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Economic Load Dispatch of Thermal Power Plants Using Differential Evolution

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***Abstract*- In present days with increasing in load demand and with large interconnection of networks it is essential to run the generating stations optimally with in its constraints so as to meet the load demand. Without optimization the price for the cost of generation is increasing day to day. So it is very essential to reduce the running charges for generating electric energy. The main economic factor in power system planning, operation and control is with the cost of generating real power. The running cost will be the main consideration with respect to the fuel for thermal power plants. So minimization of fuel cost will be criteria for thermal power plants.**

A major objective for the thermal power generation is to minimize fuel consumption by allocating optimal power generation to each unit (economic dispatch) subject to equality and inequality constraints. The optimum generation scheduling plays an extremely important role in optimal operation of utility power system. This importance is due to power savings. This paper proposed a lambda based approach for solving the Economic Dispatch (ED) problem. The ED is to minimize the operating fuel cost while satisfying the load demand and operational constraints. This paper solves sample test system of six generator system and 15 generator systems for various load demands neglecting transmission losses.

Nomenclature: Analytical method-lambda iterative method, P_G-real power generations, P_L-transmission loss, c-cost of real power generations, a_i, b_i, d_i- generator coefficients, P_D-load demand, ED-economic dispatch, EDC-economic dispatch computation

I. INTRODUCTION

The size of electric power system is increasing rapidly to meet the energy requirements. A number of power plants are connected in parallel to supply the system load by interconnection of power stations. With the development of grid system it becomes necessary to operate the plant unit most economically. The economic generation scheduling problem involves two separate steps namely the unit commitment and the online economic dispatch. The unit commitment is the selection of unit that will supply the anticipated load of the system over a required period of time at minimum cost as well as provide a specified margin of the operating reserve. The function of the online economic dispatch is to distribute the load among the generating units actually paralleled with the system in such a manner as to minimize the total cost of the fuel [1]. To calculate electric power generation of various units with different load demands, is solved by iterating the value of sum of the generator outputs equals the system load demand. Economic dispatch programs which are installed today in the most modern control centres uses the analytical methods to solve a well known exact co-ordination equations. The main difference between different techniques is the method used to solve the co-ordinations equations proposed by K.Srikrishna [2]. The co-ordination equations are generally solved by interactively adjusting the load until the generator output matches the system load demand when we neglect transmission losses. New graphical method for optimum power generation with neglecting the B-coefficient matrix is discussed [3]. The differential evolution method to optimize generation schedule neglecting the transmission losses is discussed in method proposed by kirchmayer [4]. Simplified approach to solution of co-ordination equation for generation scheduling is discussed by a method named Quick method to optimize generation scheduling proposed by C. Palanichamy [5]. The economic load dispatch solution can be analysed as the optimal solution corresponding to the minimum cost of generation proposed by K. Nagappa [6]. The cost of power generation is not the same for every unit. So, to have the minimum cost of generation for a particular load demand, we have to distribute the load among the units which minimize the overall generation cost with the constraint that no unit is overloaded.

II. OBJECTIVE FUNCTION

The majority of generating units have a non linear cost function. The objective function of thermal power plant is

$$C_i = a_i P_{Gi}^2 + b_i P_{Gi} + d_i \quad \ldots(1)$$

Where a_i is a measure of losses in the system, b_i is the fuel cost and d_i is the salary and wages, interest and depreciation.

The optimal dispatches for the thermal power plants should be such that the total electric power generation equal to the load demand when neglecting line losses, which can be written as:

$$\sum_{i=1}^{n} PGi = PD \quad \ldots (2),$$

n = total number of generating plants, PGi = generation of i[th] plant, PD = system load demand.

The inequality constraints is given by

$$P_{GiMin} \leq P_{Gi} \leq P_{GiMax} \quad \ldots\ldots (3)$$

Maximum active power generation P_{GiMax}

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Minimum active power generation P_{GiMin}

III. METHODOLOGY

The objective of optimum generation scheduling for thermal power plants is to allocate the generation to each and every units in a plant for a given load such that fuel cost is minimum subjected to equal and inequality constraints. Here, optimum generation scheduling is achieved by following technique.

