# APPLICATION OF TABU SEARCH ALGORITHM TO SECURITY CONSTRAINED ECONOMIC DISPATCH

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**ABSTRACT**

This paper presents an algorithm for solving Security Constrained Economic Dispatch (SCED) problem through the application of Tabu Search (TS). The SCED problem is formulated with base case and contingency case line flow constraints, which are important for practical implementation. Two representative systems namely 66-bus [14] and 191-bus [15] Indian utility systems are taken for investigations. The SCED results obtained using TS are compared with those obtained using Genetic Algorithm (GA) and Evolutionary Programming (EP). The investigations reveal that the proposed TS algorithm is relatively simple, reliable and efficient and suitable for practical applications.

**KEYWORDS:** Security constrained economic dispatch, Line flow constraints, Tabu search, Evolutionary programming, Genetic algorithm.

## 1. INTRODUCTION

Online control of power system for maintaining the system security has become essential and it requires performing a number of complex security analysis and control functions with widely differing control objectives. The preventive control is the key control in the security concept, since it minimises the system transitions to unwanted emergency or restorative state. The preventive control function is to determine the economic generation schedule, subject to both operating as well as postulated contingency state constraints. This problem is called as ED with security constraints or security constrained ED problem. The Linear Programming (LP) and Non-Linear Programming (NLP) methods are the most popular methods among the various methods applied for solving the Security Constrained Economic Dispatch (SCED) problem. Both of these methods suffer from certain drawbacks. In the recent past, the Genetic Algorithm (GA) and Evolutionary Programming (EP) has been applied for solving optimisation problems in power systems.

Khan and Kuppusamy [1] proposed the Successive Linear Programming (SLP) method, for solving certain steady state security related optimisation problems in power systems. Nanda et al [2-3] have developed an algorithm, to solve the ED problem with line flow constraints using modified coordination equations and the coordination equations. Vargas et al [4] developed the interior point method for solving the SCED problem through SLP method. Yan and Quintana [5] developed an advanced interior point method for solving the SCED problem through SLP method. Aganagic and Mokhtari [6] presented a new approach to solve the SCED problem based on a non-linear version of the Dantzig-Wolfe decomposition principle. Fan and Zhang [7] used the Quadratic Programming (QP) for solving the ED problem with line flow constraints. Jabr et al [8] discussed the simplified homogeneous and self-dual linear programming interior point algorithm for solving the SCED problem. Nanda and Narayanan [9] solved the ED problem with line flow constraints using the genetic algorithm. Somasundaram et al [10] solved the ED problem with line flow constraints using the EP.

Tabu search (TS) is a powerful optimization procedure that has been successfully applied to a number of combinatorial optimization problems. It is a metaheuristic method developed by Glover specifically for combinational optimisation problem [11-12]. The theory of TS is well documented by Lin et al [13]. It guides the search for the optimal solution making the use of memory systems which exploit its past history and leads to the best solution. TS avoid cycling by storing information of the past from the search. The concept of "distance" used in this methodology prevents the solution being trapped in local minimum. Hence in this paper, an attempt has been made to propose an effective TS algorithm to solve the SCED problem.

This paper presents an efficient and reliable TS based algorithm for solving the SCED problem. The proposed method solves the SCED problem subject to power balance equality constraints, limits on the active power generations and limits on MVA line flow or line phase angle as the inequality constraints pertaining to base case state as well as contingency case states. Two representative systems namely 66-bus [14] and 191-bus [15] Indian utility systems are taken for investigations. The SCED results obtained using TS are compared with those obtained using GA and EP.

