of the valves. This will supply precise feed water according to the requirement of a unit of thermal power plant. This model reduces the tripping of a unit of thermal power plant due to fluctuation of the water level in the drum of the Boiler. In thermal power plant, Boiler tube failures are one of the important reasons for unexpected shut down of power plants. The major problem is due to frequent up and down of water level leading to excess or less water supply to the turbine. Due to this also, tripping of the turbine takes place for the protection of turbine.. The tripping logics are provided to save the unit from any abnormal condition in the boiler/turbine or generator. This tripping of the power plant leads to great loss of production of power and money, at the cost of saving the equipment life

The other reasons are when either both induced fan or both forced draft fans will off other than the physical breakdown of spares and when furnaces pressure becomes very high .However, the 22% of the tripping of the Boiler is due to the high fluctuation of water level in the drum of the Boiler. The practice of tripping the generator breakers immediately would following a boiler turbine tripping. To solve the above problem, conventional proportional integral (CPI) controller is used to control the pneumatic valve. However, even after the use of CPI controller, desired precision of drum level control is not achieved. A practically efficient and mathematically rigorous fuzzy proportional integral (Fuzzy PI) controller was proposed by H.Ying et.al in [1].The fuzzy controller is precisely equivalent to the nonfuzzy linear PI controller if linear defuzzification is employed. The fuzzy controller can control the time delay process model and nonlinear process model significantly better than the nonfuzzy linear PI controller or fuzzy method by Zadeh [2] , is used. Here Malki et.al [2] inspired the better stability of fuzzy PI controller over conventional PI controller in nonlinear process. He had applied the stability principle in fuzzy PD controller. The Fuzzy PD controller enhances the self-tuning capability of the system.Chen. et.al. [5] has analyzed the stability of nonlinear fuzzy PI controller. The gain of the fuzzy PI controller change continuously with output of the process under control. Fuzzy proportional integral +derivative (Fuzzy PI+D) controller [3], and fuzzy proportional derivative integral (fuzzy PD+I) controller [4].also is inspired by the work of Ying et.el [1] for the better performance of ANN model over fuzzy PI controller [3].

The ANN model predict the degree of opening of the pneumatic valves. To control the water level in the drum, One has to control the two pneumatic valves. One valve is located in the feed control station and another one is in the scoop. This scoop is the hydraulic coupling to control the Boiler feed pump. In this coupling, the transmission of power from driving shaft of the motor to driven shaft of the Boiler feed pump is happen by the help of fluid (generally oil). There is no mechanical connection between the two shafts. It consists of a radial pump impeller mounted on a driving shaft and a radial flow reaction turbine mounted on the driven shaft. Both the impeller and runner are identical in shape and they together form a casing which is completely enclosed and filled with oil and one separated oil tank is there. In the beginning, both the shafts are at the rest. When the driving shaft is rotated, the oil started moving from the inner radius to the outer radius of the pump impeller. The pressure energy and kinetic energy of the oil increases at the outer radius of the pump impeller. This oil of increased energy enters the runner of the reaction turbine at the outer radius of the turbine runner and flows inwardly to the inner radius of the turbine runner. The oil, While flowing through the runner, transfer its energy to the blade of the runner and makes the runner rotate. The oil from the runner then flows back into the pump impeller, thus having a continuous circulation. A pneumatic valve controls the quantity of flow of oil inside the scoop. And, by this control of boiler feed pump happen. To predict the valve opening of valve of the feed control station, ANN take three inputs. That are steam flow from Boiler to the Turbine in tons per hour, feed water flow from Boiler feed pump to Boiler in tons per hour and water level in the drum of boiler in previous state. By seeing all these, ANN model predict the valve opening of feed control station as shown in figure 3. To control the feed water, scoop is there .This scoop is hydraulic coupling between Induction motor and Boiler feed pump. If more valve is open then less transmission of speed will take place. Hence flowing of feed water will reduce. The ANN model for this valve has one input and one output. The input is pressure difference of water between Boiler feed pump and near Boiler. ANN model for this is shown in figure 5.

These are the following parameter taken into consideration.