DIFFERENTIAL EVOLUTION

Differential Evolution is a method used in this paper to solve the economic load dispatch problem when transmission losses are neglected. An initially random population of individuals (trial solutions) is created. Mutations are then applied to each individual to create new individuals. Mutations vary in the severity of their effect on the behaviour of the individual. The new individuals are then compared to select which should survive to form the new population. DE is similar to a genetic algorithm, but models only the behavioural linkage between parents and their offspring, rather than seeking to emulate specific genetic operators from nature such as the encoding of behaviour in a genome and recombination by genetic crossover. Mutation, recombination, and selection are iterated with the goal of driving a population of candidate solutions toward better and better regions of the search space. We have to select the number of populations' value randomly until we get optimum scheduling which meets the sum of generations of all units equal to load demand and transmission losses. This value of number of populations is selected by using trial and error method. Then the dimensions for the system which we apply differential evolution is selected. After we select scheduling of generators optimally, we need minimum cost of generation, so from optimum scheduling the cost of real power generation which has minimum value is selected. The dimensions are selected based on the number generators we are scheduling for optimality. The cross over to solve the optimum generation scheduling is taken. Then the strategy to solve this scheduling is taken for small population sizes and fast convergence. Dimensionality should not be too high. In this paper, we consider number of dimensions with "D", number of parameter, number of populations as "N_P", cross over probability as "CR". The minimum and maximum generating constraints are considered for optimum scheduling. The weight vector is also considered for the scheduling to be optimum.

Algorithm

The Algorithm is as follows:

1. Start
2. Initially chose $\lambda=\lambda_0$, this value should be greater than the largest intercept of the incremental cost of the various units. Calculate P_{G1}, $P_{G2,\ldots\ldots}$,P_{Gi} based on equal incremental cost.
3. Assume P_{GI} = 0.0; i=1, 2 …N
4. Read the constants a_i, b_i, d_i , power demands P_D, maximum P_{GiMax}, minimum P_{GiMin} generators real power limits.

Steps including differential evolution

i. An Initial population of N_p parent vectors is considered as the trial solution and the number of dimensions is taken as D. Then cross over probability is taken as CR and weight vector is also considered.
ii. From these parents off springs are created by mutation, hence N_p off springs are obtained
iii. By combining the parents and off springs, $2N_p$ solutions are obtained
iv. Through competition and selection, first N_p optimal solutions are selected
v. The selected solutions are considered as parents for the next iteration
vi. After the required number of iterations , the best optimal solution is obtained

5. Calculate the generation at all buses using
$P_{Gi}=(1-b_i/\lambda)/(2a_i/\lambda)$ ---(4) where i=1,2,-------,n
keeping in mind that the values of powers to be substituted on the RHS of Equation during zero iteration correspond to the values calculated in step 2. For subsequent iterations the values of powers to be substituted corresponds to the powers in the previous iteration. However if any generator violates the limit of generation that generator is fixed at the limit violated.
6. Check if the difference in power at all generator buses between two consecutive iterations is less than the specified value, otherwise go backing to step 2.
7. Check if power balance equation is satisfied,
$\sum_{i=1}^{n} PGi - PD < \epsilon$------ (5)
if yes, stop. Otherwise, go to step-9.
8. Increase λ by Δλ; if
$\sum_{i=1}^{n} PGi - PD < 0$.-----(6)
decrease λ by Δλ; if
$\sum_{i=1}^{n} PGi - PD > 0$.------(7)
9. Repeat from step 5
10. Update λas $\lambda^{(k+1)} = \lambda^{(k)} - \Delta\lambda^{(k)}$ where λ is the step size

IV. TEST CASES

Here we consider two test systems. In the first case 6 generators are considered with their cost curve equations (second order polynomial expression). The optimal generation scheduling of six thermal generating units for different loads are determined and also cost of generation for different loads is determined. The cost for economic allocation of generation to each generating unit is determined and whether all units are satisfying its equality and in equality constraints are verified. In the second case 15 generators are considered with their cost curve expression (second order polynomial equation). The optimum generation scheduling for different load conditions is explained here. The optimal generation scheduling of 6 thermal generating units and 15 thermal generating units for different loads are determined and also cost of generation for different loads is determined using Differential Evolution technique. The cost for economic allocation of generation to each generating unit is determined and whether all units are satisfying its equality and in equality constraints are verified.

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Results:

Test Case I

The input data is taken from reference [7]. The result for optimum generation scheduling for different load conditions is given in table 4.1. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically [9].