## 2. SCED PROBLEM FORMULATION

The security constrained ED problem can be stated as an NLP problem as follows:

$$\text{Min.}F_T = \sum_{j\in\alpha_{GC}}\left(a_j P_{Gj}^2 + b_j P_{Gj} + c_j\right) + \left(a_s P_{Gs}^2 + b_s P_{Gs} + c_s\right)\$/h \quad (1)$$

Subject to:

The control constraints

$$P_{Gj,\,min} \le P_{Gj} \le P_{Gj,\,max} \;;\; j \in \alpha_{GC} \quad (2)$$

The base-case power flow equations

$$F(X, U, C) = 0 \quad (3)$$

The base-case line flow constraints

$$IP_k \le IP_{k,\,max}$$

Or (4)

$$\delta_K \le \delta_{k,\,max} \qquad k = 1,2,\ldots\ldots NLL$$

The slack bus constraint

$$P_{Gs,\,min} \le P_{Gs} \le P_{Gs,\,max} \quad (5)$$

The contingency case power flow equations

$$F^R(X^R, U, C^R) = 0\,;\; R \in \alpha_{NO} \quad (6)$$

and the contingency case line flow constraints

$$IP_k^R \le IP_{k,max}$$

Or (7)

$$\delta_k^R \le \delta_{k,max}\,; R \in \alpha_{NO}\ \&\ k = 1,2,\ldots NLL$$

where the triplet (**X, U, C**) and (**X**$^R$**, U, C**$^R$) characterise respectively the given base-case state and the R-th post-contingency state.

| | |
|---|---|
| $F_T$ | : total fuel cost |
| $a_j, b_j, c_j$ | : cost coefficients of the j-th generator |
| $P_{Gj}$ | : power output of j-th generator |
| $P_{GS}$ | : slack bus generation |
| $\alpha_{GC}$ | : set containing the numbers of buses having controllable real power generations (1,2,3,……NG) |
| $\alpha_{NO}$ | : set containing the numbers of single-line outages |
| $IP_k$ | : MVA line flow of k-th line |
| $\delta_k$ | : line phase angle of k-th line |
| NLL | : number of limiting lines |

The state vector **X** comprises of the bus voltage phase angles and magnitudes. The control vector **U** comprises of all the controllable system variables such as real power generations. The parameter vector **C** includes all the uncontrollable system parameters such as line parameters, loads etc.

The ED problem comprising equations (1) to (5) constitutes the base-case ED problem while ED problem comprising equations (1) to (7) constitutes the SCED problem.

## 3. ALGORITHM FOR THE SOLUTION OF SCED BY USING TS

TS algorithm functions with four major steps: Initialisation, mutation, recombination, evaluation and selection. Mutation and recombination being the diversification and intensification strategies respectively, the historically attractive regions can be investigated thoroughly. The various steps of the algorithm for solving the ED problem with line flow constraints are as follows:

### 3.1 Initialisation of parent population

The individuals in a parent are the real power outputs of the committed NG generating units excluding the slack bus unit. The initial parent population is generated randomly as follows:

Consider the i-th parent, $I_i = [P_{G1}, P_{G2}, \ldots, P_{GNG}]$ of the population of size $N_p$. The components of $I_i$ are generated as $P_{Gj} \sim U(P_{Gj,min}, P_{Gj,max})$, j =1, 2, ….,NG where $U(P_{Gj,min}, P_{Gj,max})$ denotes a uniform random variable ranging over $[P_{Gj,min}, P_{Gj,max}]$. The remaining parents are generated in the same way.

Load flow is run for the base case as well as for the contingency cases with the unit generations of each parent $I_i$ and the system transmission loss, slack bus generation and line flows are evaluated.

The fitness function for each parent of the initial population is computed by using the following relation

$$f_i = F_{Ti} + k_1 P_{Gs}^{lim} + k_2 \sum_{k=1}^{NLL} IP_k^{lim} + k_3 \sum_{R=1}^{NO} \sum_{k=1}^{NLL} IP_k^{R,lim} \quad (8)$$

where $k_1$, $k_2$ and $k_3$ are penalty factors for the constraint violations,
NO is the number of single-line outages
$F_{Ti}$ is the total fuel cost for i-th parent

$$P_{Gs}^{lim} = \begin{cases} P_{Gs,min} - P_{Gs} \\ P_{Gs} - P_{Gs,max} \end{cases} \quad (9)$$

$$IP_k^{lim} = \begin{cases} |IP_k| - IP_{k,} \\ 0 \end{cases} \quad (10)$$

and

$$IP_k^{R,lim} = \begin{cases} |IP_k^R| - IP_k \\ 0 \end{cases} \quad (11)$$

Mutation

An offspring population $I'_i$ is generated from the randomly selected parent $I_i$ as:

