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AMPLIFIED NELDER-MEAD ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER PROBLEM

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Abstract

This paper presents Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) is proposed to solve optimal reactive power problem. The proposed Hybridized - Simulated Annealing, Nelder-Mead algorithm starts with a prime solution, which is produced arbitrarily and then the solution is disturbed into partitions. The vicinity zone is created, arbitrary numbers of partitions are selected and variables modernizing procedure is started in order to create a trail of neighbour solutions. This procedure helps the SN algorithm to explore the region around an existing iterate solution. The Nelder- Mead algorithm is used in the last stage in order to progress the most excellent solution found so far and hasten the convergence in the closing stage. The proposed Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been tested in standard IEEE 57,118 bus systems and simulation results show the superior performance of the proposed SN algorithm in reducing the real power loss and voltage profiles are within the limits.

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1. Introduction

Optimal reactive power dispatch problem is one of the difficult optimization problems in power systems. The sources of the reactive power are the generators, synchronous condensers, capacitors, static compensators and tap changing transformers. The problem that has to be solved in a reactive power optimization is to determine the required reactive generation at various locations so as to optimize the objective function. Here the reactive power dispatch problem involves best utilization of the existing generator bus voltage magnitudes, transformer tap setting and the output of reactive power sources so as to minimize the loss and to maintain voltage stability of the system. It involves a nonlinear optimization problem. Various mathematical techniques have been adopted to solve this optimal reactive power dispatch problem. These include the gradient method [1, 2], Newton method [3] and linear programming [4-7]. The gradient and Newton methods suffer from the

difficulty in handling inequality constraints. To apply linear programming, the input- output function is to be expressed as a set of linear functions which may lead to loss of accuracy. Recently many global optimization techniques have been proposed to solve the reactive power flow problem [8-10]. This paper presents Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) is proposed to solve optimal reactive power problem. Simulated annealing (SA) had a major impact on the field of heuristic search for its simplicity and efficiency in solving combinatorial optimization problems [11-14]. The Nelder-Mead algorithm [15,16] is one of the most popular derivative free nonlinear optimization algorithms. The proposed Hybridized - Simulated Annealing, Nelder-Mead algorithm starts with a prime solution, which is produced arbitrarily and then the solution is disturbed into partitions. The vicinity zone is created, arbitrary numbers of partitions are selected and variables modernizing procedure is started in order to create a trail of neighbour solutions. This procedure helps the SN algorithm to explore the region around an existing iterate solution. The Nelder- Mead algorithm is used in the last stage in order to progress the most excellent solution found so far and hasten the convergence in the closing stage. The proposed Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been tested in standard IEEE 57,118 bus systems and simulation results show the superior performance of the proposed SN algorithm in reducing the real power loss and voltage profiles are within the limits.

2. Objective Function

Active Power Loss
The objective of the reactive power dispatch problem is to minimize the active power loss and can be written in equations as follows:

$$F = P_L = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij} \right) \tag{1}$$

Where F- objective function, P_L – power loss, g_k- conductance of branch, V_i and V_j are voltages at buses i,j, Nbr- total number of transmission lines in power systems.

Voltage Profile Improvement
To minimize the voltage deviation in PQ buses, the objective function (F) can be written as:

$$F = P_L + \omega_v \times VD \tag{2}$$

Where VD - voltage deviation, ω_v- is a weighting factor of voltage deviation.
And the Voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \tag{3}$$

Where Npq- number of load buses

Equality Constraint
The equality constraint of the problem is indicated by the power balance equation as follows:

$$P_G = P_D + P_L \tag{4}$$

Where P_G- total power generation, P_D - total power demand.

Inequality Constraints

The inequality constraint implies the limits on components in the power system in addition to the limits created to make sure system security. Upper and lower bounds on the active power of slack bus (P_g), and reactive power of generators (Q_g) are written as follows:

$$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max} \tag{5}$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}, i \in N_g \tag{6}$$

Upper and lower bounds on the bus voltage magnitudes (V_i) is given by:

$$V_i^{min} \leq V_i \leq V_i^{max}, i \in N \tag{7}$$

Upper and lower bounds on the transformers tap ratios (T_i) is given by:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in N_T \tag{8}$$

Upper and lower bounds on the compensators (Q_c) is given by:

$$Q_C^{min} \leq Q_c \leq Q_C^{max}, i \in N_C \tag{9}$$

Where N is the total number of buses, N_g is the total number of generators, N_T is the total number of Transformers, N_c is the total number of shunt reactive compensators.