P_{DT}	955	942	935	930	935	963
P_{G1}	347.855	351.3657	409.5106	301.3504	409.5106	354.1994
P_{G2}	165.4891	87.0835	158.0512	154.9001	158.0512	131.4445
P_{G3}	172.639	260.0927	128.1655	253.3607	128.1655	188.3619
P_{G4}	93.8989	104.7534	94.7536	63.7897	94.7536	95.2326
P_{G5}	123.317	80.3962	83.9223	97.5392	83.9223	141.3184
P_{G6}	52.1683	58.6478	59.6836	59.324	59.6836	53.864
cost	**673740**	**673740**	**670860**	**665820**	**670860**	**687000**

Table 4.1 Real power generations & cost for various loads

The result for different load conditions is given in table 4.2. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	989	1023	1126	1150	1201	1235
P_{G1}	319.842	424.2157	488.1665	446.0042	498.2154	461.1063
P_{G2}	129.2667	129.7278	131.1674	174.1568	149.5565	133.0498
P_{G3}	235.1308	260.4743	231.1982	157.3555	246.4754	262.0645
P_{G4}	72.7231	94.2599	121.8376	144.0919	71.1886	128.7715
P_{G5}	177.2277	62.7022	94.2955	166.4867	179.646	183.9628
P_{G6}	55.0187	52.0551	59.8691	63.4922	55.7837	95.9265
cost	**708720**	**733560**	**813000**	**833280**	**870780**	**895440**

Table 4.2 Real power generations & cost for various loads

The result for different load conditions is given in table 4.3. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	1190	1251	1263	1250	1221	1202
P_{G1}	440.2851	495.671	423.0091	487.0623	455.1797	476.8619
P_{G2}	134.0839	185.5982	191.9601	192.187	170.7164	181.5959
P_{G3}	284.514	254.6925	253.3523	295.0711	232.0205	200.5152
P_{G4}	119.6667	54.4792	136.3231	113.6057	137.9211	79.2849
P_{G5}	137.4186	189.2333	196.2865	94.4861	158.3475	199.7391
P_{G6}	74.4619	66.6855	62.5774	68.2622	66.7584	62.6739
cost	**860220**	**910920**	**917640**	**910740**	**884040**	**872340**

Table 4.3 Real power generations & cost for various loads

Optimal generation allocation and cost of real power generation of six generating units for different load conditions are shown in tabular column. The result for different load conditions is given in table 4.4. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	1159	1092	1023	984	975	960
P_{G1}	470.4321	416.8579	382.7402	406.9819	369.0926	405.8895
P_{G2}	184.7392	109.1763	130.3532	86.3819	187.8493	78.7465
P_{G3}	231.346	219.5047	249.7696	274.9511	203.585	246.8797
P_{G4}	69.5796	97.1723	71.6688	79.7543	70.139	75.0115
P_{G5}	138.3215	187.4964	114.2993	78.6017	88.2661	95.1121
P_{G6}	64.5786	61.6492	74.3693	57.2412	56.222	57.8889
cost	**837120**	**784920**	**731700**	**705120**	**697560**	**685800**

Table 4.4 Real power generations & cost for various loads

Thus above tabular columns show the optimal scheduling of six thermal generating plants along with their cost for real power generation. The graph shows the relation for time in 24 hrs for different load demands the cost of generating units in Rs/Hr to generate real power to meet load demands. Fig 1 shows the relation for time in hrs and cost of power generations of six units for 24 hrs to meet the load demand.

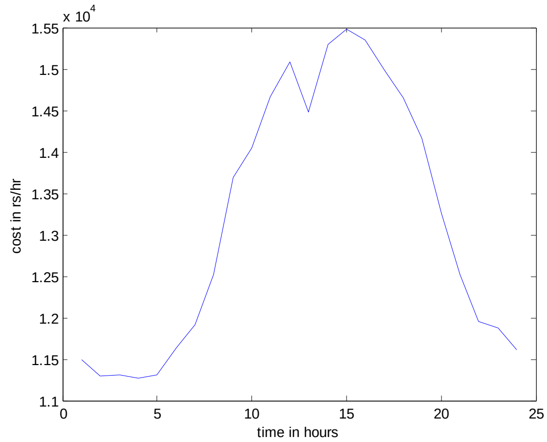

Fig 1. Time vs Cost real power generations of all units

Thus from Differential evolution programming technique we determine the real power generations for economic dispatch and cost of real power generation. The curve explains during peak load hrs cost of generation also increases. The results are shown in tabular column and graph.

