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Solving Electrical Dispatch Problem Using Sine Cosine Algorithm (SCA) with Sequential Quadratic Programming

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Abstract: The Power system faces a number of complex problems like Electrical Dispatch. The aim of Electrical dispatch problem is the efficient utilization of resources to provide the demanded power while generating cost turns out to be minimum and no constraint is violated either equality or inequality. The Electrical dispatch (ED) optimization problem, is necessary because of limited resources, high fuel cost and ever growing demand of power. In this research a new technique named Sine Cosine Algorithm (SCA) modified with Sequential Quadratic Programming (SQP) is introduced to tackle the Electrical Dispatch (ED) problem. The basic methodology of this technique is to apply SCA to Electrical Dispatch problem and then further improvement of results is evaluated using Sequential Quadratic Programming (SQP) which is a mathematical technique. The suggested algorithm has been implemented in MATLAB to solve ED problem and validated using the 40 unit IEEE test system with transmission losses. Finally the results of suggested algorithm has been compared with the other optimization algorithms reported in literature to show the applicability and feasibility of the suggested algorithm. The simulation results evidently prove that the proposed algorithm outperforms other techniques in terms of cost and convergence characteristics.

Keyword: Electrical Dispatch (ED); Sine Cosine Algorithm (SCA), Sequential Quadratic Programming (SQP)

1. INTRODUCTION

The Power system faces a number of complex problems like Electrical Dispatch. The main aim of Electrical Dispatch is basically to assign the active power values to the available thermal generating stations in a way that the total cost of generation turns out to be minimum while obeying the constraints. The constraints of Electrical Dispatch are of two kinds which are classified equality and inequality. As the Electrical dispatch is about finding the minimum cost while satisfying the load demand, so the development of heuristic and mathematical techniques which can easily account the characteristic cost function are required. However, the cost function of generators which is simply an approximation of quadratic function is not necessarily suitable to fully model the system constraints like valve point loading effect and prohibited operating zones (POZ) (Sen and Mathur 2016). This valve point loading effect is due to multiple valve operations in thermal plants to change the fuel type according to the generation and this valve operation makes the characteristic curve of the generating unit nonlinear and discontinuous. The valve point loading effect is modeled (Walters and Sheble 1993) as in the characteristic curve as cyclical sinusoidal function as shown in the **(Fig. 1).** Except the valve point loading effect, the constraint of Prohibited Operating Zones (POZ) are also considered in Electrical Dispatch (ED). The prohibited zones are basically the zones of generation in the limits of upper and lower bounds of generation, but they refer to a value at which the frequencies of components of generating units may match to each other. And this matching of frequencies may cause resonance which can be destructive for system. Moreover the POZs cause the cost function to be discontinuous and local minimum may occur (Alsumait and Sykulski 2009).

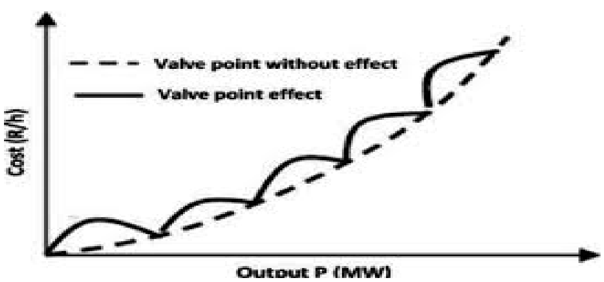

Fig. 1. Valve point loading effect causing the function to be non-smooth

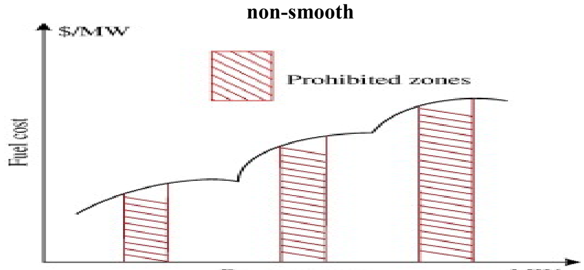

Fig. 2. Fuel Cost Curve representing the Prohibited Operating Zones

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And the involvement of these constraints make the system Electrical Dispatch more complex. The POZs are shown in the **(Fig. 2).**