1.Load	120 MW
2.Rate evaporation capacity	345t/h
3. Drum operating pressure	148 bar
4. Superheated steam temperature	545C
5. Feed water temperature	242C
6.Water wall surface area	2916.4 m^2
7. Water wall tube diameter	60 mm
8. Number of the water wall tube	798
9. Height of the water wall	45 m
10. Downcomer diameter	426 mm
11. Diameter of the leading tube	159 mm
12 Drum diameter	1600 mm
13. Drum length	25 m
14. Normal water level of drum	0.625m

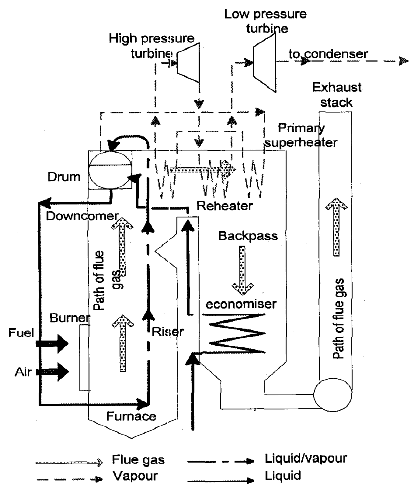


Figure 1.Thermal power plant

2. Artificial neural network

Artificial neural network (ANN) is an empirical modeling tool, which is analogous to the behavior of biological neural structures [7]. Neural networks are powerful tool that have the abilities to identify underlying highly complex relationships from input–output data only [8]. Over the last 10 years, artificial neural networks (ANNS) and particularly feed-forward artificial neural networks (FANNs) have been extensively studied to present process models, and their use in industry has been rapidly growing [11]. The main advantage of ANN is the ability to model a problem by the use of data associated with process , rather than analysis of process by some standard numerical methods. Neural networks are categorized by their architecture (number of layers), topology (connective pattern, feedforward or recurrent, etc.) and learning regime. Most of the applications in power systems have used multi-layered feed-forward networks and use error back propagation (BP) learning. A feed-forward back-propagation artificial neural networks (BPNN) is chosen in the present work which is the most prevalent and generalized neural network currently in used, and straightforward to implement [9]. Each interconnection has a scalar weight associated with it, which modifies the strength of the signal. The function of the neuron is to sum the weighted inputs to the neuron and pass the summation through a non-linear transfer function. In addition, a bias can also be used, which is another neuron parameter that is summed with the neuron's weighted inputs. Back-propagation refers to the way, the training is implemented and involves using a generalized delta rule.' Learning' rate parameter influences the rate of weight and bias adjustment and is the basis of the back-propagation algorithm. The set of input data is propagated through the network to give a prediction of the output. The error in the prediction is used to systematically update the weights based upon gradient information [10]. The network is trained by altering the weights until the error between the training data outputs and the network predicted outputs are small enough. There are many ANN architect for which the choice will depend on the type of problem and may require experimentation of different algorithms. The algorithms have different computation and storage requirements and train data at different speeds

3. Neural Model

BPNN(Back propagation neural network) application for water level in drum of boiler prediction

ANN training results in the achievement of the values of connection weights between processing elements in the input and hidden layer and between the hidden layer and output layers which minimize the differences between the network output and the measured values The data used included the steam pressure in the boiler, load of the power plant as a input and water level in the drum of boiler as a output of the model

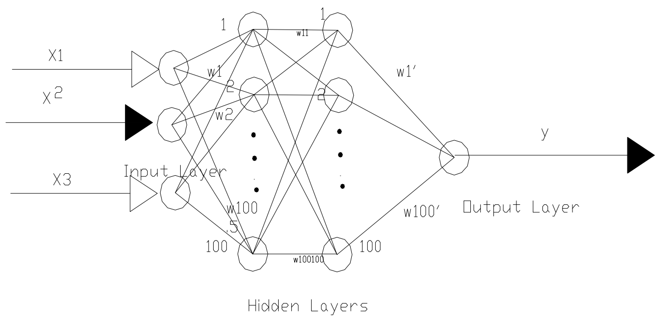


Figure 2 The ANN architecture for the feed control station

Figure 2 shows the ANN model for the feed control station of the power plant. This is use to control the feed water of the Boiler. In this model, there are three inputs and one output is there.

This is shown in figure as x1, x2, x3 and Y respectively. The input layer is represented by X and output layer is represented by Y. The input parameters are steam flow from boiler to turbine ,feed water flow in the boiler and the just previous state water level in the drum of the boiler. The output parameter is degree of opening of the pneumatic valve in the feed control station. This pneumatic valve will open from 0 to 100% based on our requirement. This valve regulates the excess water in the feed water system.

