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Efficacy of neural network and non linear regression analysis in estimating the mass flow rate of feed water from boiler feed pump

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ABSTRACT

The estimation of boiler feed water to circulation system is very important in drum level control. The performance characteristics of boiler feed pump (BFP) is usually of three dimensional in the sense that for a given speed of the BFP there exists a relationship between the head (between BFP and the drum) and feed water flow. Usually the BFP characteristics are modeled either by non linear regression equations or by neural network. In this paper, the efficacy of estimating the feed water flow using neural network and non linear regression equations is investigated for a typical 500MW boiler circulation system.

Keywords: Boiler feed pump, Regression analysis, Neural network

1-Introduction

A typical feed water control system of a utility boiler consisting of boiler feed pumps, HP heater, feed control valves, economizer and circulation system is shown in figure 1. The circulation system itself consists of drum, down comer and water walls. For high capacity utility boilers, it is usually the practice to keep the feed control valve fully open – for loads more than 30% rated capacity-and regulate the feed water flow by adjusting the speed of the boiler feed pump. The boiler performance characteristics are provided by the original equipment manufacturers and a typical performance characteristics pertaining to a 500 MW boiler is shown in figure 2. From the figure it can be observed that for a given speed of the boiler feed pump, there exists a unique relationship between the head (drum and BFP) and flow out of the BFP.

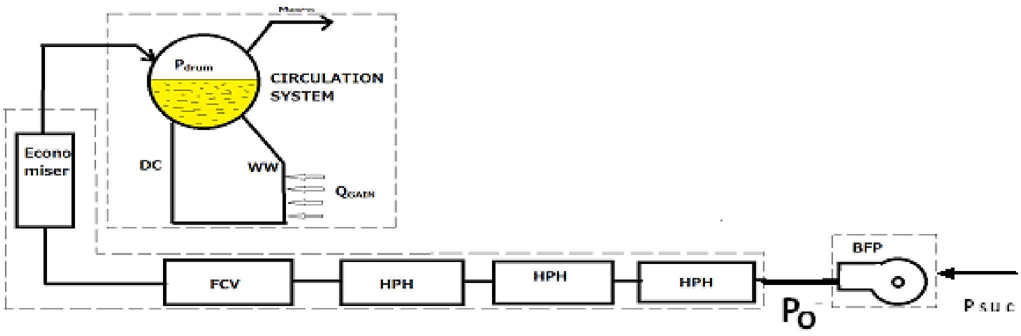

Fig.1: Block diagram of circulation system with feed water system

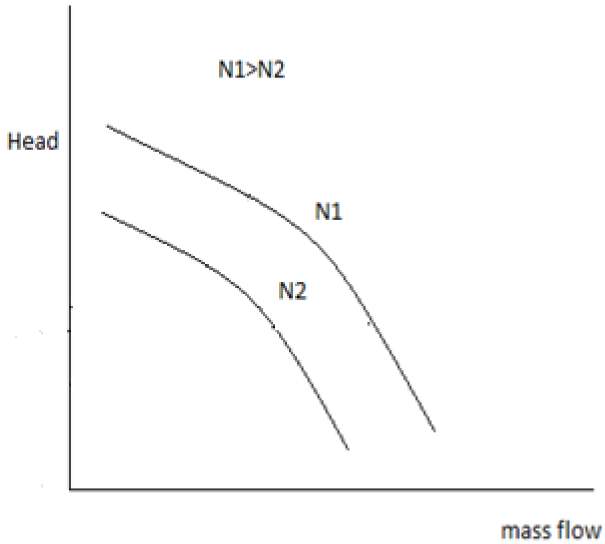

Fig.2: head Vs flow curve

In drum level control problems [1-3], the drum level controller output will modulate the speed of the boiler feed pump and corresponding to the speed, the flow will get fixed as per the momentum equation describing the pressure drop between the pump and the drum. Hence calculation of pressure drop due to friction offered by different components such as HP heaters, flow control station and economizer expressed in units of head is important and due consideration is to be given to account for spray flow(normally branches out at the exit of HP heaters) [4]. The calculation procedure is explained below.