Recently a lot of different techniques to solve the Electrical Dispatch have been developed (Wood and Wollenberg 2012), (Ali, *et al.* 2016) like λ iteration method, Newton Method and Gradient Method. But these methods are fast and reliable but they sometimes do not perform evenly in complex problems. Moreover, when we apply the classical techniques to the complex systems, we assume that the cost function unit is smooth. While as we described above, the constraints involved in the ED problem do not allow the output function to be smooth and continuous. And the initial guess in these techniques plays an important role. Therefore, if there is an incorrect initial solution these techniques may fail. Hence, these drawbacks related to the classical techniques compel the researchers to develop the Artificial Intelligence Techniques and implement them to tackle the ED. The Artificial Intelligence (AI) techniques may not necessarily be able to touch the global minimum solution but they can produce the near optimal solution in comparatively less time. Latest AI techniques applied to tackle the corresponding ED problem are Stud Krill Herd (SKH) (Bentouati, *et al.* 2017), Chaotic Particle Swarm Optimization (CPSO) (Rajapandiyan and Alex 2017), Cuckoo Search Algorithm (CSA) (Karthik, *et al.* 2017), Improved Orthogonal Design Particle Swarm Optimization (IODPSO) (Qin, *et al.* 2017), Mean Variance based Mapping Optimization technique (MVMO) (Khoa, *et al.* 2017), Lightening Flash Algorithm (LFA) (Ali, *et al.* 2017), (Kheshti, *et al.* 2017), Glowworm Swarm Optimization (GSO) (Shahinzadeh, *et al.* 2017), Improved Fireworks Algorithm with Chaotic Sequence Operator (IFWA-CSO) (Pandey, *et al.* 2017), Ant Lion Optimizer (ALO) (Kamboj, *et al.* 2017), and Chaotic Krill Herd Algorithm (CKH) (Bentouati, *et al.* 2017), (Ali, *et al.* 2018), (Ahmed, *et al.* 2018).

As described earlier, the AI methods may not find the global optimum. So combining the two or more techniques may be a good option for solving the power system complex problem and achieving the global minimum solution. In this work, the new metaheuristic technique Sine Cosine Algorithm (SCA) hybridized with the mathematical technique Sequential Quadratic Programming (SQP) has been make known to solve the Electrical Dispatch (ED) problem.

2. PROBLEM FORMULATION

2.1Description of ED problem

The Power system faces a number of complex problems like Electrical Dispatch. The main aim of ED is to minimize the fuel cost while the involvement of different constraints of generating units are considered. The objective of ED is to minimize the cost which is mathematically denoted as,

$$C.F = \sum_{i=1}^{n} F_i\,(P_i) \qquad (1)$$

Where the C.F refers to the total fuel cost and $F_i(P_i)$ is the fuel cost of ith unit 'n' denotes the number of generating units.

The expression to calculate the fuel cost of ith unit is as follows,

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad (2)$$

And, in thermal power units, there is a presence of several valves to adjust the power output. Therefore, if steam valve is operated, there comes an abrupt change in losses and the characteristic cost function becomes non smooth which is basically the non-convexity of the system. If we consider this valve point effect as a factor of objective function, so the cos function becomes,

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| d_i \times \sin\left(e_i\left(P_i^{min} + P_i\right)\right)\right| \qquad (3)$$

Where 'i' denotes the current unit and 'e' and 'f' show the valve point effect coefficients.

2.2. Constraints:

The aim of ED is to minimize the fuel cost while the involvement of different constraints of generating units are considered.

2.2.1. Power Demand Constraint

$$\sum_{i=1}^{n} P_i = P_D + P_{Loss} \qquad (4)$$

Where P_D denotes load demand and the P_{Loss} is represented by B coefficient equation as follows

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i\, B_{ij}\, P_j + \sum_{i=1}^{n} B_{i0}\, P_i + B_{00} \quad (5)$$

Where, B_{ij},B_{i0}, and B_{00} are the B-coefficients.

2.2.2. Generation Limit

The generated power of each generator must be within the limits upper and lower bound.
This can be mathematically expressed as,

$$P_i^{min} \le P_i \le P_i^{max} \quad , i \in N \quad (6)$$

2.2.3. Prohibited Operating Zones (POZs)

Except the lower and upper bound of generators there are specific regions in the limits which are also sidestepped to make the operation of generating units safe.
Mathematically,

$$P_i \in \begin{cases} P_i^{min} \le P_i \le P_{i,1}^{l} \\ P_{i,1}^{u} \le P_i \le P_{i,2}^{l} \\ \dots\dots.. \\ P_{i,n}^{u} \le P_i \le P_i^{max} \end{cases} \quad (7)$$

Where the$P_{i,n}^{u}$ and $P_{i,n}^{l}$ denote the upper and lower limits of nth prohibited zone. The POZs cause the function to be discontinuous.

