"Economic Load Dispatch by Generating Units under Varying Load Demands Using Artificial Neural Network"

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Abstract— **The problem of economic load dispatch has been tested on a generating plant having Ten units of generators operating in parallel. What shall be the load allocations to individual units for given load demand on the plant? has been found. The allocation of load to each of the ten generators in a generating plant is such that the economic load dispatch is maintained for any value of the load demand on the. It is the basic requirement of economic load dispatch. Further this is true for varying load demands. The estimation of load allocations to generators for every specific load has been carried out using mathematical approach as well as with the help of artificial neural network (ANN). After proper training of the artificial neural network when it is tested, it gave the load allocations for specific load which resulted in economic load dispatch. The results as obtained by mathematical modeling & artificial neural network show a good agreement. Thus it could be established that corresponding to certain load demand the ANN provides the loads to be taken up by the individual generators in the plant for ensuring economic load dispatch.**

Keywords-economic load dispatch, load allocations,mathematical modeling, artificial neural network

1.1 INTRODUCTION

In this paper a generating plant having ten generating units each with a generation capacity of 250MW has been considered. It is aimed that all the units dispatch economically for every load demand. The artificial neural network has been deployed to provide load allocation to individual units as certain % of the total load appearing on the generating plant. Further these load allocations always satisfy the condition of economic dispatch. Thus the rate of change of fuel with power (dF/dP) remains same [1] in all the generators under every state of load demand from no load to full load. A mathematical model has been developed to obtain the size of load allocations to the units for a specific size of load on the plant.

Though the load allocations can be found for every value of load, yet the loads which are found to be repetitive in the duration of 24 Hrs.[3] every next day have been used to obtain a generalized data set for training the ANN. The ANN when tested for new load values, it gave the desired load allocations which agree to provide economic load dispatch.

Thus it has been found that the results of ANN & mathematical model show a reasonably good agreement. Thus the ANN helps to give the load allocations for any new value of load such that optimal power flow or economic load dispatch is ensured. However this would require a specific fuel rate to be given to the turbine so that it generate power as desired by load allocation for given load demand. The paper however restricts the role of ANN to provide load allocations which ensure economic load dispatch and not upon the adjustment & control of fuel rate to agree with power demand.

2.1 FEED FORWARD NETWORK

In this type of networks, signal flow only in one direction from input to output. Their types include viz single layer and multilayer feed forward networks [11]

2.1.1 Single Layer Feed forward Networks

These are the network in which signal flows from input layer to output layer neurons, but not vice versa or in other words network is strictly a feed forward or acyclic type. It is illustrated in figure for the case of R input node and S output node. Such network is called a single layer network, with the designation "single layer" referring to the output layer of computation nodes (neurons). Perceptron is the simplest form of single layer network used for the classification of pattern said to be linearly separable.

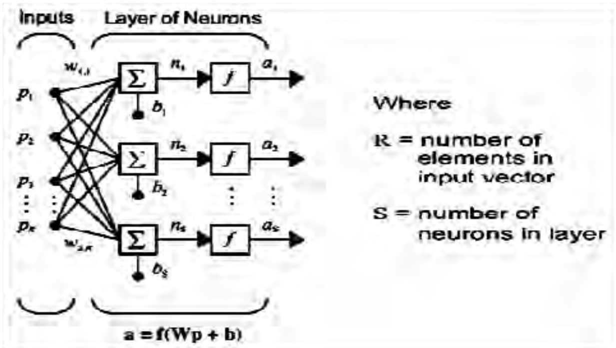

Figure 1. Single Layer Feedforward Network

2.1.2 Multilayer Feed Forward Networks

This class of feed forward network has at least one hidden layer, whose computation nodes are correspondingly called hidden neurons or hidden units. The function of hidden neuron is to intervene between the external input and the network output in some useful manner. These networks are used to implement higher order statistic. So it can deal with the nonlinear classification problem, system identification and control problems.