Frictional drop across the system is given by 'Δp' which is a function of square of mass flow rate of feed water. The sub cooled water density is assumed to be constant throughout the feed water leg. Now if the pump runs around a particular speed, it may be of interest what will be the mass flow rate of feed water, around a particular drum operating pressure. For a given drum operating pressure, there is only one unique mass flow rate satisfying system resistance curve as well as the boiler feed pump characteristic for the specified speed of the pump.

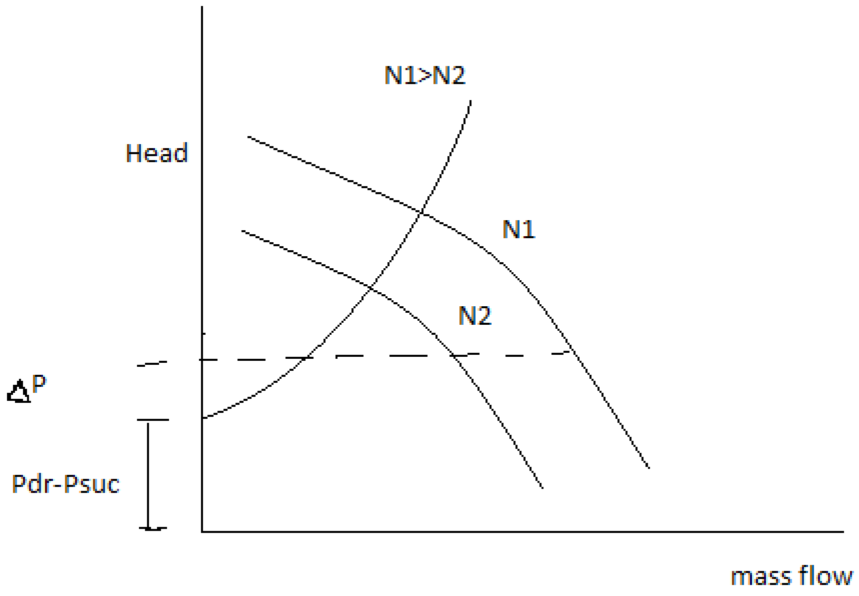

Fig.3: System resistance curve

We know that, Head = $P_o - P_{suc}$ (1)

But, $P_o = P_{dr} + LF_{fcv} *(\frac{m2}{\rho}) + LF_{HPH} *(\frac{m2}{\rho}) + LF_{eco}*(\frac{m2}{\rho})$ (2)

$P_o = P_{dr} + \Delta p$ (3)

where 'Δp' is the pressure drop due to friction and this pressure drop 'Δp' is due to feed water flow through economizer , HP heaters and flow control station.

From (1) and (3),

Head = $(P_{dr}\text{-}P_{suc}) + \Delta p$ (4)

Head = $(P_{dr}\text{-}P_{suc}) + LF *(\frac{m2}{\rho})$ (5)

where $LF = LF_{fcv} + LF_{HPH} + LF_{eco}$

Therefore,

Head = P_{dr}(in head)–P_{suc}(in head) +Δp(in head) (6)

SIMULATION OF BFP CHARACTERISTICS USING REGRESSION EQUATIONS:

The simulink diagram given below simulates the pump characteristics as a set of second order algebraic equations for each speed ranging from 6012 to 1500 rpm as M = $a_o+a_1H+a_2H^2$ where M represents the Mass flow rate and H represents head. For a family of BFP operating characteristic curves (head Vs flow) for 13 distinct speeds, the regression coefficients a0,a1 and a2 are calculated and given table 1.

