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Solution of Electrical Load Dispatch Problem by Modified Exchange Algorithm

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Abstract: In this paper a Modified Exchange Algorithm has been presented and this technique is applied to one of the main optimization problems in the Electrical Power System i.e., Electrical Load Dispatch. The proposed technique is a robust one and helps to extract the global optimum efficiently. As the name suggests, the technique is based on the working of a stock in which different shareholders achieve the maximum profit by following the elite shareholders' patterns. The search strategy is then enhanced using the Mutation and Sequential Quadratic Programming to further refine the final fitness values. The proposed technique is then implemented on 6 Unit test system with convex function in order to present the effectiveness of this technique. Finally, the results obtained from the proposed algorithm are compared with some of the already present technique on this problem. The results clearly show that the proposed technique can be a useful tool to solve Electrical Load Dispatch problem.

Keywords: Electrical Load Dispatch, Modified Exchange Algorithm, Mutation, Sequential Quadratic Programming, Valve Point Loading Effects

1. INTODUCTION

Electrical Load Dispatch (ELD) is among the most important optimization problems to be dealt with in the area of Power System Operation and Planning. Electrical Load Dispatch deals with the objective of finding the minimum price associated with the electrical power outputs form the different Generators of the power system. In this problem the generators' outputs are scheduled in such a way that the total price of the generation is minimum while meeting the total demand of the system and considering different equality and non-equality constraints. Electrical Load Dispatch is a highly non-linear, complex and multi constrained problem. In ELD the output of each generator is generally represented by a single quadratic function and it is then optimized using different optimization techniques. Many conventional optimization techniques have been used to solve the Electrical Load Dispatch. These conventional methods like Lambda Iteration method, Gradient Search Method, Newton Method, Linear Programing (LP)(El-Keib and Ding, 1994)and Dynamic Programming (DP)(Liang and Glover, 1992)take some assumptions to simplify such complex problem. For example, these mathematical methods require that the price functions of the generators be piece-wise linear functions which increase monotonically. But, the output-input characteristics of the power generators are very highly nonlinear due to the constraints like Prohibited Operating Zones and Valve Point Loading effect etc. (Wood and Wollenberg, 1996). Also, these mathematical techniques have a disadvantage that they often struck in a local optimal point and can't help to locate the global optimum point. Among these mathematical techniques only Dynamic Programming(Liang and Glover, 1992)can be used to solve the non-convex problem with such constraints but unfortunately Dynamic Programming suffers from the curse of dimensionality. Some artificial neural network based techniques have also been developed and used in ELD problem like Adaptive Hopfield Neural Networks (AHNN) (Lee, *et al.*,1998). Such techniques have been used in the past to solve non-liner, non-convex and non-differentiable optimization problems just like Electrical Load Dispatch. But due to high mathematics involved and a large number of iterations are required to optimize this problem, some robust, fast and more reliable methods are needed. In the recent years, with the improvement in the computing technologies, a lot of new population based stochastic and heuristic techniques have been developed for solving Electrical Load Dispatch (ELD) problems. These include stochastic and heuristic techniques like Genetic Algorithm (GA) (Holland, 1992), (ALI, 2016), Simulated Annealing (SA)(Wong and Wong, 1994), Evolutionary Programming (EP) (Yao, *et al.,* 1999), Particle Swarm Optimization (PSO) (Gaing, 2003), Modified PSO (MPSO) (Mekhamer *et al.*,2005), Hybrid PSO (HPSO) (Park *et al.*, 2007), Differential Evolution (DE) (Noman and Iba, 2008), Bacterial Foraging Algorithm (BFA) (Farhat and El-Hawary, 2009), Ant Colony Optimization (ACO) (Pothiya, *et al.*,2010), Ant Lion Optimization (ALO) (Nischal and Mehta, 2015)

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and Gravitational Search Algorithm (GSA) (Swain, *et al.,* 2012). All these techniques have been successfully applied to the ELD problem recently. Although these techniques perform a better global search but their performance is not that good while searching the local optimal points.