Test Case II

The input data is taken from reference [9]. In this case we determine optimal generation allocation and cost of real power generation for 15 generating units for different load conditions. The result for different load conditions is given in table 4.5. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically [7].

P_{DT}	2236	2240	2226	2236	2298	2316
P_{G1}	260.3649	328.9143	180.3993	248.7837	183.542	342.4472
P_{G2}	440.3	253.49	281.5067	336.35	277.69	303.1

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	8	17		29	18	894
P_{G3}	122.5413	103.3466	120.59	123.968	37.6498	34.7909
P_{G4}	125.3876	94.5934	114.2406	62.5626	26.1086	43.6785
P_{G5}	216.0923	236.5245	395.6461	283.5087	394.9363	211.0301
P_{G6}	186.9027	334.4409	151.361	151.8017	414.7748	316.8199
P_{G7}	323.681	292.148	436.9093	395.4314	396.3682	385.1255
P_{G8}	202.3006	108.1869	134.4656	163.5947	131.3223	218.9524
P_{G9}	120.7097	105.6239	50.5642	119.5806	143.3147	122.3768
P_{G10}	66.2848	141.0811	113.4644	112.9228	123.8535	98.5976
P_{G11}	43.6311	64.3752	68.232	63.141	23.653	53.6133
P_{G12}	40.2131	70.9036	62.652	42.7648	60.0409	39.533
P_{G13}	32.7396	55.875	76.8126	61.4183	29.3558	82.9809
P_{G14}	18.4775	28.6441	22.2384	40.8132	18.88	19.5369
P_{G15}	36.9577	22.248	17.0219	27.7895	35.6499	41.7932
cost	**997560**	**1000740**	**935040**	**914700**	**1005060**	**948900**

Table 4.5 Real power generations & cost for various loads

The result for different load conditions is given in table 4.6. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	2331	2443	2630	2728	2783	2785
P_{G1}	371.8958	265.3148	292.6161	432.7538	441.4511	441.493
P_{G2}	226.1616	278.6528	404.5755	387.1026	383.0042	445.5931
P_{G3}	102.6343	56.8437	33.9273	117.6728	121.8748	91.5232
P_{G4}	39.2682	115.439	65.8917	37.4368	93.0278	86.6007
P_{G5}	336.501	369.6571	451.1684	424.1355	427.3429	468.3327
P_{G6}	176.2453	419.6227	139.683	328.3741	313.5184	225.8016
P_{G7}	297.2865	405.4245	449.4889	269.1793	423.9108	416.6921
P_{G8}	231.6795	79.144	294.6177	227.064	118.3486	164.8033
P_{G9}	148.0727	149.4534	161.2319	158.2106	34.9734	97.116
P_{G10}	119.4719	46.0962	57.4321	111.567	117.4318	132.6543
P_{G11}	60.4262	68.7018	77.2166	73.4326	78.9978	42.6975
P_{G12}	57.7735	60.5169	71.9329	52.4447	73.2148	46.811
P_{G13}	62.9162	44.3257	70.2398	45.1195	80.4951	25.387
P_{G14}	47.7194	39.9539	42.9763	16.6398	25.2984	49.6478
P_{G15}	53.009	44.001	17.4462	47.7545	52.4718	48.446
cost	**946500**	**1100700**	**1036080**	**1239660**	**1267620**	**1259100**