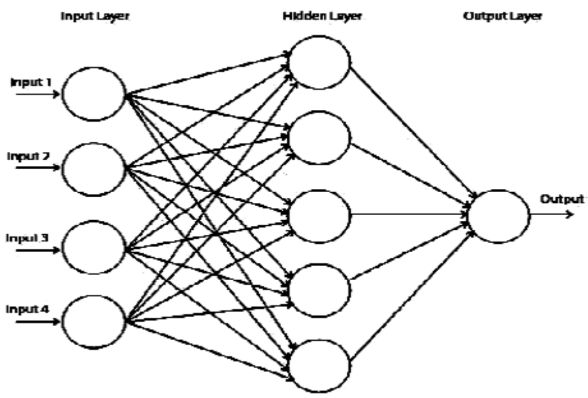

Figure 2. Multilayer Feed forward Network

3.1 THEORY OF ECONOMIC LOAD DISPATCH

A generating plant having "n" no. of generators when supply load to consumers shall operate economically, if,

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} = \cdots \dots\dots\dots\dots.. \frac{dF_n}{dP_n} = \lambda \dots\dots\dots\dots\dots\dots\dots\dots\dots.. (1.1)$$

Here

$$\lambda = \frac{change\ in\ fule\ supply}{change\ in\ power\ output} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1.2)$$

Thus "n" generating units in a plant operate economically if "λ" for all the units in a plant is same.
The cost of fuel/unit power F Rs/MW is given by

$$F = a + bP + cP^2 \quad Rs/MW \dots\dots\dots\dots.\dots\dots\dots\dots\dots\dots\dots\dots.. (1.3)$$

Thus the cost of fuel/MW depends on the size of power being generated by the generating unit. Also the cost of fuel depends on the certain design and operating constant a, b and c. These constant are different for different generating units. It is therefore even if the generators give equal power output 'P' it would cost differently to each of them. Also for all the generators to operate economically with varying values of constant a, b and c the ratio ($\frac{dF}{dP}$) should be equal for all the generating units i.e. equal to 'λ' It therefore requires Eqn. (1.1) to be satisfied.

Illustration:

Consider a generating plant having ten generating units. If (F_1, P_1), (F_2, P_2), (F_3, P_3) ... (F_{10}, P_{10}) are pairs for fuel input and power output for generators G_1, G_2, G_3 ... G_{10}.

(i) Give the condition for economic load dispatch and

(ii) Obtain load allocation to individual Units for a given load on the plant.

Also let 'X' be the load at certain time "t"

if $P_1, P_2, P_3 ..., P_{10}$ are the load allocations then

$$P_1 + P_2 + P_3 + \dots + P_{10} = X \quad \dots\dots\dots\dots (1.4)$$

For load demand 'X'.

The condition for economic load dispatch in plant with "10" Generating units would be as given in Eqn. (1.1)

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} = \cdots \dots\dots\dots \frac{dF_{10}}{dP_{10}} = \lambda \dots\dots\dots (1.5)$$

Let the fuel costs for each generators be,

$$F_1 = a_1 + b_1P_1 + c_1P_1^2$$
$$F_2 = a_2 + b_2P_2 + c_2P_2^2$$
$$\vdots$$
$$F_{10} = a_{10} + b_{10}P_{10} + c_{10}P_{10}^2$$

Here, when

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2}$$

gives.

$$P_2 = \left(\frac{b_1 - b_2}{2c_2}\right) + \frac{c_1}{c_2}.(P_1)$$

Similarly

$$P_3 = \left(\frac{b_2 - b_3}{2c_3}\right) + \frac{c_2}{c_3}.(P_2);$$

$$P_4 = \left(\frac{b_3 - b_4}{2c_4}\right) + \frac{c_3}{c_4}.(P_3)$$

$$P_5 = \left(\frac{b_4 - b_5}{2c_5}\right) + \frac{c_4}{c_5}.(P_4)$$

$$P_6 = \left(\frac{b_5 - b_6}{2c_6}\right) + \frac{c_5}{c_6}.(P_5)$$

$$P_7 = \left(\frac{b_6 - b_7}{2c_7}\right) + \frac{c_6}{c_7}.(P_6)$$

$$P_8 = \left(\frac{b_7 - b_8}{2c_8}\right) + \frac{c_7}{c_8}.(P_7)$$

$$P_9 = \left(\frac{b_8 - b_9}{2c_9}\right) + \frac{c_8}{c_9}.(P_8)$$

$$P_{10} = \left(\frac{b_9 - b_{10}}{2c_{10}}\right) + \frac{c_9}{c_{10}}.(P_9)$$

$$P_1 = \left(\frac{b_{10} - b_1}{2c_1}\right) + \frac{c_{10}}{c_1}.(P_{10})$$

Again

$$P_{10} = \left(\frac{b_1 - b_{10}}{2c_{10}}\right) + \frac{c_1}{c_{10}}.(P_1)$$

