Particle Swarm Optimization based Economic Dispatch of Kerala Power System

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ABSTRACT

The economic load dispatch problem aims at controlling the committed generating unit outputs so as to meet the required load demand at minimum operating cost while satisfying the power demand and system equality and inequality constraints. The economic load dispatch is a non-linear constrained optimization method whose complexity increases when constraints such as system power balance constraints and generator constraints are considered. This paper describes the use of particle swarm optimization algorithm in finding out which combination of generators should be worked together in order to meet the required load demand at minimum operating cost

Keywords

Economic load dispatch, particle swarm optimization and power balance constraints.

1. INTRODUCTION

In economic dispatch, the objective is to calculate the output power of every generating unit, for a single period of time, so that all the demands are satisfied at the minimum cost, while satisfying different constraints of the model. Optimization is a nonlinear mathematical model of a real-world problem. In this paper, particle swarm optimization technique is utilized for economic load dispatch problem to find the generating units that minimize the generation cost while satisfying a set of constraints.

The major qualitative factors in power industry are frequency, voltage and stability. In the integrated environment, it is not possible to take a corrective action by Kerala to modify the grid frequency [1]. This will be more acute when the Southern Region is integrated to the rest of India through 800kV links. Voltage and stability are within the control of the grid operators, transmission and distribution managers, where optimization is possible. The cost aspect lies in the domain of system operators in the regulated power market. Since the hourly consumption of power is several thousands of MW even a single paise per MW saves several crores of Rupees to Kerala power economy [2].

The cost of supplying electricity to consumers can be divided in to demand costs and energy cost, compared to the common industrial classification of fixed and variable costs. Demand costs are the capacity related costs for generation, transmission and distribution and vary with the quality of plant and equipment and the associated investment. Energy costs are those which vary directly with the quantity of units generated [3].

This paper focuses on an economic dispatch of Kerala power system by the formulation of cost optimization problem and finding out solution through particle swarm optimization. The data collected from Kerala State Electricity Board Ltd., are used for the model representation which portrays a real physical problem. The data consists of varying operational and maintenance costs of different generators per hour on daily basis as well as hourly load generated from 50 generators in 17 stations across the State.

2. KERALA POWER SYSTEM: THE NEED FOR OPTIMISATION

The cost of power procurement alone works out at present 70% of the total revenue requirement of Kerala State Electricity Board Ltd (KSEB Ltd) depending on the availability of monsoon. This necessitates for framing an optimization strategy in the management of power system. To meet the increase in energy demand the KSEB Ltd has been heavily depending on the short-term market and energy exchanges, because new major hydel projects have not yet been materialized in the State due to various reasons. At present about 15 to 20% of the energy requirement of the State is being met from short-term market i.e., high dependence on costlier power [4]. Water is the only commercially viable source for power generation within the State to ensure reliability of supply as well as energy security addition in Kerala. The need for equipping Kerala Power System to meet the demands of the excepted explosive growth in the industrial sector is well recognized.

The cost of generation and power purchase are increased on account of the reduction in hydel availability and the consequent increase in demand and excessive energy prices of short-term markets, transmission constraints on importing power from outside the State, increase in cost of liquid fuel stations etc.

During 2016-17 the total capacity addition from all sources was 55.03MW. Total installed capacity of power in the State as on March 2017 is 2,961.11MW. Of which, hydel contributed the major share of 2,107.96 MW (71.19 %); while 718.46MW was contributed by thermal projects, 59.27MW from wind and 75.42MW from solar [5]. During 2017-18 the total installed capacity in Kerala was 2791.25MW. Of which KSEB Ltd contribution was 2215.24MW and others 576.01MW.

The total energy consumption for a day as on 20th Aug 2018 was 50.3843MU. The availability of energy from Central Generating Station was 20.99MU and purchase was 8.3512MU and energy from hydro was 21.04 MU. Evening peak on the same day was 3040MW. The total availability was 2099.345 MW. The remaining 940.655MW was purchased. For this purchase Rs 16.931crore was required for one day. That is, the KSEB Ltd was running at a loss. For reducing this loss, the imported power has to be reduced by using the optimization techniques.