Sample data is to be shown in table 1. Trials are performed using two hidden layers with the number of neurons one hundred in each of hidden layer ,two neurons in the input layer and one in the output layer. Training the ANN is an important step for developing a useful network. The experimental data are used as the learning samples to train the ANN. Each time a pattern is presented to the network, the weights leading to an output node are modified slightly during learning in the direction required to produce a smaller error the next time the same pattern is presented. The amount of weight modification is the learning rate times the error. The larger the learning rate, the larger the weight changes, and the faster the learning will proceed. Oscillation or no convergence can occur if the learning rate is too large. Here the learning rate is 0.9. Large learning rates often lead to oscillation of weight changes and learning never completes, or the model converges to a solution that is not optimum. One way to allow faster learning without oscillation is to make the weight change a function of the previous weight change to provide a smoothing effect. The momentum factor determines the proportion of the last weight change that is added into the new weight change. Here momentum factor is taken as 0.8. As neurons pass values from one layer of the network to the next layer in back propagation networks, the values are modified by a weight value in the link that represents connection strengths between the neurons. Here weight is 0.8.

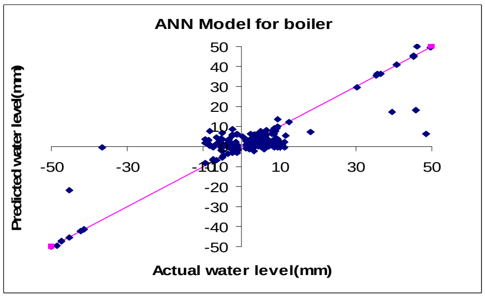


Fig. 3 The ANN for the feed control station

The training will stop when the 0.975 correlation coefficient for model of feed control station as shown in the fig.3. The ordinate of this figure is the predicted opening of the valve and the abscissa of this graph is actual opening of the valve. The total of 10000 epochs is needed to achieve the correct weight and threshold values. One has selected these parameters by trial and error method. The inhibitory and excitatory effect of the weight factors is straightforward which makes the transfer function quite advantageous. So the sigmoid transfer function (logistic) is chosen for the neurons in the all layers. After this Neuroshell will give a c-program, which based on our model. When one give the input parameters in this program then this will gives output parameter. Then one will pass this predicted valve opening information to the valve controller by this precise valve opening take place and this leads to precise control of the water level in the drum of the boiler. Due to this, tripping due to high/low water level in the drum will easily avoided.