Exchange Algorithm (EMA) is a recently proposed meta-heuristic technique (Ghorbani and Babaei, 2014). The lower ranked members on the list try to follow the higher ranked members by taking certain risks just like real. In this algorithm the shareholders are intelligent agents and they have act in the same way like the real life persons. The main advantage of this algorithm is that this technique uses two search operators for the exploration and two absorbent operators used for the exploitation as compared to the one search and one absorbent operators in other algorithms. This helps in creating and updating the population in the best possible way. Exchange Algorithm (EMA) has some advantages over other algorithms such as overcoming the problem of premature convergence which causes local optimum trapping (exploration), the inability of the algorithm to find the nearby optimal points (exploitation) and the inability to handle the constraints of the system in a better way (constraint handling problem).

In this paper a Modified Exchanged Algorithm (MEMA) is proposed which helps to improve the problems faced in the Exchange Algorithm. The proposed technique uses the Sequential Quadratic Programing and Mutation techniques combined with the already present Exchange Algorithm. This combination helps in improving the exploration procedure due to the diversity of population generated by Mutation (Basu, *et al.*,2016), (Ahmed, *et al.*,. 2018) and refining the final results using SQP (Elaiw, Xia and Shehata, 2012) .The Modified Exchange Algorithm (MEMA) is then applied to different bench systems i.e. 3 and 6 Units, present in the literature and the results are compared with the other strong techniques available in the literature. The results and comparisons obtained clearly shows that the proposed Modified Exchange Algorithm (MEMA) is a useful tool for solving the ELD problem.

The paper is organized in the following pattern. The section, 'ED Problem Formulation', deals with the mathematical problem formulation of ELD including the constraints. 'Exchange Algorithm (EMA)' involves the EMA technique. 'Modified Exchange Algorithm (MEMA)' deals with the modification in the EMA. Under, 'Implementation ofMEMA on Electrical Load Dispatch Problem', the implantation of MEMA is performed on ELD, then 'Results' shows the comparison of this technique's results with the other techniques. At end of the paper, the conclusions are drawn.

2. ED PROBLEM FORMULATION

Electrical load dispatch is a price minimization problem which involves different constraints. The problem is mathematically formulated as under:

2.1 Objective Function

$$\text{Min: } F_T = \sum_{i=1}^{N} F_I(P_i) \quad (1)$$

where$N$is the total number of generators in the system,F_t is the total price of generation, P_i is the power output of the *i-th* generator and $F_I(P_i)$ is the fuel price of the *i-th*generator.

Generating units have multiple valves operating at a time which changes the output/ input characteristics of a thermal unit. This behavior is called the valve point loading effect and is incorporated in the objective function as:

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 + |e_i + \sin(f_i \times (P_{imin} - P_i))(2)$$

Here $a_i, b_i, c_i, e_i$and f_i are coefficients of the *i-th* generator.

2.2. Constraints

(1) The equality constraint of the system is given as:

$$P_L + P_{loss} = \sum_{i=1}^{N} P_i \quad (3)$$

Where $P_L$and P_{loss} are the load demand and power loss in the transmission system respectively. The transmission losses of a power system are given in terms of a loss factor B as follows:

$$P_{loss} = \sum_i^N \sum_j^N P_i B_{ij} P_j + \sum_i^N B_{0i} P_i + B_{00} \quad (4)$$

(2) Every generators runs between a range of output power. The upper and lower limits which must be met by the algorithm are given below:

$$P_{i,min} \leq P_i \leq P_{i,max}(5)$$

where $P_{i,min}$ and $P_{i,max}$ are the upper and lower generating limits of the *i-th* generator.

(3) Apart from the upper and lower limits on a generator, there are specific prohibited operating zones in generator's output due to some deficiencies present in the generators. The feasible operating zones are given by the following equations:

$$\begin{aligned} P_{i,min} \leq P_i \leq P_{i,1}^l \\ P_{i,j-1}^U \leq P_i \leq P_{i,j}^l \\ P_{i,ni}^U \leq P_i \leq P_{i,\max} \end{aligned} \quad (6)$$

where the lower and upper bounds of the jth prohibited zone are $P_{i,1}^{l}$ *and* $P_{i,ni}^{U}$ respectively.