3. PROPOSED SINE COSINE ALGORITHM

The algorithms which start to optimize the objective function using a set of population are called population based algorithms. This set of population is generated randomly. Then this population is updated again and again and correspondingly the cost function is evaluated. The population is updated according to the set of equations which are basically the core of any optimization technique.

The population based techniques are better as compared to individual based methods as they have better chance to avoid the local optima entrapment.
Similarly, the Sine Cosine Algorithm (SCA) is a population based algorithm.

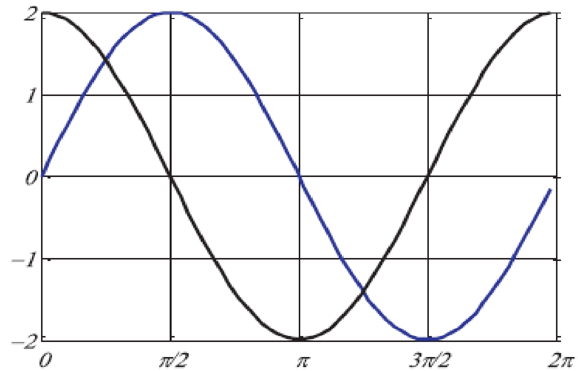

Fig. 3: Sine, Cosine in range of [-2,2].

The characteristic of sine and cosine function of being periodic in cycle forces the solution to reposition itself around another solution. This pattern of search guarantees the exploitation search space between two solutions in SCA. And for exploitation of search area the range of sine and cosine trigonometric functions can be increased as shown in the Fig. 3.In more detail, the influence of sine and cosine trigonometric functions in the specified range as in figure3. i.e [-2,2] is explained in **(Fig. 4).**

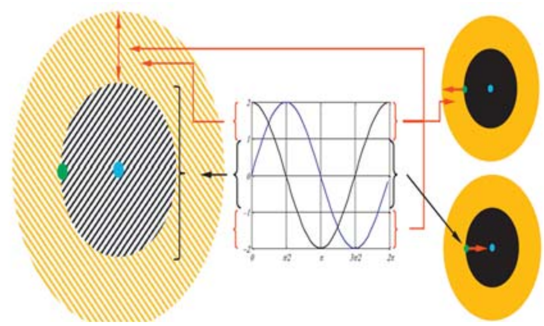

Fig. 4: Sine, cosine in the range in [−2,2] representing how a solution goes inside or outside the space confined.

This figure clearly describes the effect of changing the operating range of sine and cosine that how this change necessitates a solution to decide its next location inside or outside the search area in between its current position and next solution.

4. APPLICATION OF SINE COSINE ALGORITHMWITH SQP ON ED

In this research the Sine Cosine Algorithm (SCA) with Sequential Quadratic Programming (SQP) on Electrical Dispatch (ED) problem.

Step 1

The random population is generated according to the lower and upper limits of generating units.
Mathematically,

$$P = P^{min} + rand.(P^{max} - P^{min}) \qquad (8)$$

Step 2

The fitness of population is evaluated according to the nonconvex objective function.

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left|d_i \times \sin\left(e_i(P_i^{min} + P_i)\right)\right| \qquad (9)$$

Step 3

The population is updated according to the Sine Cosine Algorithm (SCA). The updating equations of SCA are as follows,

$$P_i^{t+1} = P + r_1 \times sin(r_2) \times \left|r_3 p_{best_i}^{t} - P_i^t\right| \;, r_4 < 0.5 \qquad (10)$$

$$P_i^{t+1} = P + r_1 \times cos(r_2) \times \left|r_3 p_{best_i}^{t} - P_i^t\right| \;, r_4 \geq 0.5 \qquad (11)$$

The equations 10 and 11 show that the there are four random parameters. The parameter r_4 is a switch betweeen the two updating the equation and r_1 is a linearly decreasing parameter.

Where "t" is the current iteration and "T" represent the total number of iterations.

Step 4

The equality and inequality constraints are satisfied according to the given statement.

If there is a violation of upper or lower limit then the generated power is clamped on to the lower or upper limit according to the violation of constraint. After the inequality constraint satisfied, the equality constraint are checked.