3. ECONOMIC LOAD DISPATCH PROBLEM FORMULATION

The complex nature of generation of electricity signifies ample opportunity of improvement towards the optimal power generation solution. The demand of power system varies throughout the day and reaches a different peak value from one day to another. To satisfy this demand, to start-up and shut-down, a number of generating units at various power stations each day is needed [6]. The difficult task is to decide when and which generating units are to turn on and turn off together with minimizing the total cost. Similarly, the total generation must be equal to the forecasted demand of electricity. For reducing the generation cost, optimized scheduling for economic load dispatch is necessary. Thus, the economic dispatch is one of the most important problems to be solved in the operation and planning of a power system.

The primary objective of the electric power generation is to schedule the committed generating unit outputs so as to meet the required load demand at minimum operating cost while satisfying all unit and system constraints [7]. Extensive amount of power is drawn daily from external sources that are not under the authority of Kerala power system, despite the load being much lesser than the installed capacity. Hence, this economic dispatch formulation tries to reduce external import of power and attempts to introduce self-sustainability into Kerala power system.

In the traditional economic dispatch problem, the cost function for each generator has been approximately represented by a single quadratic function and is solved using mathematical programming based on the optimization techniques [8]. Lagrange Relaxation (LR) method is commonly used to solve large scaled unit commitment problems. LR has been successfully applied to the complex unit commit problem including various hard constraints (ramp rate constraints, minimum up and down time, etc.). Unit commitment is a nonlinear mixed integer optimization problem. It schedules the operation of the generating units as minimum operating cost satisfying the demand and other constraints. [9]

Based on the data obtained from KSEB Ltd and the Kerala State Electricity Regulatory Commission, the required parameters are made into an economic dispatch model. Figure 1 depicts the system structure of the proposed method.

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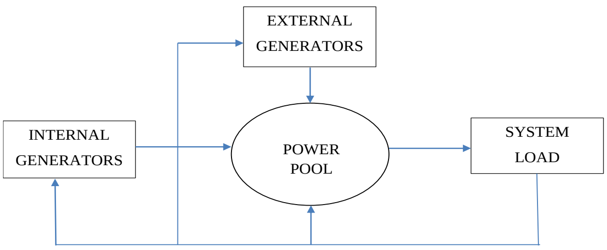

Fig .1: Power system structure

3.1 Objective Function

The objective function of the economic dispatch problem can be expressed in the following equation:

$$Min(F_t) = \sum_{i=1}^{N_g} F_i(P_i) \quad (1)$$

The generation cost function $F_i(P_i)$ is usually expressed as a quadratic polynomial as in the equation (2) [10].

$$Min(F_t) = \sum_{i=1}^{N_g} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (2)$$

Where,
N_g - Number of internal generators
P_i - Load dispatch of i^{th} generator at time t
$\alpha_i, \beta_i, \gamma_i$ - Cost coefficients of i^{th} generator

Each generating unit has a unique production cost defined by its cost coefficients. Here the curve fitting method is used in order to find the cost coefficients $\alpha_i, \beta_i, \gamma_i$ by giving input as matrices of load in MW and cost in Rupees per hour. Curve fitting tool in MATLAB is used to obtain the value of cost coefficient.

3.2 Constraints

The objective function in equation (1) is minimized subjected to a set of constraints. The various constraints to be considered in the economic dispatch problem are: system power balance constraints and generator constraints. The major constraints considered are the following:

a) System power balance constraint is mathematically expressed as:

$$\sum_{i=1}^{N_g}(P_{i,t}) = P_L(t) + P_{loss}(t) \quad (3)$$

Where,
$P_{i,t}$ - the scheduled optimal generation of i^{th} unit.
N_g - the number of generators available for generating the load.
$P_L(t)$ - the active power load at time point t.
$P_{loss}(t)$ - the estimated loss at time point, t.

b) Generator constraint is expressed as in the equation below:

$$P_{i,min} \le P_{i,t} \le P_{i,max} \quad (4)$$

Where,
$P_{i,min}$ - the minimum load generated from i^{th} unit.
$P_{i,max}$ - the maximum load generated from i^{th} unit.

4. PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization (PSO) algorithm was introduced by Kennedy and Eberhart in 1995. The original objective of this technique was to mathematically simulate the social behavior of bird flocks and fish schools. For developing the simulation was to model human social behavior, which is not identical to fish schooling or bird flocking. In PSO [11]-[13] the potential solutions, called particles, "fly" through the problem space by following some simple rules. All of the particles have fitness values based on their position and have velocities which direct the flight of the particles. PSO is initialized with a group of random particles (solutions), and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) the particle has achieved so far. This value is called "*pbest*" or the individual particle best. Another "*best*" value that is tracked by the particle swarm optimizer is the best value obtained so far by any particle in the population. This best value is a global best and called "*gbest*" or the global best among all the considered particles, considering the current as well as all the previous iterations. After finding the two best values explained above, the particle updates its parameters, velocity and position with following equations (5) and (6):

$$V_n(k+1) = w * V_n(k) + c_1.rand_1.\left(Pbest_n(k) - P_n(k)\right) + c_2.rand_2.\left(G_{best} - P_n(k)\right) \quad (5)$$

$$P_n(k+1) = P_n(k) + V_n(k+1)$$

Where, w is the inertia coefficient which slows velocity over time; $V_n(k)$ is the nth particle velocity after the kth iteration; $P_n(k)$ is the current nth particle position in the search space; $pbest_n(k)$ and $gbest$ are the"personal" or individual best (describe the individuality) and global best (describing the social nature of the particle); $rand_1$ and $rand_2$ random numbers between (0,1); c_1 and c_2 are learning factors. The stop condition is usually the maximum number of allowed iterations for PSO to execute or the minimum error requirement. As with the other parameters, the stop condition depends on the problem to be optimized [14].

A total 50 generators are considered and particle of size 30 is selected. Also, a matrix of size 50×30 is initialized. For each of these generators, *pbest* and *gbest* are found in each iteration. Cost per unit is selected as *pbest* for each of the particles. The constraints explained in the system such as a) and b) are considered while optimizing the cost of production in each iteration. The algorithm used for this optimization includes the following steps:

Step 1**:** Read internal generation available for time t. Here 50 major generating stations are taken as internal generators as explained;

Step 2: Read cost coefficients $\alpha_i, \beta_i, \gamma_i$ that has been calculated beforehand using curve fitting tool;

Step 3: Initialize particle size, number of iteration and maximum error, learning factors (c_1, c_2) and inertia weight (w). Define initial velocity and position of particles for each generating unit;

Step 4: Calculate dispatch and cost per unit and select cost per unit as *pbest*;

Step 5: Check maximum minimum conditions of dispatch from each unit;

Step 6: Select *gbest* (minimum of cost per unit);

Step 7: Update particle parameters;

Step 8: Calculate new dispatch and cost per unit and update *pbest*;

Step 9: Check maximum and minimum conditions of dispatch and update *gbest*;

Step 10: Check and enforce pattern of internal and external generations; and

Step 11: Increment time slot.

Go to step 9.

In this work, PSO with time varying inertia weight (PSO-TVIW) factor is used. The optimal solution is improved by varying the value of inertia weight from 0.4 to 0.9. The entire methodology is summarized as a flow chart in figure 2.