3. EXCHANGE ALGORITHM (EMA)

Exchange Algorithm (EMA) is a latest meta-heuristic technique (Ghorbani and Babaei, 2014). In this technique we have two abso buy number of shares to get the maximum profit. Here, answer is the outcome of every member. The number of shares in ELD corresponds to the number of generating units. Every buys shares which corresponds to the output of every generating unit. These members perform in such an intelligent way to get the maximum possible profit which corresponds to the minimum fuel price in the ELD problem. The constraints should be met while doing all this.

Exchange Algorithm (EMA) uses two modes to work. As in real , there are different conditions depending upon the conditions of political situation in the country and many other factors. One mode is the normal or non-oscillation mode and the other being abnormal or oscillation mode. In the normal mode of EMA, shareholders with lower ranks try to copy the pattern of the members with higher fitness in order to get the maximum profit and improve their ranks among the shareholders, no risks are involved in the normal mode. In the other mode i.e., oscillation mode, the members with lower fitness try to get the better position among the different members by taking some risks intelligently. So we can say that in normal mode we search around the optimum point while in oscillation mode we try to find out the unknown points by widening our range of search. In both conditions, the shareholders have been divided in three different groups.

3.1 Non-oscillation Mode

3.1.1 First Group: Elite Members

This group contains the members with the highest fitness in ranking list. They don't change their fitness during this mode and they try t

3.1.2 Second Group: Members with Medium Fitness

The members of this try to improve their fitness by taking least possible risk and follow the pattern of the best members of the population. This group comprises of 20-50% of the total population. This group updates its fitness according to the following formula.

$$pop_j^{g(2)} = r \text{ x } pop_{1,i}^{g(1)} + (1-r) \text{ x } pop_{2,i}^{g(1)} \quad (7)$$

Where i and j corresponds to the first and 2nd group respectively. $pop_{1,i}^{g(1)}$ and $pop_{2,i}^{g(1)}$ are the members of first group while $pop_j^{g(2)}$ are the members of 2nd group.

3.1.3 Third Group: Members with lowest Fitness

This group consists of the remaining members of the population with the lowest fitness among the population. This group's members update their fitness using the following two equations:

$$pop_k^{g(3),new} = pop_k^{g(3)} + 0.8 \text{ x } S_k \quad (8)$$

$$S_k = 2 \text{ x } r_1 \text{ x } \left(pop_{i,1}^{g(1)} - pop_k^{g(3)}\right) + 2 \text{ x } r_2 \text{ x } \left(pop_{i,2}^{g(1)} - pop_k^{g(3)}\right) \quad (9)$$

Here r_1, r_2 are random numbers and $k = 1,2,3,\dots,n_k$, where n_k is the *k-th* member of the 3rd group and S_k is the shared variation of the members of this group.

3.2 Oscillation Mode

After the members are reevaluated and ranked at the end of normal mode, the members with low fitness take some intelligent risks in oscillation mode to get a maximum possible profit and by doing so get themselves a high rank in the fitness list. So we can say that the members of the population in this mode try search unknown points in wider range. Similar to the normal mode, the population is divided into three groups.

3.2.1 First Group: Elite Members

Just like non oscillation mode, the members of the first group in this mode are the elite members of the population with respect to fitness and they try to maintain their ranks while not taking any risk. This first group consists of 10-30% of the total population.