Step 5

As the constraints are satisfied, the Sequential Quadratic Programming (SQP) is applied to the results obtained so far from SCA.

Sequential Quadratic Programming

Sequential Quadratic programming is a mathematical technique and uses the feasible solution of the subset of a bigger problem to reach to the global optimum. Apparently, the SQP executes very closely to Quasi Newton and Newton method. SQP differs from the Quasi Newton and Newton Method in terms of constraint handling.

Mathematically, SQP Technique is represented as follows, (Subathra, *et al.* 2015).

Minimize

$$\nabla F(P_k)^T + \frac{1}{2} d_k^T H_k d_k \qquad (12)$$

Subjected to

$$g_i(P_K) + [\nabla g(P_K)]^T d_K = 0 \;\; i = 1, \ldots\ldots, m_e \qquad (13)$$

$$g_i(P_K) + [\nabla g(P_K)]^T d_K \leq 0 \;\; i = m_e + 1, \ldots\ldots, m \qquad (14)$$

$$L(P, \lambda) = F(P) + g(P)^T \lambda \qquad (15)$$

m_e is the equality constraint's quantity while m represents quantity of constraints. Where λ represents the langragian multiplier and H_k is formulated with the help of Quasi Newton.

$$H_{K+1} = H_K + \frac{q_K q_K^T}{q_K^T S_K} - \frac{H_K^T S_K^T H_K}{S_K^T H_K S_K} \qquad (17)$$

And

$$S_K = P_{K+1} - P_K \qquad (18)$$

$$q_K = \nabla L(P_{K+1}, \lambda_{K+1}) - \nabla L(P_K, \lambda_{K+1}) \qquad (19)$$

In each iteration, the direction of sub-problem is achieved and the solution is found from new iteration as follows

$$P_{K+1} = P_K - \alpha_K d_K \qquad (20)$$

For calculation of step length (α_k) the following formula is used as this step length is significant for the decrease in the langragian merit function.

$$r_1 = a - t\frac{a}{T} \qquad (16)$$

$$L_A(P, \lambda, \rho) = F(P) - \lambda^T g(P) + \frac{\rho}{2} g(P)^T g(P) \qquad (21)$$

Step 6

The stopping criteria checked at the end of the program and if the criteria is not satisfied then the steps from 2 are repeated until the stopping criteria is achieved. Here in this case, the stopping criteria is maximum number of iterations.

5. EXPERIMENTAL METHODS AND RESULTS

The proposed technique has been implemented on 40 unit IEEE standard system with losses and load demand **10500 MW** to validate the proposed research.

Parameters:

The parameters used to obtain the optimum for 40 unit test system with loss are as follows,

Iter.tion	50	**Search Agents**	25

Trials	40	Total Computations	2000

The **(Table I)** shows the individual generations of units satisfying the load demand.

Table I: Power output of individual unit and corresponding cost for Test System

Unit	P^{min} (MW)	P^{max} (MW)	Generation (MW)	Fuel cost ($/hr)
1	36	114	114	978.1563
2	36	114	114	978.1563
3	60	120	97.4282	1191.1
4	80	190	179.7343	2143.6
5	47	97	87.7999	706.5001
6	68	140	68	822.5361
7	110	300	300	3297.4
8	135	300	300	3052.3
9	135	300	300	3072
10	130	300	279.6026	4802.7
11	94	375	243.5991	4083.2
12	94	375	168.8005	2977.5
13	125	500	484.0402	7950.3
14	125	500	484.04	7801.2
15	125	500	484.0425	7816.1
16	125	500	484.0392	7816.1
17	220	500	489.2796	5296.7
18	220	550	489.2795	5288.8
19	242	550	511.2792	5540.9
20	242	550	511.2814	5541
21	254	550	523.2845	5071.4
22	254	550	527.019	5146.9
23	254	550	523.2787	5057.2
24	254	550	523.2794	5057.2
25	254	550	523.2802	5275.1
26	254	550	523.2831	5275.2
27	10	150	10	1140.5
28	10	150	10	1140.5
29	10	150	10	1140.5
30	47	97	47	425.5226
31	60	190	190	1644
32	60	190	190	1619.3
33	60	190	190	1644
34	90	220	220	2228.4
35	90	220	220	2164.5
36	90	220	220	2164.5
37	25	110	110	1220.2
38	25	110	110	1220.2
39	25	110	110	1220.2
40	242	550	511.282	5541
Total			**11481.95**	**136552.5**
Transmission Loss			**981.9530**	

In **(Table 2)** there is the statistical comparison of proposed algorithm with other techniques and clearly shows that "Sine Cosine Algorithm (SCA) with SQP" saves fuel cost as compared to other techniques mentioned in the table.