If the power generated by generator G_1, is P_1, and if P_1 & Non P_1 constants are then m_1& n_1

$P_2 = m_1 + n_1 P_1$

$P_3 = m_2 + n_2 (m_1 + n_1 (P_1))$

$P_4 = m_3 + n_3 (m_2 + n_2 (m_1 + n_1 P_1))$

$P_5 = m_4 + n_4 (m_3 + n_3 (m_2 + n_2 (m_1 + n_1 (P_1))))$

$P_6 = m_5 + n_5 (m_4 + n_4 (m_3 + n_3 (m_2 + n_2 (m_1 + n_1 (P_1)))))$ ....

$P_{10} = m_9 + n_9 (m_8 + n_8 (m_7 + n_7 (m_6 + n_6 (m_5 + n_5 (m_4 + n_4 (m_3 + n_3 (m_2 + n_2 (m_1 + n_1 (P_1)))))))))$

On generalization the load allocation to i^{th} generator is given by

$P_{i+1} = m_i + n_i (m_{i-1} + n_{i-1} (m_{i-2} + n_{i-2} (m_{i-3} + n_{i-3} (m_{i-4} + n_{i-4} (\ldots\ldots\ldots\ldots m_{i-j} + n_{i-j}(P_1))$ ……………………. (1.5)

Also

$$\left.\begin{aligned} m_i &= \left(\frac{b_i - b_{i+1}}{2c_{i+1}}\right) \\ n_i &= \left(\frac{c_i}{c_{i+1}}\right) \\ &\text{Where } i = 1, 2, 3, 4, 5 \ldots 9 \text{ and } j = i-1 \end{aligned}\right\} \ldots\ldots\ldots\ldots (1.6)$$

4.1 FLOW CHART

The Flowchart to determine load allocations to individual units in a generating plant having ten units is as below