Table 1: Regression equations for calculating mass flow rate of feed water

Sl.no	Speed	Co-efficients of mass flow rate using regression analysis		
		ao	a1	a2
1	6012	0.4371216e3	0.1240617e1	-0.3709815e-3
2	5740	0.2547433e4	0.3427420e1	-0.8015792e-3
3	5465	-0.2509946e4	0.3666657e1	-0.9378118e-3
4	5430	-0.2239625e4	0.3540242e1	-0.9464289e-3
5	5260	-0.2327982e4	0.3817240e1	-0.1064524e-2
6	5000	-0.7707878e3	0.2590571e1	-0.9091598e-3
7	4500	-0.1298834e4	0.3564360e1	-0.1428654e-2
8	4000	-0.2066386e3	0.2569790e1	-0.1506167e-2
9	3500	0.7195473e3	0.1023245e1	-0.1247985e-2
10	3000	-0.640773e3	0.6383832e1	-0.8603110e-2
11	2500	-0.9178922e3	0.7387582e1	-0.9509163e-2
12	2000	0.1902222e2	0.4427894e1	-0.1102308e-1
13	1500	0.1612769e4	-0.1159416e2	0.2106890e-1

For any speed lying between 6012 to 1500 rpm and not corresponding to the rpm given in the table suitable appropriate interpolations will be used for obtaining the mass flow rate of BFP. A simulink setup which enables the calculation of 'a0','a1' and 'a2' for any intermediate speed is shown below. This setup simulates a typical 500MW utility boiler feed pump. These characteristics can be used for the study of drum level control problems.