3.2.2 Second Group: Members with Medium Fitness

In this mode, the total sum of shares remains constant while only the some of the share increase or decrease keeping the total number shares constant. Firstly, following equation is used to increase the number of shares of each member of this group:

$$\Delta n_{t1} = n_{t1} - \delta + (2 \text{ x } r \text{ x } \mu \text{x } \eta_1) \quad (10)$$

$$\mu = \left(\frac{t_{pop}}{n_{pop}}\right)$$

$$n_{t1} = \sum_{y=1}^{N} |S_{ty}| \qquad y = 1,2,3,\dots,n \quad \eta_1 = n_{t1} \text{x } g_1$$

$$g_1^k = g_{1,max} - \left(\frac{g_{1,max} - g_{1,min}}{iter_{max}}\right) \text{ x } k$$

here, Δn_{t1} is the total shares to be added to the group randomly. n_{t1} is total share of the *tth* member of group before updating. The share of each member is S_{ty} and δ is the information (here $\delta = n_{t1}$ because penalty factor has been used in our problem), r is number form the range [0-1], η_1 is the level of risk related to every member of this group, μ is a constant value assigned to each member, t_{pop} is the number of the *t-th* member while n_{pop} is the total number of members in the problem, g_1 is the risk amount of common which is inversely proportion to the number of iterations and it decreases as iterations increase In the next part of this step, random members should sell some random shares equal to the number of shares which were bought in the first step in order to keep the total number of shares constant. The formula used by every member to shares certain amount of shares is given by:

$$\Delta n_{t2} = n_{t2} - \delta (11)$$

where Δn_{t2} is the share amount to be reduced by the member while n_{t2} is the total share amount of the *t-th* member.

3.3.3 Third Group: Members with lowest Fitness

In this step, unlike the members of 2nd Group, every member of this group undergoes some change in its shares. We can say that every member either buys or sell shares and its amount changes after every trade. The members buy or sell shares following the below mentioned formula:

$$\Delta n_{t3} = 4 \text{ x} r_s \text{x } \mu \text{ x } \eta_2 (12)$$

$$\eta_2 = n_{t1} \text{x } g_2$$

$$g_2^k = g_{2,max} - \left(\frac{g_{2,max} - g_{2,min}}{iter_{max}} \right) \text{ x } k$$

Here, $\Delta n_{t3}$is the amount of share applied to the each member of the 3rd Group. $g_2$is the risk while $\eta_2$is the risk related to each member.

This continues until the stopping criteria reaches and the best results are printed.

4. MODIFIED EXCHANGE ALGORITHM (MEMA)

Mutation and Sequential Quadratic Programming techniques have been used to enhance the global and local search of the algorithm. Mutation helps to move across the search area in a wider range by generating random populations which helps in exploration. On the other hand, Sequential Programming helps to improve the exploitation.

4.1 Mutation

Mutation helps in achieving wider range of search area by creating different sets of population (Basu, and Panigrahi, 2016). It brings diversity to the population and so the exploration rate increases.

4.2 Sequential Quadratic Programming

One of the most efficient and effective techniques for solving nonlinear and constrained optimization problems is ***Sequential quadratic programming*** (SQP) (Elaiw, 2012). In this work Sequential Quadratic Programing has been applied on the final best results that were obtained from Exchange Algorithm combined with mutation.

5. IMPLEMENTATION OF MEMA ON ED PROBLEM

In this work the Modified Exchange Algorithm has been used to solve the Static Electrical Load Dispatch Problem. The procedure to implement the problem has been step wise discussed below.

Step 1: Random population is generated, and initial values are assigned.

Step 2: The price of shareholders is calculated using *Eq (1)* and are ranked on the basis of their fitness values.

Step 3 (Non- Oscillation Mode): Updating the values of members of 2nd Group occurs hereupdated using *Eq. (7).*

Step 4*:* Updating the values of members of 3rd Group occurs here. These members are the lowest ranked members on the fitness list and they update their values using *Eq. (8,9).*

Step 5: After the new population has been formed, the fitness of each member is again calculated using *Eq (1)* and the whole population ranked against based on the new fitness values.

Step 6 (Oscillation Mode): First off all the members of the 1st group are kept unchanged as done in the Non-Oscillation mode. The members of the 2nd Group are updated using *Eq. (10,11)*.

Step 7: This is the second step of the Oscillation mode. In this step the members of 3rd Group are updated using *Eq. (12).* The trading of shares in this step are carried out without keeping in mind the total share values.