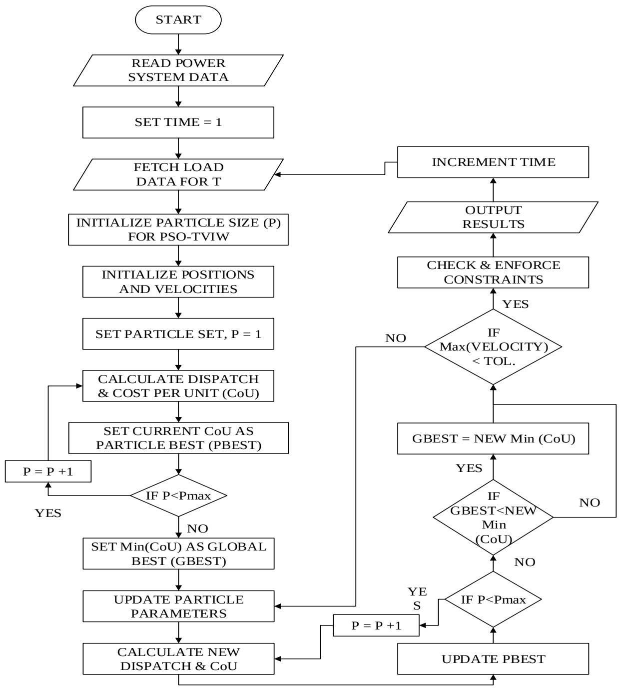

Fig.2: Flow chart for PSO based economic load dispatch

Table.1: Cost function coefficients of 50 units system

Generating Units	α Rs/hr	β Rs/MWhr	γ Rs/MWhr^2	P_Optimal
1	1744.7236	0	0.0000490787	99.404936
2	1835.7919	0.00387579	0.0000930924	99.404936
3	1056.9862	0.006459667	0.0001356974	99.404936
4	1843.3758	0.001937896	0.0002987879	99.404936
5	1562.3592	0.001937896	0.000409986	99.404936
6	1027.5404	0.001937896	0.000459206	99.404936
7	1208.4982	0.0019479356	0.0009618129	42.055934
8	1476.8815	0.0038958706	0.0014026736	42.055934
9	1887.5068	0.0038958706	0.0017053512	42.055934
10	1894.8885	0.0038958706	0.001776971	42.055934
11	1087.6130	0.0038958706	0.0008436269	45.879201
12	1900.5927	0.003895876	0.0011952770	45.879201
13	1887.1669	0.000481958	-0.0001607599	2.6762867
14	1415.3756	0.002891467	-0.0059924722	2.6762867
15	1730.2804	0.00192764237	-0.0036757594	2.6762867
16	1071.8863	0.005799594728	0.0004526858	45.879201
17	1351.7612	0	0.0015765130	45.879201
18	1845.7355	0.00231983787	0.0023847449	45.879201
19	1722.2073	0.022905835	-0.0007750620	13.381433
20	1889.4924	0	-0.000473742972	13.381433
21	1585.7407	0.0152705575	-0.00007071814	13.381433
22	965.71167	0.00416582519	-0.00034552462	19.116334
23	1779.1293	0	-0.0027212523	28.674501
24	1863.9932	0	-0.00226187310	28.674501
25	1608.7351	0.0005671898	-0.00415059163	3.8232667
26	1687.7401	0.0017015687	-0.00876417201	3.8232667
27	1673.1324	0.0017015687	-0.0017019061	3.8232667
28	1322.2270	0	-0.0016889454	5.7349001
29	1585.4778	0.00226875857	-0.0080733552	5.7349001
30	1101.1866	0.0034031377	0.0049812530	5.7349001
31	1636.0469	0.0064610707	-0.0016276787	9.1758403
32	961.83284	0.00403816887	-0.00883832794	9.1758403
33	1206.9229	0.000470438	-0.00126463984	9.1758403
34	976.1713	0,0001974298	0.000739784736	9.1758403
35	1027.1317	0.0010349637	0.000201753141	12.234453
36	1753.4578	0.00075270098	0.000472815265	12.234453
37	1624.8286	0.00019742978	0.0008590879	6.1172268
38	1247.0994	0	0.0001993692	6.1172268
39	1880.2220	0.00019742978	0.000562894	6.1172268
40	964.44608	0.001579438368	0.0001062650	6.1172268
41	1368.7443	0.0001237119	-0.0001188750	12.234453
42	1311.5584	0	0.0001604344	13.763760
43	1695.5167	0	-0.0004649355	13.763760
44	1725.1999	0.00983596057	0.0002980414	13.763760
45	1116.8726	0.0009437548	0.0002663307	19.116334
46	1419.7644	0.0005243078	0.000277830	19.116334
47	1375.5862	0.0020972317	0.000435668	19.116334
48	1576.3130	0.0029361237	0.0000163413	38.232667
49	1639.3648	0.0016777857	0.0000142703	38.232667
50	1684.6866	0.0016777857	0.0000235636	38.232667

