A VERY FAST AND EFFECTIVE NON-ITERATIVE "λ - LOGIC BASED" ALGORITHM FOR ECONOMIC DISPATCH OF THERMAL UNITS

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Abstract

In this paper a very fast and effective non-iterative "λ-logic based" algorithm for Economic Dispatch of Thermal units has been presented. As this is a direct or non-iterative method it does not demand any initial guess value of λ for ED (Economic Dispatch) of units for given P_{demand} (=P_D). Many of the existing conventional methods fail to impose P-limits at violating units. Improper selection of initial value for λ may cause slow convergence or at times leads to divergence for the conventional algorithms. Further, each specified P_D the problem is to be attempted a fresh with new guess value of λ. If the load various from $(P_D)_{min}$ to $(P_D)_{max}$ on the plant having K-units, the solution time becomes significantly large for higher values of K. Unlike to this, the proposed algorithm always offers the solution in an non-iterative mode with very low solution time as it is computationally very fast. The proposed algorithm is tested on K=38 units and results reported in the paper.

Key words:

ED	= Economic Dispatch
P_D	= Power demand on a plant
PPD	= Pre-prepared power demand data
dF_i/dP_i	= incremental fuel cost of i^{th}-unit.

I. INTRODUCTION

Economic dispatch (ED) is the scheduling of generators to minimise the total operating cost depending on equality and inequality constraints. Many techniques have been applied to ED to obtain better solutions [1] to [11]. These include the lambda-iteration method, the base point and participation factors method, gradient method, Artificial Neural Network (ANN) method and Genetic Algorithm (GA) method. The ANN based and GA based methods employ pre-prepared data to obtain the solution very fast for a specified power demand (=P_D). The actual support for such fast solution is the pre-prepared data in both ANN and GA methods. The present paper presents a very fast and effective non-iterative λ-logic based algorithm for Economic Dispatch with 'pre-prepared data' as big support for obtaining the solutions for any specified P_D in the range of $(P_D)_{min.}$ to $(P_D)_{max.}$

II. PROBLEM FORMULATION

The proposed algorithm for ED consists of **two stages** i.e., (i) **Pre-prepared power demand data (=PPD) using λ-logic** and (ii) **calculation of solution P_1, P_2,....,P_k for specified Pdemand (=P_D)**. The first step involves a systematic approach with fixed number of steps and offers unique PPD (pre-prepared Power Demand Data) for K units.

This PPD acts as a big source in reducing the computational burden of ED of K-units. This PPD remains unaltered for all values of P_D variations (ranging from P_{Dmin} to P_{Dmax}).

The above two steps are illustrated for K=3 units case and the test results of K=38 units are also presented.

For Economic Dispatch of K Thermal Units of plant, the ED condition is

$$dF_1/dP_1 = dF_2/dP_2 = ..., dF_k/dP_k = \lambda \quad .... (1)$$

$$\& \; P_1 + P_2 + ... P_k = P_D \quad .... (2)$$

At i^{th} unit, $F_i(P_i) = a_i + b_iP_i + c_iP_i^2$ \$/hr. .... (3)

$$dF_i/dPi = \lambda = \alpha_i + \beta_iP_i \text{ \$/Mwhr.} \quad .... (4)$$

This eqn. (4) gives linear variation of incremental fuel cost with respect to output power P_i

Then $P_i = (\lambda - \alpha_i) / \beta_i$, $i = 1$ to k. .... (5)

Data of 3 units:

$F_1(P_1) = 510 + 7.20P_1 + 0.00142 P_1^2$ \$/hr.
$F_2(P_2) = 310 + 7.85P_2 + 0.00194 P_2^2$ \$/hr.
$F_3(P_3) = 78 + 7.97P_3 + 0.00482 P_3^2$ \$/hr.

$dF_1/dP_1 = 7.2 + 0.00284 P_1 = \alpha_1+\beta_1P_1$, $150 \leq P_1 \leq 600$MW
$dF_2/dP_2 = 7.2 + 0.00388 P_2 = \alpha_2+\beta_2P_2$, $100 \leq P_2 \leq 400$MW
$dF_3/dP_3 = 7.97 + 0.00964 P_3 = \alpha_3+\beta_3P_3$, $50 \leq P_3 \leq 200$MW

(i) <u>Steps for pre-prepared power demand data (PPD)</u>:

Step a) Calculate

$$\lambda_{i\,min} = (dF_i/dP_i) \text{ at } P_i=P_{i\,min} \quad .... \quad (6)$$
$$\lambda_{i\,max} = (dF_i/dP_i) \text{ at } P_i=P_{i\,max} \quad .... \quad (7)$$

i = 1 to 3 (=K) units.