The fitness of the members is again calculated at the end of Oscillation mode and the best value of fitness and corresponding population is saved.

Step 8: Mutation is carried out for using the best population obtained from the above steps. The program returns to the Step 3 and keeps on running unless the stopping criteria is met i.e., number of iterations.

Step 9: After the stopping criteria is met i.e., the number of iterations limit exceed, the overall best values of fitness and best population is then used to perform Sequential Quadratic Programming. And the final result is printed.

A flow chart of the proposed technique has been shown in **(Fig.1).**

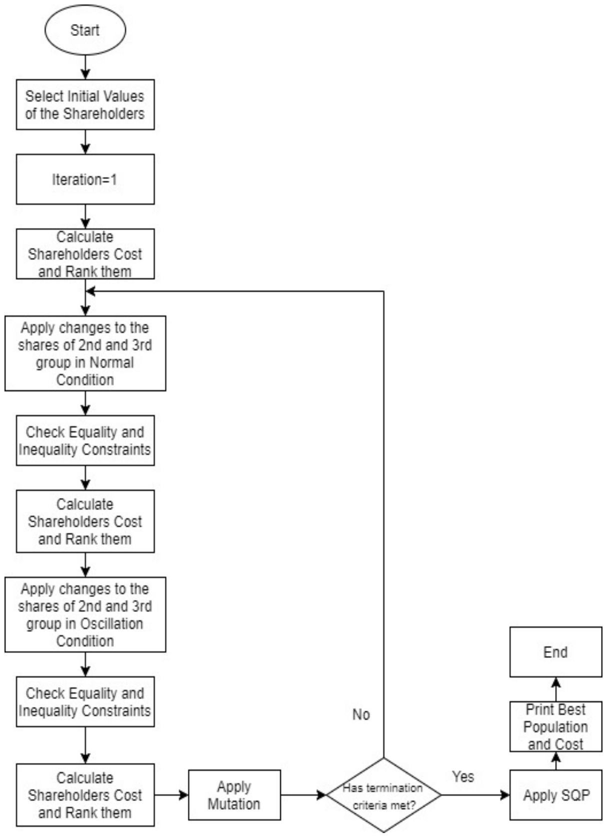

Fig. 1. Flow Chart of MEMA

6. NUMERICAL RESULTS

Modified Exchange Algorithm (MEMA) has been investigated on a Standard System that consisted 6Units on MATLAB platform. Different constraints have been considered in this work which include Real Power Balance Constraint, Generator's Capacity Limits, Transmission Losses, Prohibited Operating Zones and Valve Point Loading Effect (VPLE). All these Simulations have been run using MATLAB R2015a version.

The test case is consisted of a Convex system of 6 Units and have a Load demand of 1263MW. Prohibited Operating Zones (POZs) and Transmission Losses have been considered in this case.

As presented in the Table 1, the best price obtained from the proposed technique for this test system is 15,444.186 $/hr. Also in this table, the MW generation of each Unit has been shown separately along with their individual prices. The total generation in this case was 1275.422MW. Total generation and the transmission losses were 1275.422MW and 12.43MW respectively. The average price of for 50 trials was 15.444.186 $/hrthe results were then compared with different techniques present in the literature.

Table 1. Results for the 6 Units Test System (1263MW)

Unit No.	$P_{i,min}$ (MW)	$P_{i,max}$ (MW)	Generation (MW)	Fuel Price ($/hr)
1	100	500	446.716	4763.892
2	50	200	173.149	2216.309
3	80	300	262.795	3075.312
4	50	150	143.489	1963.683
5	50	200	163.917	2156.076
6	50	120	85.356	1268.914
Total			**1275.422**	**15,444.186**
Transmission Losses 12.422 MW				