3. Simulated Annealing

The SA algorithm is a probabilistic hill-climbing technique that is based on the annealing/cooling process of metals. This annealing process occurs after the heat source is removed from a molten metal and its temperature starts to decrease. At each temperature level the energy of the metal molecules reduces and the metal becomes more rigid. The procedure continues until the metal temperature has reached the surrounding ambient temperature, at which stage the energy has reached its lowest value and the metal is perfectly solid. The SA procedure begins by generating an initial solution at random. At initial stages, a small random change is made in the current solution X_c. The new solution is called X_n. The perturbation depends on a temperate parameter *T*, and a scaling constant k.

$$pert(T) = k \times T \times r_3 \tag{10}$$

Here r_3 is a random value between 0 and 1 with uniform distribution. The temperature *T* decreases with each iteration of the algorithm, thus reducing the size of the perturbations as the search progresses. This mechanism produces large perturbation in the initial stages of the search and ensures that the resulting parameters are fine-tuned towards the end of the optimization. A move is made to the new solution X_n if it has better energy *F* or if the probability function has a higher value than a randomly generated number. Otherwise a new solution is generated, evaluated and compared again. The probability *p* of accepting a new solution X_n which called "Metropolis law" is given as follows:

$$P = \begin{cases} 1 & if\ F(X_n) < F(X_c) \\ exp\left(\frac{F(X_c)-F(X_n)}{T}\right) otherwise \end{cases} \tag{11}$$

In order to avoid getting trapped at local extreme points, the reduction rate of T should be slow enough. In this study the following method to reduce the temperature has been used. Here T_0 is the initial temperature, β is the reduction constant, and n is the number of iterations.

4. Nelder-Mead Algorithm

Nelder-Mead algorithm is one of the most popular derivative free nonlinear optimization algorithms. The Nelder-Mead algorithm starts with $n + 1$ point (vertices) as x1, x2, ..., xn+1. The algorithm evaluates order and re-labels the vertices. At each iteration, new points are computed, along with their function values, to form a new simplex. Four scalar parameters must be specified to define a complete Nelder-Mead algorithm; coefficients of reflection ρ, expansion χ, contraction γ, and shrinkage σ. These parameters are chosen to satisfy ρ > 0, χ > 1, 0 < γ < 1 and 0 < σ < 1.

Hybridization of Simulated Annealing with Nelder-Mead Algorithm
The projected Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) starts with a primary solution generated arbitrarily, which consists of n variables. The solution is divided into η partitions; each partition contains υ variables. At a fixed temperature, arbitrary partitions are selected, and trail solutions are produced by updating arbitrary numbers of variables in the selected partition. The neighbour solution with the best objective function value is always acknowledged. Else, the neighbour is selected with a given probability that depends on the current temperature and the amount of deprivation ΔE of the objective value. ΔE represents the difference in the objective value between the current solution and produced neighbouring solution. At a particular level of temperature, many trails solutions are explored until the equipoise state is reached, which is a given number of iterations executed at each temperature T in our in SN algorithm. The temperature is progressively decreased according to a cooling schedule. The consequence is repeated until T reached to T_{min}. SN uses the Nelder-Mead algorithm as a local search algorithm in order to refine the best solution found so far. Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) starts with an initial solution x^0 produced arbitrarily. At each iteration the solution is divided into η partitions. The neighbourhood zone is produced in order to generate trail neighbourhood solutions. The produced neighbour solution that improves the objective function is always selected. Else the solution is accepted with a given probability e-ΔE/T, where T is the current temperature, and ΔE is the amount of the degradation of the objective function. The consequence is repeated until the equipoise state is reached. In SN algorithm, the equipoise state is a given number of iterations executed at each temperature, this number is equals to and μ is a user predefined number. Once the equilibrium state is reached, the temperature is diminished gradually according to a cooling schedule. This procedure is repeated until the stopping criteria satisfied, which is in our algorithm $T \leq T_{min}$. In order to refine the best solution, SN uses the Nelder-Mead algorithm as a local search algorithm in the final stage.
Choose an preliminary solution x^0.
Set prime values for T_{max}, T_{min}, β, μ, υ, z0.
Set z= z0, T= T_{max}, x=x^0.
Repeat
k: =0.

Repeat

Partition the solution x into η partitions, where η=n/ υ.

Create neighbourhood trail solutions y^1,...y^n around x.

Set x$'$ equal to the best trail solution from y^1,...y^n.

ΔE =f(x$'$)-f(x); If $\Delta E \leq 0$ then x=x$'$.

$Z = \tau z_{max}$, $\tau > 1$

Else

$z = \alpha z_{min}$, $\alpha < 1$

If rand ()< e-$^{\Delta E/T}$ then   x=x$'$.

End If

End If

k=k+1.

Until $k \leq \mu$; T=T-β.

Until $T \leq T$ min; Apply Nelder-Mead algorithm at N_{elite} solutions.

5. Simulation Results

At first Proposed Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been tested in standard IEEE-57 bus power system. The reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is selected as slack-bus. The system variable limits are given in Table 1.

The preliminary conditions for the IEEE-57 bus power system are given as follows:

P_{load} = 12.012 p.u. Q_{load} = 3.016 p.u.

The total initial generations and power losses are obtained as follows:

$\sum P_G$ = 12.5041 p.u. $\sum Q_G$ = 3.3210 p.u.