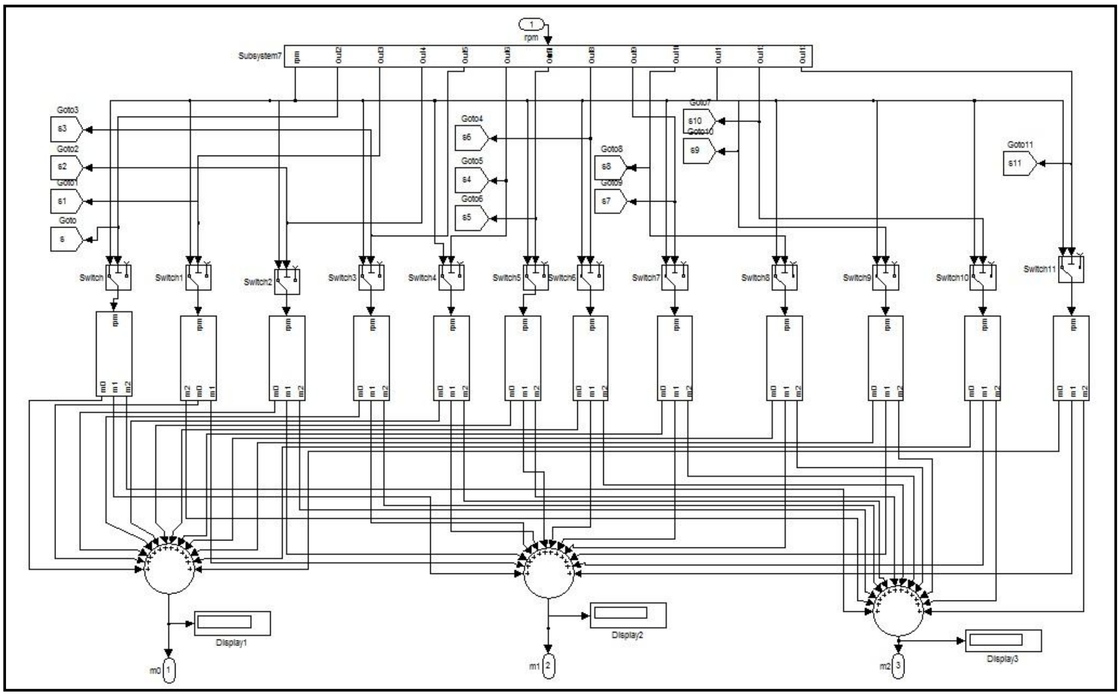

Fig.4: The simulink diagram of the speed block ranging from 6012 to 1500 rpm

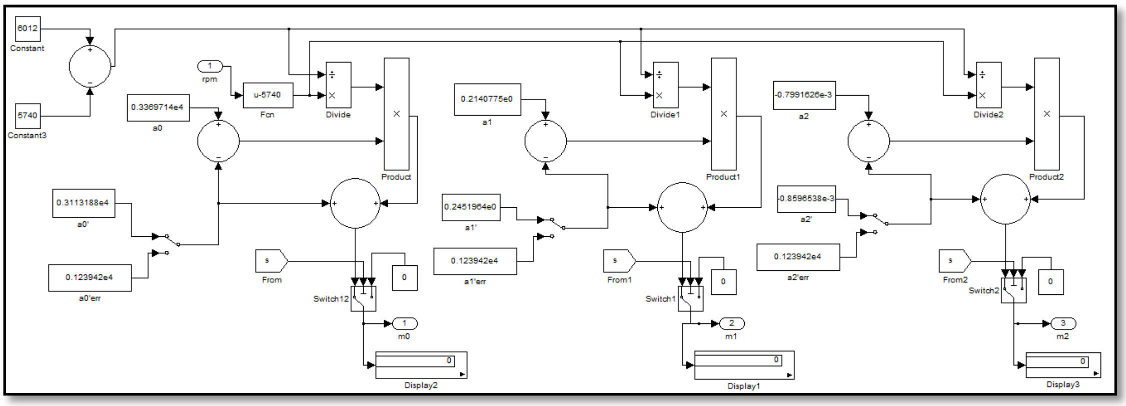

Fig.5: The simulink diagram for the estimation of the coefficients of mass flow for different speeds

SIMULATION OF BFP CHARACTERISTICS USING NEURAL NETWORK:

Neural networks are widely used to identify unknown parameters of dynamical systems as well as to map steady state inputs and outputs of systems with negligible time constants[4-5].The mass flow rate of the boiler feed pump is estimated with speed and head as the inputs. A neural network model (to represent boiler feed pump characteristics) with 2 inputs, 2 hidden layers with 20 neurons in each hidden layer, 1 output layer and activation functions has been considered [2]. The activation function used for hidden layers are sigmoid function and for output layer it is purelin function. The data points used for regression equations have been used to train the neural network. The neural network has been fully trained using Matlab R2011a. The corresponding simulink diagram is shown below. The neural network trained here contains a training algorithm namely Levenberg-Marquardt algorithm.