$$I'_i = [P'_{G1}, \ldots P'_{GNG}]; i = N_p + 1, N_p + 2, \ldots N_p + N_m \quad (12)$$

where, $P'_{Gj} = P_{Gj} + N(0, \sigma_j^2); j = 1,2,\ldots NG$ (13)

subject to

$$P'_{Gj} = \begin{cases} P_{Gj,min} \text{ if } P'_{Gj} < P_{Gj,min} \\ P_{Gj,max} \text{ if } P'_{Gj} > P_{Gj,max} \end{cases} ; j = 1,2,\ldots NG \quad (14)$$

where $N_m$ is the number of mutated individuals randomly selected, $N(0, \sigma^2_j)$ represents a normal random variable with mean zero and standard deviation $\sigma_j$. The standard deviation $\sigma_j$ decides the width of the normal distribution curve corresponding to jth generating unit. $\sigma_j$ is computed as:

$$\sigma_j = \beta \times \frac{f_i}{f_{max}} (P_{Gj,max} - P_{Gj,min}) \quad (15)$$

where $\beta$ is a scaling factor, $f_i$ is the value of the objective function corresponding to $I_i$ and $f_{max}$ is the maximum objective function value among the parent population. The fitness value corresponding to each offspring obtained from mutation is computed by running a load flow with the unit generations of each offspring and using equation (8).

The value of $\sigma_j$ is chosen according to the relative value of $f_i$ so that the width of the normal distribution curve is small if $f_i$ is low and vice-versa. Hence if $f_i$ is low the offspring generated is nearer to the parent and vice-versa.

Generally during mutation $\beta$ is fixed throughout the whole search process. However in practical applications a small fixed mutation scale factor may result in a premature convergence while a search with a large fixed mutation scale factor may not converge. To over come this problem, an adaptive mutation scale factor is used. In this approach the scaling factor $\beta$ is fixed arbitrarily to start with and $\beta$ is decreased judiciously during successive offspring generation to produce smooth and faster convergence.

Recombination

Recombination is a mechanism to generate a new offspring $I'_i$ by using parameters from two randomly selected parent individuals $I_{i1}$ and $I_{i2}$. It generates an individual, with certain qualities inherited from the parents. The recombination function can be found by,

$$I'_i = I_{i1} + U(0,1) \cdot (I_{i2} - I_{i1}); i = N_p + N_m + 1, N_p + N_m + 2, \ldots 2N_p \quad (16)$$

$= [P_G'_1, \ldots, P_G'_j, \ldots, P_G'_{NG}]$ ; $j = 1,2,\ldots\ldots\ldots\ldots,N_G$

The fitness value corresponding to each offspring obtained from recombination is computed by running a load flow with the unit generations of each offspring and using equation (8).

$N_m$ and $N_r$ were both initialised to 1/2 $N_p$. $N_m$ and $N_r$ must satisfy the following conditions,

$N_m + N_r = N_p$ (17)

$N_{m,min} \leq N_m \leq N_{m,max}$ (18)

$N_{r,min} \leq N_r \leq N_{r,max}$ (19)

The number of mutated individuals in the next generation will be increased if the previous best solution is from mutation that is

$N_m(g+1) = N_m(g) + I_N$ (20)

$N_r(g+1) = N_p - N_m(g+1)$ (21)

where g is the generation number and $I_N$ is the intensification number.

Similarly if the best solution is from recombination, then we have to increase the number of individuals to be recombined as,

$N_r(g+1) = N_r(g) + I_N$ (22)

$N_m(g+1) = N_p - N_r(g+1)$ (23)

Evaluation and selection

Assign the rank of the calculated fitness, $RC_i$, to the individuals of the combined population with $2N_p$ individuals formed with parent and offspring population. A best solution would gain the first number place, i.e., the highest rank $RC_i$ =1. The concept of distance was added to the weight value of each individual to prevent it from being trapped in local minimum. A far away point needs a higher rank to be selected, even if the fitness is slightly worse. The weight for each individual in the combined population decides the survival. The weight $W_i$ is computed as:

$W_i = RC_i + \alpha * RD_i$ , $i = 1,2 \ldots 2N_p$

$RD_i$, is the rank of $D_i$ assigned to the i-th individual and $D_i$ is the sum of distances from the individual to each solution in the tabu list and is given by

$$D_i = \sum_{t=1}^{TLS} \left| I_i - I_{tabu,\ t} \right| \qquad (24)$$

where TLS is the Tabu List Size

Individuals will be ranked in ascending order to their weight. The first $N_p$ individuals are transcribed along with their fitness value for next generation. If the new population does not include the current best solution, the best solution must replace the worst individual in the new population.