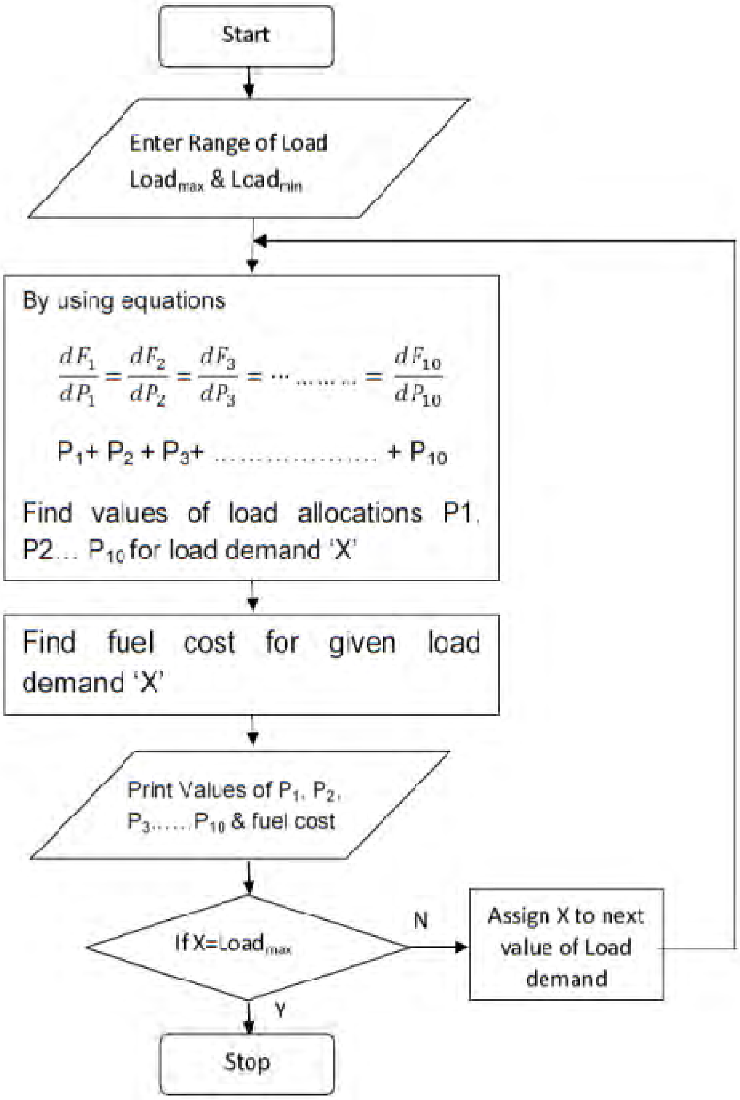

Figure 3. Flow chart for Economic Load Dispatch

The algorithm for above problem is given in appendix-1

5.1 Determination Of Load Allocations Using Mathematical Approach

A computer program whose algorithm is as given in appendix-1 has been developed on the basis of formula for load allocation given by Eqn (1.4), (1.5) & (1.6). The results for load allocation as obtained by above equation [4] is given as under. Though the load is varying from no-load to full load. The data corresponding to some specific loads which remains repetitive has been chosen these data are:

TABLE I. LOAD ALLOCATIONS USING MATHEMATICAL APPROACH

Sr. No.	**Generator**	**Load on individual Generator**			
		1600 MW	**1800 MW**	**2000 MW**	**2200 MW**
1.	**G1**	168.226339	189.217407	210.208475	231.199543
2.	**G2**	152.023945	171.106734	190.189523	209.272312
3.	**G3**	148.882754	167.295971	185.709189	204.122406
4.	**G4**	170.128918	191.548375	212.967832	234.387289
5.	**G5**	164.927783	185.507262	206.08674	226.666219
6.	**G6**	149.487803	168.229828	186.971853	205.713878
7.	**G7**	153.842127	172.924916	192.007705	211.090494
8.	**G8**	177.368446	199.699369	222.030293	244.361216
9.	**G9**	140.188616	157.681173	175.173729	192.666286
10.	**G10**	174.92327	196.78896	218.65466	240.52035

5.2 DETERMINATION OF LOAD ALLOCATIONS USING ANN APPROACH.

The ANN has been organized on MATLAB platform architecture and training [7] is shown in the training window as below in figure

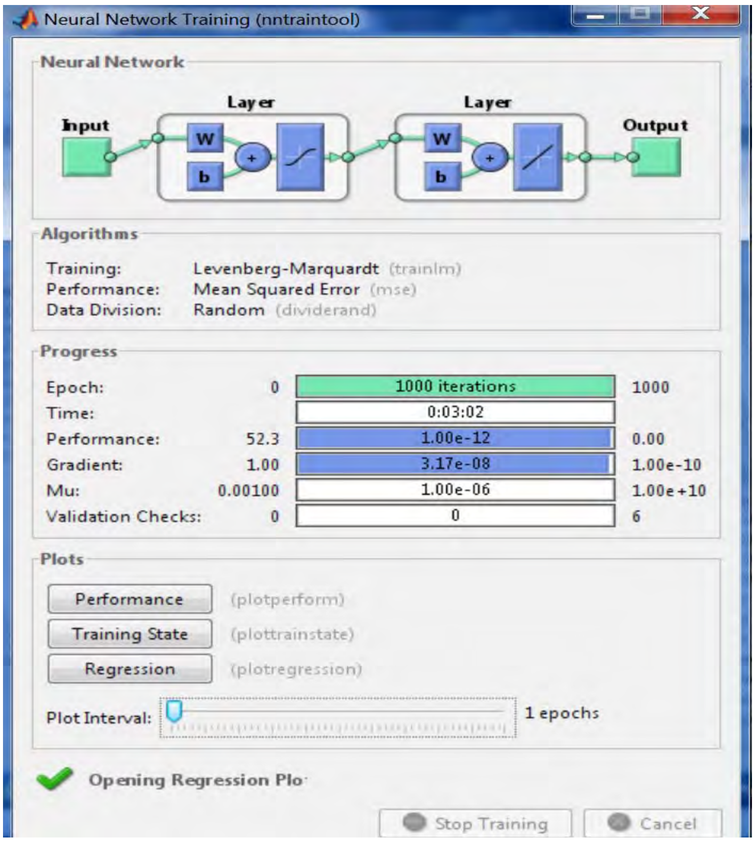

Figure 4. ANN Training Window

The training data for load near 1600MW, 1800MW, 2000MW, & 2200MW has been developed after training the testing of ANN has been done it gave results as shown in Table-II

TABLE II. LOAD ALLOCATION USING ANN APPROACH.