P_{loss} = 0.25620 p.u. Q_{loss} = -1.2012 p.u.

Table 2 shows the various system control variables i.e. generator bus voltages, shunt capacitances and transformer tap settings obtained after SN based optimization which are within the acceptable limits. In Table 3, shows the comparison of optimum results obtained from proposed SN with other optimization techniques. These results indicate the robustness of proposed SN approach for providing better optimal solution in case of IEEE-57 bus system.

Table 1: Variable limits

Reactive Power Generation Limits							
Bus no	1	2	3	6	8	9	12
Qgmin	-1.4	-.015	-.02	-0.04	-1.3	-0.03	-0.4
Qgmax	1	0.3	0.4	0.21	1	0.04	1.50
Voltage And Tap Setting Limits							
vgmin	Vgmax	vpqmin	Vpqmax	tkmin	tkmax		
0.9	1.0	0.91	1.05	0.9	1.0		
Shunt Capacitor Limits							
Bus no	18	25	53				
Qcmin	0	0	0				
Qcmax	10	5.2	6.1				

Table 2: Control variables obtained after optimization

Control Variables	SN
V1	1.1
V2	1.039
V3	1.042
V6	1.031
V8	1.034
V9	1.016
V12	1.028
Qc18	0.0650
Qc25	0.200
Qc53	0.0451
T4-18	1.010
T21-20	1.052
T24-25	0.875
T24-26	0.811
T7-29	1.052
T34-32	0.886
T11-41	1.020
T15-45	1.041
T14-46	0.910
T10-51	1.020
T13-49	1.060
T11-43	0.910
T40-56	0.900
T39-57	0.950
T9-55	0.950

Table 3: Comparison Results

S.No.	Optimization Algorithm	Finest Solution	Poorest Solution	Normal Solution
1	NLP [17]	0.25902	0.30854	0.27858
2	CGA [17]	0.25244	0.27507	0.26293
3	AGA [17]	0.24564	0.26671	0.25127
4	PSO-w [17]	0.24270	0.26152	0.24725
5	PSO-cf [17]	0.24280	0.26032	0.24698
6	CLPSO [17]	0.24515	0.24780	0.24673
7	SPSO-07 [17]	0.24430	0.25457	0.24752
8	L-DE [17]	0.27812	0.41909	0.33177
9	L-SACP-DE [17]	0.27915	0.36978	0.31032
10	L-SaDE [17]	0.24267	0.24391	0.24311
11	SOA [17]	0.24265	0.24280	0.24270
12	LM [18]	0.2484	0.2922	0.2641
13	MBEP1 [18]	0.2474	0.2848	0.2643
14	MBEP2 [18]	0.2482	0.283	0.2592
15	BES100 [18]	0.2438	0.263	0.2541

| 16 | BES200 [18] | 0.3417 | 0.2486 | 0.2443 |
| 17 | Proposed SN | 0.22102 | 0.23154 | 0.22198 |

Proposed Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been tested in standard IEEE 118-bus test system [19]. The system has 54 generator buses, 64 load buses, 186 branches and 9 of them are with the tap setting transformers. The limits of voltage on generator buses are 0.95-1.1 per-unit., and on load buses are 0.95-1.05 per-unit. The limit of transformer rate is 0.9-1.1, with the changes step of 0.025. The limitations of reactive power source are listed in Table 4, with the change in step of 0.01.

Table 4: Limitation of reactive power sources

BUS	5	34	37	44	45	46	48
QCMAX	0	14	0	10	10	10	15
QCMIN	-40	0	-25	0	0	0	0
BUS	74	79	82	83	105	107	110
QCMAX	12	20	20	10	20	6	6
QCMIN	0	0	0	0	0	0	0

The statistical comparison results have been listed in Table 5 and the results clearly show the better performance of proposed SN algorithm.

Table 5: Comparison results

Active power loss (MW)	BBO [20]	ILSBBO/ strategy1 [20]	ILSBBO/ strategy1 [20]	Proposed SN
Min	128.77	126.98	124.78	116.02
Max	132.64	137.34	132.39	122.86
Average	130.21	130.37	129.22	118.74

6. Conclusion

In this paper, Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been successfully solved the optimal reactive power problem. The proposed Hybridized - Simulated Annealing, Nelder-Mead algorithm starts with a prime solution, which is produced arbitrarily and then the solution is disturbed into partitions. The vicinity zone is created, arbitrary numbers of partitions are selected and variables modernizing procedure is started in order to create a trail of neighbour solutions. This procedure helps the SN algorithm to explore the region around an existing iterate solution. The Nelder- Mead algorithm is used in the last stage in order to progress the most excellent solution found so far and hasten the convergence in the closing stage. The proposed Hybridization of Simulated Annealing with Nelder-Mead algorithm (SN) has been tested in standard IEEE 57,118 bus systems and simulation results show the superior performance of the proposed SN algorithm in reducing the real power loss and voltage profiles are within the limits.

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