The steps given under 3.2, 3.3 and 3.4 are repeated until convergence is reached. The entire algorithm is represented by a flowchart in Figure 1.

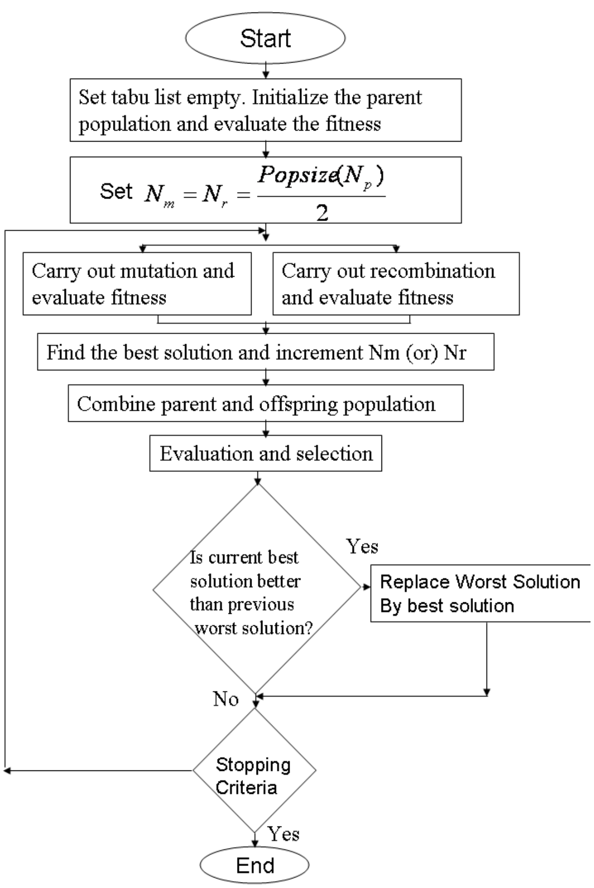


*Figure 1. Flow chart for tabu search algorithm*

## 4. SAMPLE SYSTEM STUDIES AND RESULTS

The algorithm discussed earlier has been tested on 66-bus [14] and 191-bus [15] Indian utility systems to assess the performance of the proposed algorithm.

### 4.1 66-bus Indian utility system

The 66-bus Indian utility system consists of 4 generators, 93 lines and a total demand of 1250 MW [14]. The load data, line data, line phase angle limits and generation cost data for the system are taken from [14]. The objective function is the total fuel cost and the fuel cost curve of the units are represented by quadratic cost functions. The line limits are expressed in terms of line phase angles. Ten lines are taken as critical lines for imposing line flow constraints. Five single line outages are considered. The line phase angle limits are taken to be the same in the base case and postulated contingency cases. The parameter used for GA, EP and TS are given in Table 1.

***Table 1: Parameters Used***

| Parameters | GA | EP | TS |
|---|---|---|---|
| Population size | 10 | 10 | 10 |
| Scaling factor $\beta$ | Adaptive | Adaptive | Adaptive |
| $\alpha$ and $\gamma$ | - | - | Adaptive |
| Maximum number of iterations | 200 | 200 | 200 |

There are several lines having limit violation in the base case and contingency cases with each parent of the initial population. The line flow limit violations are found in the range of 0 - 200% of its line limits. The fitness function convergence characteristics with GA, EP and proposed TS are given in Figure 2. It is seen from Figure 2 that the fitness function converges smoothly to the optimum value without any abrupt oscillations. The convergence is reached after 200 iterations. The results obtained using TS are compared with those obtained using GA and EP. The optimal generation schedule and fuel cost obtained are given in Table 2. The fitness function convergence is same for several trial runs. This shows the convergence reliability of the proposed algorithm. And also the results are closely matching with that of the results obtained from GA and EP.