Table 2. Comparison of the Results of MEMA with other techniques

Technique	Best Price ($/hr)	Worst Price ($/hr)	Average Price ($/hr)
MTS	15450.06	15453.64	15451.17
DE	15449.766	15449.874	15449.777
PSO	15450.84	15,492	-
GAAPI	15607.47	15449.85	15449.81
KHA-3	15445.356	15449.607	15447.21
MABC	15449.8995	15449.8995	15449.8995
CBA	15450	15518.6588	15454.76
EMA	15,452.27	15,485.21	15,4555.1
MEMA	**15444.186**	**15444.186**	**15444.186**

In **(Table. 2),** the results obtained from the proposed technique have been compared with some other techniques available in the literature. shows the comparison of fuel prices obtained from MEMA and others techniques like MTS (Pothiya, and Kongprawechnon, 2008), DE *(Basu, et al.,* 2016), PSO (Basu, 2015), (Ali, 2017), GAAPI (Ciornei and Kyriakides, 2012), KHA-3 (Mandal, and Mandal, 2014), MABC (Secui, 2015), and CBA (Adarsh *et al.*, 2016). It is evident from that the lowest price, which is 15,444.186 $/hr, among these different techniques has been obtained by the proposed technique. The difference between prices calculated from MEMA and those calculated from MTS (Pothiya, Ngamroo and Kongprawechnon, 2008), DE (Basu, *et al.,* 2016), PSO (Basu, 2015) , GAAPI (Ciornei and Kyriakides, 2012), (Ali, Athar, 2018), KHA-3 (Mandal, *et al.,* 2014), MABC (Secui, 2015), and CBA (Adarsh *et al.*, 2016).are 5.875 $/hr, 5.580 $/hr, 6.654 $/hr, 163.284 $/hr, 1.170 $/hr, 5.713 $/hr and 5.814 $/hr respectively. A bar graph has been used to visualize this comparison in Fig.2.

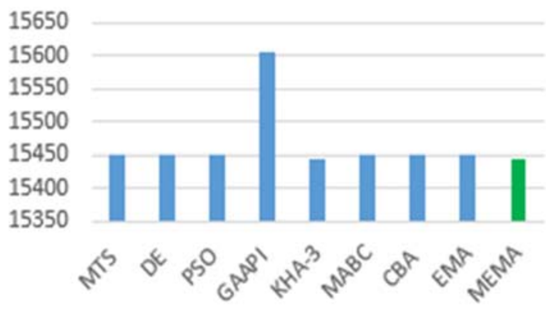

Fig. 2. Comparison Bar Chart for 6 Unit System

The minimum fuel prices calculated for 6 Unit System was 15,444.186 $/hr. These results were than compared with some other techniques available in the literature and the effectiveness of this technique was verified by the better results among all those techniques.

A convergence curve for the test system for 300 iterations has been shown in the **(Fig. 3).**

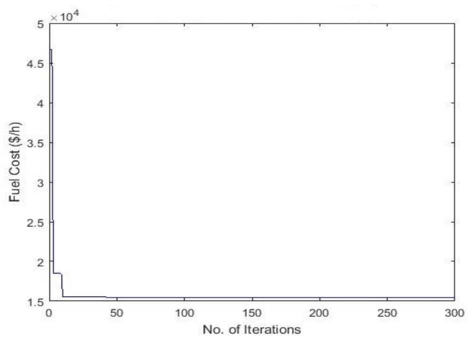

Fig. 3. Convergence Curve

7. CONCLUSION

A Modified Exchange Algorithm (MEMA) has been proposed in this research work. Mutation operator and Sequential Quadratic Programming (SQP) have been used to modify the already present Exchange Algorithm (EMA). Mutation operator was used to enhance the global search of the algorithm while SQP in nature has the ability to enhance the ability to find the better results in the area around local minima. The proposed technique was used for the solution of Electrical Dispatch which involved various constraints like Real Power Balance, Transmission Losses, Upper and Lower limits of generators, Transmission Losses and Valve Point Loading Effect on a 6 bench system. The minimum fuel prices calculated for 6 Unit Test System was 15,444.186 $/hr, these results were than compared with some other techniques available in the literature and the effectiveness of this technique was verified by the better results among all those techniques.

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