<u>Table – 1.</u>

Unit = i	P_I	λ_i
1	$P_{1min} = 150$	$\lambda_{1min} = 7.626$
1	$P_{1max} = 600$	$\lambda_{1max} = 8.904$
2	$P_{2min} = 100$	$\lambda_{2min} = 8.238$
2	$P_{2max} = 400$	$\lambda_{2max} = 9.402$
3	$P_{3min} = 50$	$\lambda_{3min} = 8.452$
3	$P_{3max} = 200$	$\lambda_{3max} = 9.898$

Step (b) Arrange λ-vector in Ascending order as below

<u>Table – 2</u>

J=S. No	λasc=λ-Vector	Unit-index vector	Total power = PPD(i) = ΣP_i	Slope = m
1	7.626	1	300.00MW	2.8400×10^{-3}
2	8.238	2	515.49MW	1.6397×10^{-3}
3	8.452	3	646.00MW	1.4014×10^{-3}
4	8.904	1	968.54MW	2.7665×10^{-3}
5	9.402	2	1148.55MW	9.6404×10^{-3}
6	9.898	3	1200.00MW	

Step (c). Now calculate total power Demand at each λ_j of the λ_{asc}-vector. For this, the following *fundamental observation* of ED (Economic Dispatch) condition is used.

$$\text{If } \lambda_J \le \lambda_{i\,min} \text{ then, } P_i = P_{i\,min} \quad .... \quad (8)$$
$$\text{If } \lambda_J \ge \lambda_{i\,max} \text{ then, } P_i = P_{i\,max} \quad .... \quad (9)$$
$$\text{and for } \lambda_{i\,min} < \lambda_J < \lambda_{i\,max}, \text{ the } P_i = (\lambda_J - \alpha_i)/\beta_i \quad .... \quad (10)$$

J=1; $\lambda_J = 7.626$,

i = 1; $\lambda_J = \lambda_{1min}$, $P_1 = 150MW$

i = 2; $\lambda_J < \lambda_{2min}$, $P_2 = 100MW$

i = 3; $\lambda_J \le \lambda_{3min}$, $P_3 = 50MW$

Thus, pre-prepared power demand for λ_J is (PPD(J)) $= P_1 + P_2 + P_3 = 300MW$

Similarly for J=2, $\lambda_J = 8.238$,

i=1; $\lambda_{1min} < \lambda_J < \lambda_{1max}$,

then $P_1 = (\lambda_J - \alpha_1)/\beta_1 = 365.49MW$

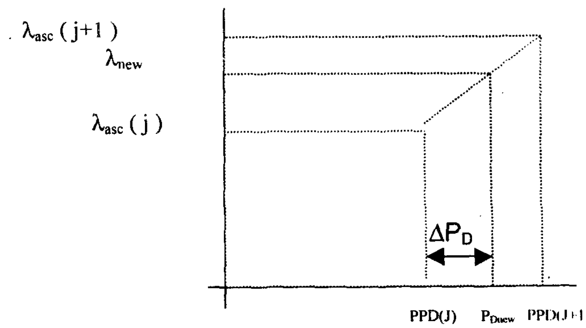
i=2; $\lambda_J \le \lambda_{2min}$, $P_2 = 100MW$

i=3; $\lambda_J \le \lambda_{2min}$, $P_3 = 50MW$

Thus, the pre-prepared power demand for λ_J is PPD(J) $= P_1+P_2+P_3=515.49$

These calculations of the PPD(J) are performed **only once** and *tabulated against corresponding values of increment fuel cost.* This information can be treated as *static system data* and can be **supplied as input data** along *with the coefficients of fuel cost functions.*

A close observation of λ_{asc} Vector of **step-b** clearly indicates that unit-1 is having lower incremental cost compared to unit 2 and 3. Thus, unit-1 governs the λ - value till the demand reaches to 515.49MW from 300MW. This implies that the graph between any two entries of λ_{asc} and PPD(J) is a straight line. Thus, the following figure shows the relationship between λ_{asc} and PPD(J).



We can calculate the slope between any two intervals and the λ_{new} corresponding P_{Dnew} which lies between PPD(J) and PPD(J+1) is given by

$$\lambda_{new} = (\text{slope})\,(\Delta P) + \lambda_{asc}(J). \quad .... \quad (11)$$

The slope between various intervals *also remains constant* and *needs to be evaluated only once.* The calculated slopes are shown in table-2 of step-b.

The steps a,b and c completes the first step of the proposed λ-logic method, i.e., pre-prepared power demand data (=PPD(J)). *This part can be done off-line (and similar to the part of Network training of Artificial Neural Network approach) and $\lambda_{asc}(J)$, PPD(J) and slope m(J) vectors would remain as static data.*

Step (ii). <u>Estimation of $P_1, P_2, ..., P_k$ for specified P_D</u>

Say, $P_D = 800$ MW $= P_{Dnew}$

Scan PPD(J) and identify the interval J and J+1 corresponding to P_{Dnew}.

J = 3; J+1 = 4;

$\lambda_{asc}(J) = 8.452$, PPD(J) = 646.00MW, $P_{Dnew} = 800MW$

$\Delta P_D = 800\text{-}646 = 154$, Slope $= 1.4014 \times 10^{-3}$

Then from Eqn. (11),

$\lambda_{new} = (1.4014\times10^{-3})\,(154.00) + 8.452 = 8.6678$ \$/MWh.