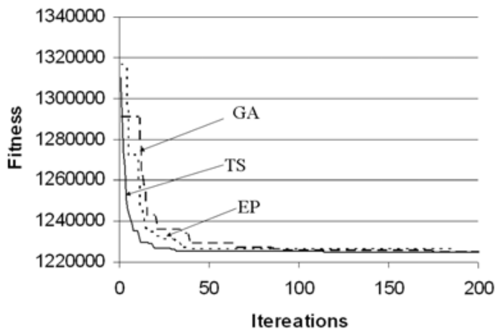


*Figure 2. Convergence characteristics of fitness function 66-bus*

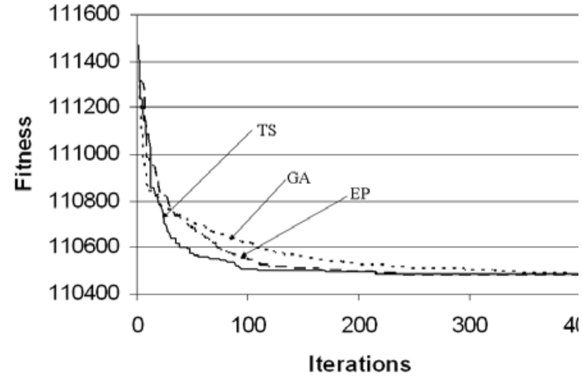


*Figure 3. Convergence characteristics of fitness function 191-bus system*

For the purpose of analysis the problem is solved considering four population sizes of 5, 10, 15 and 20 and the results are shown in Table 3. The optimum fuel cost is observed to be the same in all the cases but for the difference in computation time. The computation time varies with the population size and it is less for the population size of 10 compared to all other population sizes.

4.2. 191- bus Indian utility system

The 191-bus [15] Indian utility system consists of 17 generators, 200 lines, 55 transformers and a total demand of 4772.1 MW. The objective function is the total fuel cost and the fuel cost curve of the units is represented by quadratic cost functions. Twenty eight lines are taken as critical lines for imposing line flow constraints. Ten single-line outages are considered. The line flow limits are expressed in MVA and taken to be the same in the base case and postulated contingency cases. From the analysis a population size of 20 is chosen.

The problem is solved using the proposed TS, GA and EP and the optimum schedule, total fuel cost and transmission loss obtained are compared in Table 4.

## 5. CONCLUSIONS

This paper presents an efficient and simple approach for solving the SCED problem. This paper demonstrates with clarity, chronological development and successful application of TS to the solution of SCED. Two test systems 66 bus and 191-bus Indian utility systems have been tested and the results are compared with those obtained from genetic algorithm and evolutionary programming. The proposed approach is relatively simple, reliable and efficient and suitable for practical applications.

*Table 2 Optimum generation schedule for 66-bus system*

| Output (MW) | GA | EP | TS |
|---|---|---|---|
| PG1 | 816.801 | 816.721 | 816.879 |
| PG2 | 176.656 | 177.204 | 177.523 |
| PG3 | 179.684 | 180.210 | 178.887 |
| PG4 | 119.999 | 118.988 | 119.836 |
| Loss (MW) | 43.142 | 43.126 | 43.126 |
| Fuel cost (Rs/hr) | 1225415.875 | 1225415.75 | 1225415.375 |
| Computation time (sec) | 247.2 | 235.9 | 220.5 |

***Table 3. Optimum solution with different population sizes***

| | Popsize 5 | Popsize 10 | Popsize 15 | Popsize 20 |
|---|---|---|---|---|
| **Fuel cost (Rs/h)** | 1225415.394 | 1225415.375 | 1225415.371 | 1225415.362 |
| **Computation time (sec)** | 230.2 | 220.5 | 244.7 | 278.6 |