Table 4.6 Real power generations & cost for various loads

Optimal generation allocation and cost of real power generation for six generating units for different load conditions are shown in tabular column. The result for different load conditions is given in table 4.7. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	2780	2830	2970	2950	2902	2803
P_{G1}	395.0907	383.7313	385.6522	335.2032	426.5487	324.2011
P_{G2}	434.594	440.6461	445.8044	412.4008	398.9391	388.7657
P_{G3}	60.4221	24.5895	128.6548	95.8039	112.8647	40.6349
P_{G4}	101.5333	128.3337	53.6952	28.8733	112.9658	114.1803
P_{G5}	435.5896	433.9823	333.5991	386.2302	428.2469	317.327
P_{G6}	452.8634	414.0266	426.7893	456.4481	439.6549	296.2421
P_{G7}	407.5947	440.1124	429.8513	418.1397	343.1651	463.746
P_{G8}	148.5852	272.2082	281.4859	294.9473	188.1452	264.8242
P_{G9}	94.3833	64.1885	133.29	100.0685	145.1658	136.5093
P_{G10}	41.9241	28.3262	128.8659	159.9421	126.2345	147.23
P_{G11}	40.6318	27.3333	67.4654	66.7399	48.0024	68.4582
P_{G12}	42.7936	61.6484	38.2159	35.0207	27.0851	79.2956
P_{G13}	62.4615	40.3068	40.1815	83.3243	42.833	77.3878
P_{G14}	41.018	32.5908	53.4633	27.9399	18.1944	42.447
P_{G15}	18.982	38.182	23.1049	50.3975	44.295	43.1436
cost	**1334640**	**1301460**	**1266540**	**1233540**	**1353540**	**1085820**

Table 4.7 Real power generations & cost for various loads

The result for different load conditions is given in table 4.8. From the tabular column it is cleared that all generators are operating within its constraint limits. It means that all generators are operating economically.

P_{DT}	2651	2584	2432	2312	2261	2254
P_{G1}	328.3683	337.5947	309.6425	406.0148	179.2934	388.5734
P_{G2}	420.1364	447.9077	423.1832	196.0881	287.7982	239.8477
P_{G3}	40.5646	62.2366	85.536	68.661	126.3102	68.5217
P_{G4}	65.0121	43.5522	87.7102	110.703	109.4472	37.945
P_{G5}	395.0422	351.7498	362.7477	319.1975	340.1538	401.8706
P_{G6}	386.6808	211.7652	147.5861	172.2206	405.2802	218.9307
P_{G7}	374.0531	397.1496	445.6577	451.517	428.365	267.282
P_{G8}	181.3784	272.2082	90.6046	174.0881	132.6237	226.2371
P_{G9}	25.6981	116.1875	104.1513	121.1038	48.7248	42.9174
P_{G10}	156.8187	88.2073	88.34	56.81	27.7643	106.9299
P_{G11}	48.0707	73.9427	77.2654	61.5718	23.3377	52.1649

P_{G12}	66.4383	77.385	72.7851	32.6224	60.8286	52.5364
P_{G13}	83.1848	38.8344	52.6337	70.0082	30.4547	69.3769
P_{G14}	26.1092	47.5121	41.729	17.6643	40.8715	51.7473
P_{G15}	53.576	17.0227	39.6985	51.6939	21.2524	28.3766
cost	**1186680**	**1075140**	**1046580**	**955680**	**1059180**	**1014360**

Table 4.8 Generations and cost of generations for various loads

Thus above tabular columns show the optimal scheduling of fifteen thermal generating plants along with their cost for real power generation. The graph shows the relation for time in 24 hrs for different load demands the cost of generating units to generate real power to meet load demands. Fig 2 shows the relation for time in hrs and cost of power generations of six units for 24 hrs to meet the load demand.

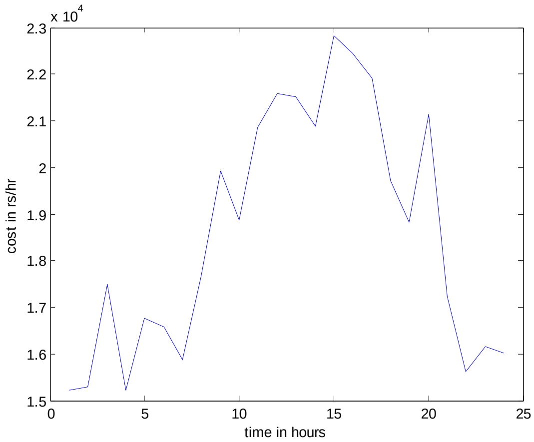

Fig 2. Time vs Cost of real power generations of all units

V. CONCLUSION:

This paper deals with optimal generation scheduling in thermal power plant using differential evolution programming method. The equality and inequality constraints are considered while optimizing generation scheduling. In both case studies it is clear that all generators run within its constraint limits for optimum generation allocation or economic load dispatch. If the generators do not run in its constraint limits whether below its minimum generation capacity or above its maximum generation capacity economic load dispatch is not possible. Therefore economic load dispatch is possible only if all generating units run within its constraints limits. This paper concludes that scheduling through Differential Evolution programming technique is economical compared to analytical solution technique.

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