Sr. No.	Generator	Load on individual Generator			
		1600 MW	1800 MW	2000 MW	2200 MW
1.	G1	168.226341	189.217412	210.208504	231.199547
2.	G2	152.023947	171.106738	190.18955	209.272315
3.	G3	148.882755	167.295975	185.709214	204.122409
4.	G4	170.12892	191.548379	212.967862	234.387293
5.	G5	164.927786	185.507266	206.086769	226.666222
6.	G6	149.487805	168.229832	186.971879	205.713881
7.	G7	153.842128	172.92492	192.007731	211.090497
8.	G8	177.368448	199.699374	222.030324	244.36122
9.	G9	140.188618	157.681176	175.173754	192.666289
10.	G10	174.923272	196.78897	218.654692	240.520361

A comparison of output from mathematical approach & ANN approach is shown in Table-III

TABLE III. COMPARISON OF MATHEMATICAL & ANN OUTCOMES OF LOAD ALLOCATION

Sr. No.	Generator	Approach	Load on individual Generator			
			1600 MW	1800 MW	2000 MW	2200 MW
1.	G1	Mathematical	168.226339	189.217407	210.208475	231.199543
		ANN	168.226341	189.217412	210.208504	231.199547
		Error	2.34E-06	4.63E-06	2.94E-05	3.93E-06
2.	G2	Mathematical	152.023945	171.106734	190.189523	209.272312
		ANN	152.023947	171.106738	190.18955	209.272315
		Error	1.57E-06	4.01E-06	2.65E-05	3.16E-06
3.	G3	Mathematical	148.882754	167.295971	185.709189	204.122406
		ANN	148.882755	167.295975	185.709214	204.122409
		Error	1.43E-06	3.90E-06	2.54E-05	3.43E-06
4.	G4	Mathematical	170.128918	191.548375	212.967832	234.387289
		ANN	170.12892	191.548379	212.967862	234.387293
		Error	1.61E-06	4.43E-06	2.97E-05	3.98E-06
5.	G5	Mathematical	164.927783	185.507262	206.08674	226.666219
		ANN	164.927786	185.507266	206.086769	226.666222
		Error	2.60E-06	4.21E-06	2.91E-05	3.43E-06
6.	G6	Mathematical	149.487803	168.229828	186.971853	205.713878
		ANN	149.487805	168.229832	186.971879	205.713881
		Error	1.65E-06	3.77E-06	2.57E-05	3.12E-06
7.	G7	Mathmatical	153.842127	172.924916	192.007705	211.090494
		ANN	153.842128	172.92492	192.007731	211.090497
		Error	1.43E-06	3.95E-06	2.63E-05	3.20E-06
8.	G8	Mathematical	177.368446	199.699369	222.030293	244.361216
		ANN	177.368448	199.699374	222.030324	244.36122
		Error	2.17E-06	5.08E-06	3.09E-05	3.91E-06
9.	G9	Mathematical	140.188616	157.681173	175.173729	192.666286
		ANN	140.188618	157.681176	175.173754	192.666289
		Error	1.90E-06	3.23E-06	2.48E-05	3.10E-06
10.	G10	Mathematical	174.92327	196.788966	218.654662	240.520357
		ANN	174.9232723	196.7889704	218.6546922	240.5203612
		Error	2.32E-06	4.38E-06	3.02E-05	4.20E-06

Since the errors are within 5%, the results show good agreement hence the ANN-approach can suitably be used to determine the load allocation to ensure economic load dispatch.

CONCLUSION

- The load allocations to the individual generators which gives economic load dispatch can be obtained for any load from no load to full load using ANN
- The load allocations as obtained by ANN Approach and the mathematical approach exhibit close agreement, it is therefore the ANN approach can be used for determination of the load allocations for the economic load dispatch.
- The error in mathematical & ANN approach is within 2%.
- The mathematical model has been implemented through a computer programme.

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Appendix-1

The Algorithm to determine load allocations to individual units in a generating plant having ten units is as below

1. Start
2. Enter Range of Load ($Load_{min,}L_{max}$)
3. By using equation

$$\frac{dF_1}{dP_1} = \frac{dF_2}{dP_2} = \frac{dF_3}{dP_3} = \cdots \ldots \ldots \ldots \ldots . . \frac{dF_{10}}{dP_{10}}$$

   - P1+ P2 + P3+ ……………….+ P10=X
   - Find values of P_1, P_2, ………….P_n

4. Find fuel cost for given load X
5. Print Values of P1, P2, P3…… & fuel cost.
6. If X=Lmax
7. No Go for next value of load
8. Yes Exit

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