***Table 4 Optimum generation schedule for 191-bus system***

| Output (MW) | GA | EP | TS |
|---|---|---|---|
| PG1 | 499.977 | 499.996 | 499.956 |
| PG2 | 58.044 | 58.087 | 58.087 |
| PG3 | 199.761 | 199.947 | 199.994 |
| PG4 | 299.976 | 300.000 | 300.000 |
| PG5 | 143.215 | 143.230 | 143.296 |
| PG6 | 200.000 | 200.000 | 200.019 |
| PG7 | 174.807 | 174.585 | 174.502 |
| PG8 | 134.315 | 134.349 | 134.257 |
| PG9 | 85.944 | 86.256 | 86.321 |
| PG10 | 191.146 | 191.080 | 191.132 |
| PG11 | 411.311 | 411.478 | 411.742 |
| PG12 | 683.802 | 684.205 | 684.338 |
| PG13 | 271.664 | 271.036 | 270.587 |
| PG14 | 408.592 | 408.517 | 408.547 |
| PG15 | 200.000 | 200.000 | 200.000 |
| PG16 | 327.536 | 327.336 | 327.460 |
| PG17 | 585.362 | 585.371 | 585.239 |
| Loss (MW) | 103.355 | 103.373 | 103.379 |
| Fuel cost ($/hr) | 110486.633 | 110485.375 | 110484.922 |
| Computation time in sec | 512.6 | 473.3 | 460.5 |

## REFERENCES


[1]. Khan, M and Kuppusamy, K, "Security constrained dispatch through successive relinearization using constant matrices", IEEE PES winter meeting, Paper No. A 79 085-2, (1979) New York.

[2]. Nanda, J Hari, L Kothari, M L and Henry, J "Extremely fast economic load dispatch algorithm through modified co-ordination equations", IEE Proc.-C, 139(1) (1992) 39-46.

[3]. Nanda, J Hari, L and Kothari, M L, "Economic emission load dispatch with line flow constraints using a classical technique", IEE Proc.-Gener. Transm. Distrib., 141(1) (1994) 1-10.

[4]. Vargas, L S Quintana, V H and Vannelli, A, "A tutorial description of an interior point method and its application to security-constrained economic dispatch", IEEE Trans Power Systems, 8(3) (1993) 1315-1324.

[5]. Yan, X and Quintana, V H, "An efficient predictor-corrector interior point algorithm for security-constrained economic dispatch", IEEE Trans Power Systems, 12(2) (1997) 803-810.

[6]. Aganagic, M and Mokhtari, S, "Security constrained economic dispatch using nonlinear Dantzig-Wolfe decomposition", IEEE Trans Power Systems, 12(1) (1997) 105-112.

[7]. Fan, J Y and Zhang, L, "Real-time economic dispatch with line flow and emission constraints using quadratic programming", IEEE Trans. on Power Systems, 13(2) (1998) 320-325.

[8]. Jabr, R A Coonick, A H and Cory, B J, "A homogeneous linear programming algorithm for the security constrained economic dispatch problem", IEEE Trans Power Systems, 15(3) (2000) 930-936.

[9]. Nanda, J Badri Narayanan, R, "Application of genetic algorithm to economic load dispatch with line flow constraints", Electrical Power Energy Syst, 24 (2002) 723-729.

[10]. Somasundaram, P Kuppusamy, K and Kumudini Devi, R P, "Evolutionary programming based economic dispatch with line flow constraints", International Journal of Computational Engineering Science, 5(1) (2004) 81-90.

[11]. Glover, F, "Tabu search: Part I", ORSA J. Comput., 1(3) (1989) 190-206.

[12]. Glover, F, "Tabu search: Part II", ORSA J. Comput., 2(1) (1990) 4-32.

[13]. Lin, W M Cheng, F S and Tsay, M T, "An Improved Tabu Search for Economic Dispatch With Multiple Minima", IEEE Transactions on power systems, 17(1) (2002) 108-112.

[14]. Baskar, G Kumarappan, N and Mohan, M R, "Optimal Dispatch Using Improved Lambda-Based Genetic Algorithm Suitable for Utility Systems", Electric Power Components and Systems, 31(7) (2003) 627-638.

[15]. Venkatesh, B Arunagiri, A and Gooi, H B, "Unified OPF method for maximizing voltage stability margin using successive fuzzy LP", Electric Power Systems Research, 64 (2003) 119-128.


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