Table 2: Comparison of 40 units test system

Algorithm	Total Generation Cost ($/hr)		
	Minimum Cost	**Maximum Cost**	**Average Cost**
SDE (Mandal, Roy et al. 2014)	138157.46	-	-
GAAPI(Secui 2015)	139864.96	-	-
KHA-1 [16]	136702.58	136723.84	136715.08
KHA-2 [16]	136692.65	136713.11	136704.67
KHA-3 [16]	136683.65	136698.50	136690.76
KHA-4 [16]	136670.37	136671.86	136671.22
ORC-CRO(Jayabarathi, Raghunathan et al. 2016)	136855.19	-	-
DE/BBO [18]	136950.77	-	136966.77
BBO [18]	137026.82	-	137111.58
HGWO [18]	136681	136684	-
Proposed SCA-SQP	136522.5	139740.1	138117.4

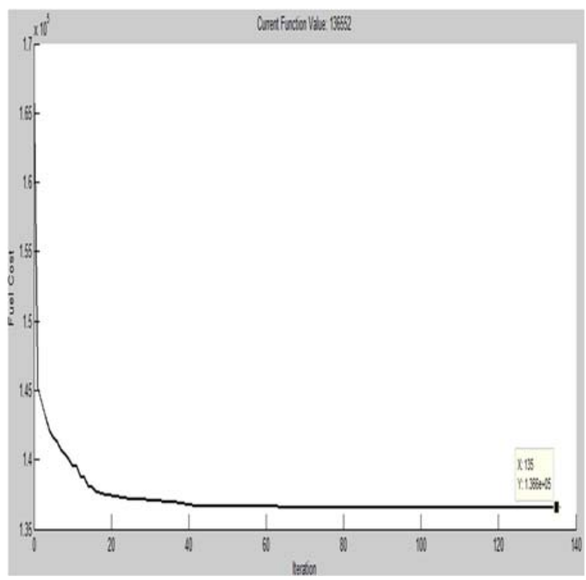

Fig.5 Convergence Curve of 40 Unit System

(Fig.5) shows the convergence curve of 13 unit test system solved using SCA and clearly describes that the system nverges to optimum before stopping criteria.

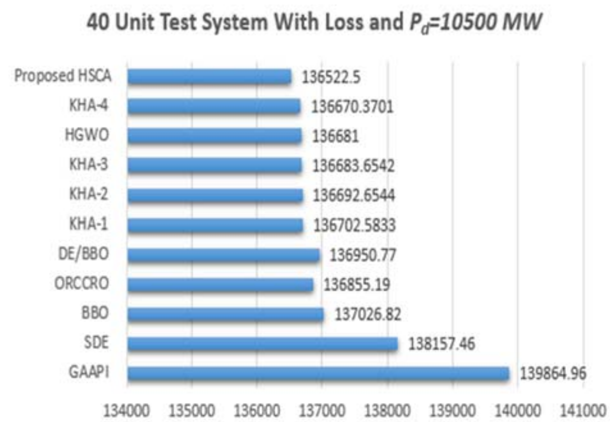

Fig. 6 Comparison for 40 Unit Test System with loss & P_d= 10500 MW.

5.1 DISCUSSION

The proposed technique owns significantly lesser fuel cost as compared to the other techniques reported in literature. The proposed technique saves about 1635 $/hr, 3342 $/hr, and 504 $/hr as compared to SDE, GAAPI and BBO respectively.

6. CONCLUSION

In this paper a novel Sine Cosine Algorithm with SQP has been implemented in MATLAB 2014a to solve Electrical Dispatch (ED) problem. The basic Sine Cosine Algorithm has been hybridized with SQP to enhance its local search capability. The mathematical comparison show that the proposed technique clearly owns very less fuel cost as compared to the other techniques reported in literature. The proposed technique gives 13655.5 $/hr for 40 unit test system which is significantly lower than other techniques. Moreover, as the hybrid technique performed better than other techniques, hence, hybridization of other evolutionary operators like Differential Evolution based mutation ,Crossover, levy flights etc. with basic SCA may be a future research area for this technique.

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