Table 1

S. NO.	Steam flow	Feed flow	Drum level	Fe.val. open.	Diff. pre.	Sc.val. open.	S. No.	Steam flow	Feed flow	Drum level	Fe.val. open.	Diff. pre.	Sc.val. open.
1	225	200	-5	32	5	32	51	370	355	3	32.2	14	98
2	225	203	5	32.5	4.9	50	52	360	345	-6	32.1	13	91
3	225	199	-4	31.8	5.1	51	53	350	335	5	32.3	12	88
4	230	210	8	32.5	6	63	54	340	325	-8	32.1	11	83
5	240	215	7	32.4	8	73	55	330	325	7	32.4	10.5	75
6	250	225	-9	32	10	80	56	320	310	-3	32.2	10	70
7	258	230	7	32.4	10.5	82	57	310	305	5	32.3	8.5	65
8	247	235	-5	31.8	11	84	58	300	280	-4	32.2	7.5	55
9	300	210	-220	32	8	50	59	290	270	6	32.4	3	15
10	260	250	8	31.5	11.5	70	60	285	199	230	31.2	6	32
11	270	260	-7	31.3	12	80	61	270	255	-3	32	6.3	32.4
12	280	275	6	31.6	12.3	86	62	280	260	6	32.4	6.5	32.2
13	288	272	-7	31.3	12.1	79	63	290	263	-3	32.2	7.5	32.4
14	297	280	8	32	12.4	82	64	300	283	8	32.4	8.5	35
15	299	279	-6	31.7	12.3	83	65	310	295	-4	32.3	6.3	32.5
16	287	280	7	32.3	12.4	84	66	300	275	6	32.5	6.4	33
17	299	290	-6	32	12.5	85	67	300	278	-3	32.3	7	35
18	310	300	8	32.4	12.6	89	68	300	283	4	32.4	6.8	32.3
19	315	325	230	32.3	14	100	69	300	280	-3	32.3	6.79	31
20	320	210	3	31.6	5	31.6	70	300	279	2	32.4	5.4	25
21	230	230	-6	31.2	6	45	71	200	256	-240	31.2	7.5	32
22	250	251	7	31.6	7	55	72	280	278	2	32	7.4	31.8
23	260	258	-6	31.4	7.5	65	73	280	276	-6	31.8	7.5	32.1
24	270	271	8	32	9	79	74	280	275	5	32.1	7.6	33
25	279	272	-6	31.8	9.1	80	75	280	277	-4	32	7.63	34
26	289	280	9	32.4	9.9	90	76	290	278	6	32.3	7.69	33.3
27	299	290	-8	32	10.3	92	77	290	282	-8	32.1	7.7	33.9
28	310	300	7	32.5	10.6	95	78	290	285	6	32.4	7.75	34
29	320	220	-220	30	5	30	79	290	287	-3	32.2	7.79	34.1
30	290	280	3	31.5	8	46	80	220	288	1	32.3	7.5	32.2
31	299	285	-6	31.2	8.2	49	81	253	280	-220	32.2	3.6	15
32	310	295	8	31.8	9.2	59	82	253	243	2	32.3	3.9	16
33	320	310	-4	31.4	10.9	72	83	253	247	-6	32.1	4	17
34	340	320	7	31.8	11.3	75	84	253	248	7	32.3	4.1	20
35	350	330	-6	31.3	11.9	80	85	254	249	-3	32.1	4.15	21
36	360	350	5	31.6	12.8	95	86	255	250	6	32.4	4.2	22
37	370	360	-3	31.3	12.9	90	87	256	253	-8	32.2	4.25	23
38	380	370	2	31.6	13.2	99	88	257	254	9	32.3	4.3	24
39	372	320	-220	31	10.1	31	89	258	255	-3	32.2	4.4	25
40	320	305	-2	31.5	8.5	25	90	370	257	2	32.1	5.4	29
41	330	320	6	31.9	10	31.9	91	260	268	306	32	5	25
42	348	330	-7	31.8	10.5	39	92	260	256	-1	32.1	4.9	30
43	323	315	5	32.1	9.5	32.1	93	270	257	6	32.3	5	31
44	310	300	-3	32	8	29	94	265	258	-7	32.4	5.1	32.3
45	320	310	6	32.6	9	32.6	95	267	260	8	32.3	5.2	32.5
46	315	300	-7	32.2	8	32.2	96	277	262	-7	32.5	5.3	33.8
47	310	290	6	32.6	7	32.6	97	287	263	6	32.4	6.3	43.5
48	305	295	-9	32.4	7.5	36	98	297	270	-3	32.6	7.3	53.2
49	180	280	-308	32.1	6.5	32.1	99	298	280	8	32.4	8.3	73.8
50	200	180	10	35.5	15	100	100	380	290	220	35.10	14	98