No. of Days	April,2015 Actual Power (Hydro)MW	Optimised power (Hydro)MW	Demand/Consumption (MW)	Import power (MW)	Optimised cost (Rs.)	Cost of imported power (Rs.)	Cost saving (Rs.)
1	583.375	1869.294	2348.833542	1765.458542	41722642.08	155925298.4	114202656.3
2	696.9483	1884.776	2577.406667	1880.458367	42068200.32	166082082.9	124013882.6
3	707.0006	1895.793	2586.229792	1879.229192	42314099.76	165973522.2	123659422.4
4	726.7267	1900.361	2588.342917	1861.616217	42416057.52	164417944.3	122001886.7
5	805.2898	1871.402	2608.727292	1803.437492	41769692.64	159279599.3	117509906.6
6	780.9167	1894.732	2571.4375	1790.5208	42290418.24	158138797.1	115848378.8
7	1108.91	1960.7286	2869.769792	1760.859792	43763462.35	155519136.8	111755674.4
8	691.1335	1911.06	2517.737708	1826.604208	42654859.2	161325683.7	118670824.5
9	509.6863	1911.991	2344.18625	1834.49995	42675639.12	162023035.6	119347396.5
10	772.0631	1898.427	2562.854792	1790.791692	42372890.64	158162722.2	115789831.6
11	813.3913	1885.964	2663.89125	1850.49995	42094716.48	163436155.6	121341439.1
12	897.6962	1879.037	2680.905	1783.2088	41940105.84	157493001.2	115552895.4
13	987.4973	1892.007	2870.472292	1882.974992	42229596.24	166304351.3	124074755
14	987.4973	1918.799	2729.893125	1742.395825	42827593.68	153888399.3	111060805.6
15	1046.674	1909.516	2792.194792	1745.520792	42620397.12	154164396.3	111543999.2
16	929.3985	1873.7701	2642.231875	1712.833375	41822548.63	151277443.7	109454895
17	1065.873	1947.4246	2834.908125	1769.035125	43466517.07	156241182.2	112774665.2
18	811.3067	1908.314	2519.056667	1707.749967	42593568.48	150828477.1	108234908.6
19	658.4935	1881.351	2372.264375	1713.770875	41991754.32	151360243.7	109368489.4
20	710.1985	1887.489	2520.136042	1809.937542	42128754.48	159853683.7	117724929.2
21	821.3923	1910.71	2652.996458	1831.604158	42647047.2	161767279.3	119120232.1
22	815.155	1838.3188	2831.83125	2016.67625	41031275.62	178112846.4	137081570.8
23	1014.736	1901.868	2756.902917	1742.166917	42449693.76	153868182.1	111418488.3
24	995.3971	1883.575	2766.355417	1770.958317	42041394	156411038.5	114369644.5
25	1046.156	1893.948	2792.760625	1746.604625	42272919.36	154260120.5	111987201.1
26	1004.426	1872.152	2764.321458	1759.895458	41786432.64	155433966.9	113647534.2
27	1096.679	1902.131	2578.4675	1481.7885	42455563.92	130871560.3	88415996.4
28	1098.085	1907.211	2804.772708	1706.687708	42568949.52	150734658.4	108165708.9
29	1148.448	1911.751	2879.8225	1731.3745	42670282.32	152914995.8	110244713.5
30	1149.784	1914.541	2869.700833	1719.916833	42732555.12	151903054.7	109170499.6