Using this λ_{new} and equations (8), (9) and (10), the values of P_1, P_2, and P_3 are :

$P_1 = 516.83$MW, $P_2 = 210.77$MW,
$P_3 = 72.39$MW, $P_D = P_1+P_2+P_3 = 799.99 \cong 800$ MW.

Similarly for any other P_D in the range of $300 \le P_D \le 1200$, P_1, P_2, and P_3 can be calculated very easily and quickly with very low computational burden. The various P_D values for testing purpose are:

S.No	1	2	3	4	5	6	7	8	9
P_D	750	300	400	550	950	450	550	600	350
10	11	12	13	14	15	16	17	18	
800	850	900	650	1000	1050	1100	1150	1200	

For any of the P_D, we need to repeat step (ii) only where λ_{new} is computed quickly without any iterative approach. This is mainly due to the pre-prepared data (PPD) using λ-Logic.

In all cases, though the P_D is in a random order, the P_1,P_2, and P_3 are computed *accurately and reliably.*

III. RESULTS

The above algorithm is tested on 38 units test system data. The results of P_1,P_2, ... P_{38} are reported in this paper for P_D = 6000.00MW in Table No.3.

Table 3.

$F_i(P_i) = a_i + b_iP_i + c_iP_i^2$, Data for Thermal Generating units of 38 units Test System. [Ref.2]

Unit	P_{min} MW	P_{max} MW	a_i ($)	b_i ($1MW)	c_i ($1MW^2)	Solution for P_D=6000MW λ = 1064.2114
1	220	550	64,782	796.9	0.3133	P_1=426.6061
2	220	550	64,782	796.9	0.3133	P_2=426.6061
3	200	500	64,670	795.5	0.3127	P_3=429.6633
4	200	500	64,670	795.5	0.3127	P_4=429.6633
5	200	500	64,670	795.5	0.3127	P_5=429.6633
6	200	500	64,670	795.5	0.3127	P_6=429.6633
7	200	500	64,670	795.5	0.3127	P_7=429.6633
8	200	500	64,670	795.5	0.3127	P_8=429.6633
9	114	500	172,832	915.7	0.7075	P_9=114.0000
10	114	500	172,832	915.7	0.7075	P_{10}=114.0000
11	114	500	176,003	884.2	0.7515	P_{11}=119.7681
12	114	500	173,028	884.2	0.7083	P_{12}=127.0729
13	110	500	91,340	1,250.1	0.4211	P_{13}=110.0000
14	90	365	63,440	1,298.6	0.5145	P_{14}=90.0000
15	82	365	65,468	1,298.6	0.5691	P_{15}=82.0000
16	120	325	77,282	1,290.8	0.5691	P_{16}=120.0000
17	65	315	190,928	238.1	2.5881	P_{17}=159.5981
18	65	315	285,372	1,149.5	3.8734	P_{18}=65.0000
19	65	315	271,676	1269.1	3.6842	P_{19}=65.0000
20	120	272	39,197	696.1	0.4921	P_{20}=272.0000
21	120	272	45,576	660.2	0.5728	P_{21}=272.0000
22	110	260	28,770	803.2	0.3572	P_{22}=260.0000
23	80	190	36,902	818.2	0.9415	P_{23}=130.6487
24	10	150	105,510	33.5	52.123	P_{24}=10.0000
25	60	125	22,233	805.4	1.1421	P_{25}=113.3051
26	55	110	30,953	707.1	2.0275	P_{26}=88.0669
27	35	75	17,044	833.6	3.0744	P_{27}=37.5051
28	20	70	81,079	2,188.7	16.765	P_{28}=20.0000
29	20	70	124,767	1,024.4	26.355	P_{29}=20.0000
30	20	70	121,915	837.1	30.575	P_{30}=20.0000
31	20	70	120,780	1,305.2	25.098	P_{31}=20.0000
32	20	60	104,441	716.6	33.722	P_{32}=20.0000
33	25	60	83,224	1,633.9	23.915	P_{33}=35.0000
34	18	60	111,281	969.6	32.562	P_{34}=18.0000
35	8	60	64,142	2,625.8	18.362	P_{35}=8.0000
36	25	60	103,519	1,633.9	23.915	P_{36}=25.0000
37	20	38	13,547	694.7	8.482	P_{37}=21.0000
38	20	38	13,518	655.9	9.693	P_{38}=21.0000

IV. CONCLUSIONS

The proposed λ-logic method is *new contribution* in the area of economic dispatch. It has two stages. At first stage, pre-prepared power demand (PPD-Vector) is to be calculated only once. At second stage solution vector ($P_1, P_2, \ldots P_k$) is calculated with very little computation as λ is directly calculated for specified P_D from eqn. (11) without any iterative approach. P_{min} and P_{max} limits are automatically accounted. Further, for any number of P_D values the solution vector can easily be computed with negligible CPU time. Thus, the proposed technique is superior to many of the available methods of Economic Dispatch.

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