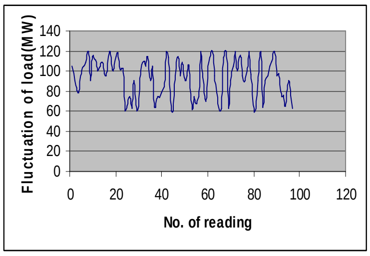


Fig.4Variations of load in MW

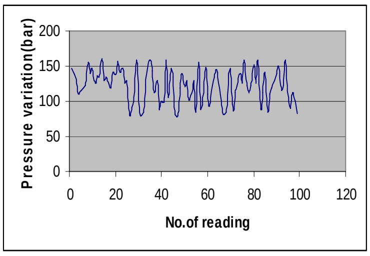


Fig.5.Variation of pressure inside drum

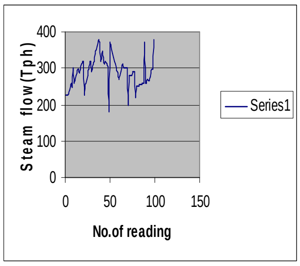


Fig.6.Variation of steam flow

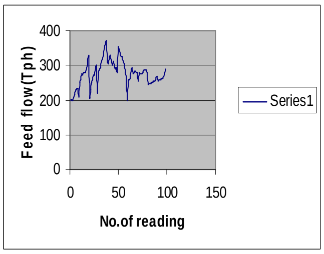


Fig.7 Variation in feed flow

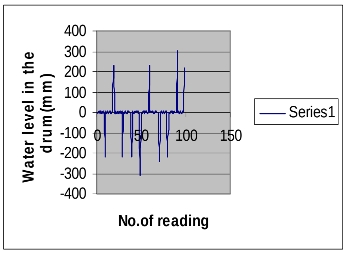


Fig. 8 Variation in water level

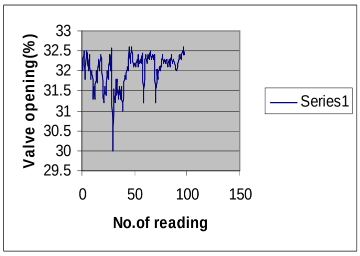


Fig. 9 Variation in opening of feed valve

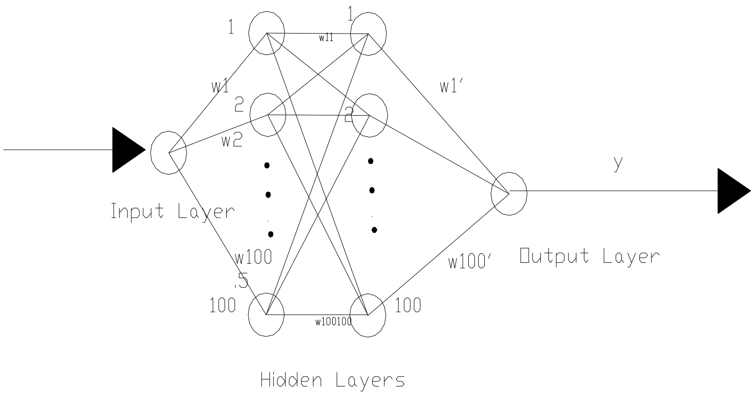


Figure 10 The ANN architecture for the scoop

Here , the abscissa of the above all figures are number of consecutive readings with respect to change in requirement of power plant taken in a unit of thermal power plant. In figure 4, shows the fluction of load of a particular unit of thermal power plant . This shows about variation in demand of power in the captive power plant The high fluctuations of load is also due to of the tripping of the Boiler of a unit of power plant. The scale of power generation is taken in MW. Figure 5 shows the variation of pressure inside the drum of the Boiler. The pressure increases as the load of generation increases. At the time of tripping also large variation in pressure take place. The scale of pressure is in bar. Figure 6 shows the variation of steam flow from Boiler to the Turbine. The measurement of this is done in the tons of steam flowing per hour. The temperature and pressure of this steam is very high. Figure 7 clearly shows the variation of feed water flows in the Boiler. The measurement of this is done in the tons of water flow per hour. This water is coming from the Boiler feed pump.. Figure 8 shows the variation of water level in the drum of the Boiler. The dimension of this is to taken in the mm. These fluctuations are controlled by the help of scoop and feed control station. Figure 9 shows the variation of opening of the pneumatic valve in the feed water control loop. This valve is pneumatic controlled valve. This can be open either 10% or 90% .This is all depend upon our requirement. The opening and closing of this valve is responsible of the fluctuations water level in the drum of Boiler.

Figure 10 shows the ANN architecture for the scoop of the power plant. This is use to control the speed of the Boiler feed pump. In this model, there is one input and one output is there. The input parameter is pressure difference between pressure at Boiler and pressure at the Boiler feed pump and output parameter is degree of opening of the pneumatic valve in the scoop. This valve controls the flow of oil in the hydraulic coupling. If flow of oil in the scoop is more then Boiler feed pump will run in high speed and vice versa.

Sample data is to be shown in table 1. Trials are performed using two hidden layers with the number of neurons one hundred in each of hidden layer ,two neurons in the input layer and one in the output layer. Training the ANN is an important step for developing a useful network. The experimental data are used as the learning samples to train the ANN. According to our requirement based on ANN model ,the learning rate ,momentum factor and initial weight are taken as .9,.8and .8 respectively.