Table.2: The optimum cost corresponding to optimum scheduling for the month April 2015

5. RESULTS AND DISCUSSION

5.1: Case I - PSO based hourly economic scheduling and cumulative daily optimal cost evaluation

The implementation of the PSO algorithm and problem formulation is done using MATLAB. Short term and mid-term load of the month April 2015 data is used for getting optimum cost withPSO. The load for the time slot of 00.30hrs to 24.00hrs of is considered. Table 1 shows the cost coefficient values of $\alpha_i, \beta_i, \gamma_i$ of 50 generators and the optimum generated load. In this study, the steps of the algorithm explained above are implemented by using the load of 1st April 2015 in one hour and the results are shown in the table 1. The cost per unit of internal generation is 93 paise per kWhr and cost per unit of imported power is rupees 3.68 per kWhr respectively. From the results obtained, it can be found that hydro generation can be increased by 57.68% and import of power can be reduced by 63.72%. Thus, there is a daily saving of Rupees 1356475.92 per hour.

5.2:Case II - PSO based hourly economic scheduling and cumulative monthly optimal cost evaluation

The generation cost evaluation of 30 days can be done by changing the time slot from 00.00 to 24.00 hours in steps of 30 minutes time slots. The actual internal power, optimized power, demand in MW, imported power in MW (purchased power), cost of optimized power, cost of imported power and cost savings are shown in table 2. Fig 3 shows the optimum cost corresponding to optimum scheduling of April 2015. Fig 4 shows the optimum power corresponding to actual power which is inferred from the table 2.

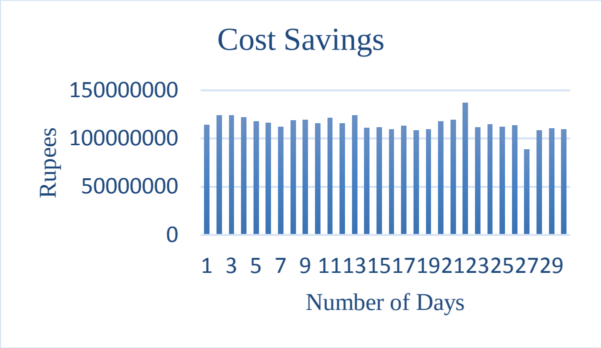

Fig.3: Graphical representation of table 2.

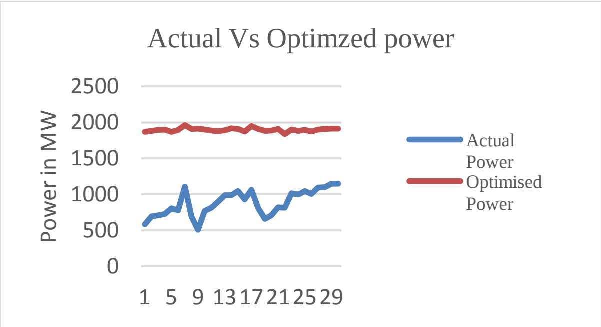

Fig. 4: Graphical representation of actual and optimized power.

6. CONCLUSION

In this paper, the cost optimization of Kerala power system based on economic load dispatch has been done. The PSO is used as a tool for solving the economic load dispatch problem. PSO-TVIW based optimum scheduling with STLF (for one day and one month) data has been carried out. The algorithm used in this program and the results in each are described in detail. Half-hourly economic scheduling and cumulative daily and monthly optimal cost evaluation and steps involved in monthly cost calculation are also described. It is clear from the result that the actual expenditure occurred in KSEB Ltd is higher than that obtained by using PSO. That means, the total production cost of KSEB Ltd can be minimized by applying PSO-TVIW.

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