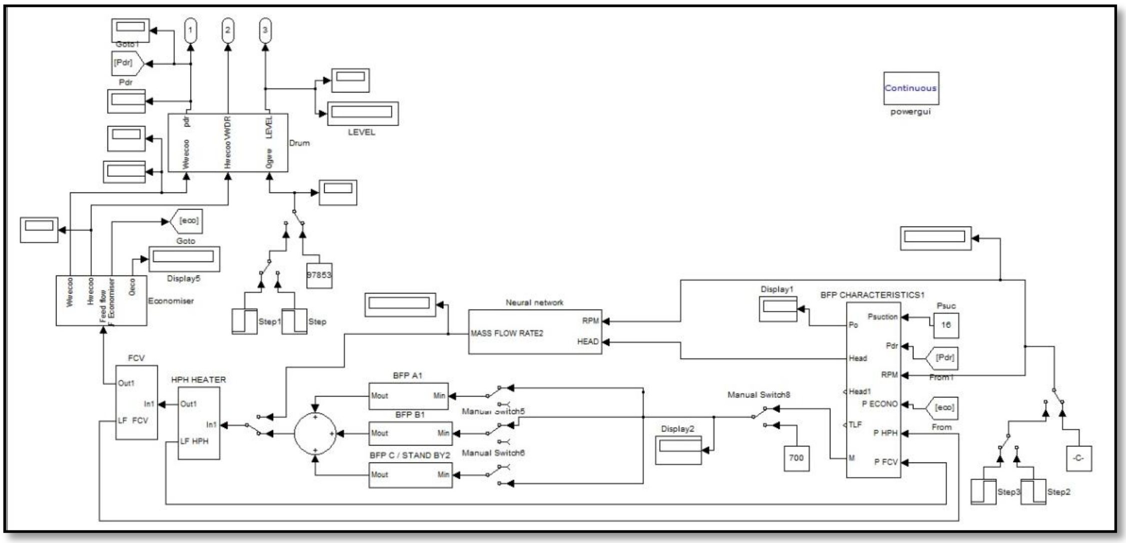

Fig.6:Simulink model of regression and neural network

COMPARISON OF SIMULATION RESULTS WITH REGRESSION AND NEURAL NETWORK:

A few sets of speed and head have been chosen randomly and the mass flow rate was computed using regression equation and neural network. The computed results are illustrated in table 3.

Table 2: Estimation of mass flow for a speed of 5465 rpm using regression method and neural network

Sl. No.	RPM	Head (in Meters of liquid column)	True Mass flow rate of feed water (Kg/sec)	Estimated Mass flow rate of feed water (Kg/sec)			
				Based on Regression analysis		Based on Neural network analysis	
				Estimated Output	% Error in estimation	Estimated Output	% Error in estimation
1	6012	3100	720	717.9	0.291667	722.9	-0.40278
2	5900	2800	932.3	940	-0.82591	929.3	0.321785
3	5465	2580	700	707.6	-1.08571	700.1	-0.01429
4	2500	600	100	92.4063	7.5937	103	-3

It is observed that neural network gives better results than regression equations.

PREDICTION WITH ERRONEOUS DATA:

It is quite likely that error occur during data entry for regression analysis or neural network training. The authors are interested to study the immunity for these errors by each of the method. Intentionally some of the data-highlighted in yellow color-pertaining to boiler feed pump characteristics corresponding to a speed of 5430 rpm has been entered for the speed 5465 rpm. With this error both regression equations and neural network has been obtained. The simulated results are compared and given in table 3.

Table 3: Estimation of mass flow for a speed of 5465 rpm using regression method and neural network with erroneous data

Sl. No.	Head (in Meters of liquid column)	True Mass flow rate of feed water (Kg/sec)	Erroneous data fed as input	Mass flow rate of feed water (Kg/sec)-Error Data			
				Based on Regression analysis		Based on Neural network analysis	
				Estimated Output	% Error in estimation	Estimated Output	% Error in estimation
1	2800	400	400	350.3	12.425	415.1	-3.775
2	2740	500	340	405.9	18.82	473.9	5.22
3	2580	700	550	572.3	18.24286	648	7.428571
4	2500	800	700	665.4	16.825	736.6	7.925
5	2380	900	830	817.3	9.188889	861	4.333333
6	2240	1000	1000	1013	-1.3	996.4	0.36

It is observed that the neural network seems to have a self correcting property considering the overall data domain. Whereas this is not applicable in the case of regression analysis. The percentage error obtained for neural network is quite promising in modeling rotating equipments such as BFP, induced draught fans, forced draught fans, primary air fans etc.

CONCLUSION:

Modeling of quite a few rotating equipments are encountered in thermal power plant control applications. BFP is an important subsystem and the description of this equipment operating characteristics accurately is vital in drum level control. The authors have considered both regression equations and neural network for this purpose. The investigation shows that neural network representation is better for systems exhibiting non linear characteristics compared to non linear regression equations. Further neural network seems to have immunity for errors in feeding the input data.

Nomenclature

Pdr – Drum pressure
LF_{fcv} – loss factor for flow control valve
LF_{HPH}-loss factor for HP heater
LF_{eco}-loss factor for economizer
LF – Total loss factor
Δp-the pressure drop due to friction
P_o – Output pressure
ρ-density of water

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BIOGRAPHY

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