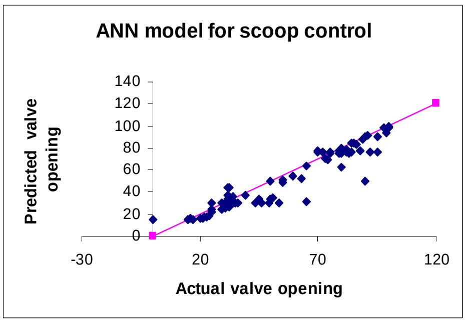
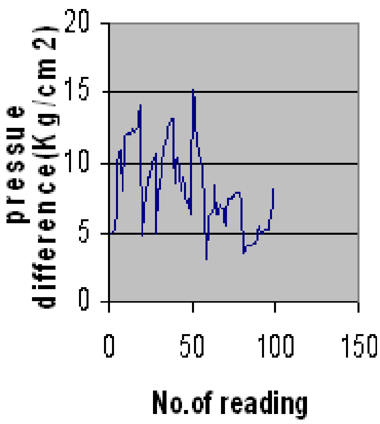


Figure. 11 ANN model for scoop

The training will stop when the 0.875 correlation coefficient for model of scoop as shown in the fig.11. The ordinate of this figure is the predicted opening of the valve and the abscissa of this graph is actual opening of the valve. The total of 10000 epochs is needed to achieve the correct weight and threshold values. One has selected these parameters by trial and error method. The inhibitory and excitatory effect of the weight factors is straightforward which makes the transfer function quite advantageous. So the sigmoid transfer function (logistic) is chosen for the neurons in the all layers. After this Neuroshell will give a c-program, which based on our model. When one give the input parameters in this program then this will gives output parameter. Then one will pass this predicted valve opening information to the valve controller by this precise valve opening take place and this leads to precise control of the water level in the drum of the boiler. Due to this, tripping due to high/low water level in the drum will easily avoided.



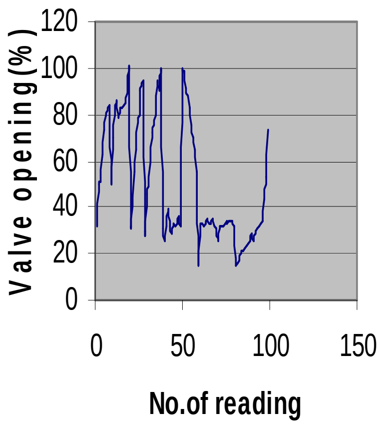


Fig. 12 variation of the pressure difference **Figure 13 variation of opening of the valve**

Figure 12 show the variations of the pressure difference between near Boiler and near Boiler feed pump. The dimension is taken in c.g.s. unit system Figure 13 shows the ANN model for the feed control station. Here abscissa is the actual value and ordinate is the predicted value.

RESULTS AND DISCUSSION

The water level in the drum of the Boiler is one of the most sensitive parameter involved in the process of Steam Pressure control in all Thermal Power Plants. This parameter is directly related to the control of the scoop and the control of the feed control station. This proves to be an efficient modeling system for calculation and analysis of the water level in the Boiler Drums. By the ANN modeling of the water tube boiler water feed system to the drum, the frequency of deviations and the degree of deviation of the water level in the drum are significantly reduced. Applying this model to the boiler feed system in the Power plant not only increases the efficiency of the system but shall considerably reduce the tripping of the boiler that usually occurs due to sudden fluctuations of the load. Fig3. Clearly shows the relationship between actual water level and predicted water level of the boiler. A careful study was done on the existing PI controller system in the Power plant and compared with the designed ANN model. It has been clearly proved that the ANN model is more accurate and efficient making the system robust and reliable as compared to the former. The accuracy and precision generated by the ANN model also impacts the factor of safety of the Boiler design. The reliability offered by the ANN model helps design the drum of a Boiler to a more precise size. This further enhances the efficiency and results in an optimum sizing of the Drum making the manufacturing process more economical.

CONCLUSION

1. The ANN life prediction model is an easier way in comparison with other type of model
2. The results of ANN are very sensitive to number of neurons. It might have different results in each run even with fixed number of neurons. Increasing the number of neurons in hidden layer will decrease the number of calculation steps with subsequent decrease in sum squared error.
3. ANN method having several input data, may predict remaining lifetime more accurately than other method.

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