

Power Flow with Thyristor-Controlled Series Capacitor using Genetic Algorithm

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Abstract:

The basic OPF solution is obtained with fuel cost minimization as the objective function and the optimal settings of the power system are determined. For reactive power optimization, active power loss has been taken as the objective function. OPF solution with Thyristor Controlled Series Compensator (TCSC) device is carried out considering fuel cost minimization and active power loss minimization as objective. TCSC is used to minimize the total fuel cost and active power losses. All the above cases are studied using Genetic Algorithm. Results obtained using IEEE 30 bus system and 75-bus Indian system are presented.

1. Introduction

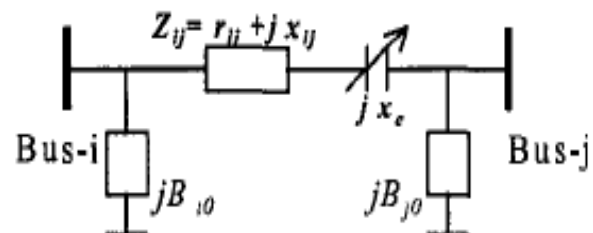
FACTS devices have opened a new world in power system control. They have made the power systems operation more flexible and secure. They have the ability to control, in a fast and effective manner, the three effective players in power flow. These are circuit impedance, voltage magnitude and phase angle. Gaining flexibility in power flow is not a little achievement. The great economic and technical benefits of this to the power systems have been well proven.

Installing FACTS devices in any power system is an investment issue. It offers some flexibility to the power system at the expense of cost. Therefore, it is necessary for any new installation of FACTS to be very well planned. Planning of FACTS devices mainly means the allocation of those devices in the power system. This needs an off-line simulation of the power

system with the different candidate FACTS devices location to assess the value added to the system in terms of system operation improvement. Among the different assessment tools used for this purpose, optimal power flow (OPF) seems to be the best. By incorporating FACTS devices in OPF with some modification, it can give scalar measures of its economic and technical benefits and so help in deciding for the optimal investment. OPF is a non-linear problem and can be non-convex in some cases. Moreover, incorporating FACTS devices complicates the problem further. Such complicated problem needs a well-efficient optimization technique for solving. Genetic algorithm is such efficient technique employed for this task in this paper.

2. FACTS MODELING

2.1 Thyristor controlled series compensation (TCSC).



Where X_{ij} is the reactance of the line, R_{ij} is the resistance of the line, B_{i0} and B_{j0} are the half-line charging susceptance of the line at bus-i and bus-j. The difference between the line susceptance before and after the addition of TCSC can be expressed as:

$$\Delta y_{ij} = y'_{ij} - y_{ij} = (g'_{ij} + jb'_{ij}) - (g_{ij} + jb_{ij})$$

$$g_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}}, b_{ij} = -\frac{x_{ij}}{\sqrt{r_{ij}^2 + x_{ij}^2}}$$

$$g'_{ij} = \frac{r_{ij}}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}}$$

$$b'_{ij} = -\frac{x_{ij} + x_c}{\sqrt{r_{ij}^2 + (x_{ij} + x_c)^2}}$$

After adding TCSC on the line between bus i and bus j of a general power system, the new system admittance matrix Y'_{bus} can be updated as:

$$Y'_{bus} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & \Delta y_{ij} & 0 & \dots & 0 & -\Delta y_{ij} & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & 0 & \dots & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & -\Delta y_{ij} & 0 & \dots & 0 & \Delta y_{ij} & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 & 0 \end{bmatrix} \begin{matrix} \\ \text{row}-i \\ \\ \\ \text{row}-j \\ \\ \text{col}-i \quad \quad \quad \text{col}-j \end{matrix}$$

3. PROBLEM FORMULATION

3.1 Problem Variables

Optimal power system operation seeks to optimize the steady state performance of a power system in terms of an objective function while satisfying several equality and inequality constraints. Generally, OPF is formulated an optimization problem as follows:

Minimize $J(x, u)$

Subject to

$$g(x, u) = 0$$

$$h(x, u) \leq 0$$

u : Vector of problem control variable

x : Vector of system state variables

$J(x, u)$: Objective function to be minimized

$g(x, u)$: Equality Constraints represents nonlinear load flow equations.

$h(x, u)$: Inequality Constraints i.e. system functional operating constraints.

Where u is a vector of control variables consisting of generator voltages V_G , generator real power outputs P_G except at slack bus P_{G_1} ,

transformer tap settings T and shunt VAR compensation Q_c . Hence u can be expressed as

$$u^T = [V_{G_1} \dots V_{G_{NG}}, P_{G_2} \dots P_{G_{NG}}, T_1 \dots T_{NT}, Q_{C_1} \dots Q_{C_{NC}}]$$

3.2 Objective Functions

J is the objective function to be minimize, which is one of the following:

3.2.1 Fuel cost minimization

It seeks to find the optimal active power outputs of the generation plants so as to minimize the total fuel cost. This can be expressed as

$$J = \sum_{i=1}^{NG} f_i (\$/hr)$$

Where f_i is the fuel cost curve of the i th generator and it is assumed here to be represented by the following quadratic function:

$$f_i = a_i + b_i P_{G_i} + c_i P_{G_i}^2 (\$/hr)$$

Where a_i , b_i , and c_i are the cost coefficients of the i th generator

3.2.2 Active power loss minimization

The objective function J is considered as active power loss of the system.

$$J = f_c(x, y) = \sum_{i=1}^{nline} Loss_i$$

Where $nline$ is number of branches.

3.3 Problem Constraints

3.3.1 Equality constraints

The equality constraints that are the power flow equations corresponding to both real and reactive power balance equations, which can be written as:

$$P_{G_i} - P_{D_i} - P_i(V, \delta) = 0$$

$$Q_{G_i} - Q_{D_i} - Q_i(V, \delta) = 0$$

Where

$$P_i = \sum V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij})$$

$$Q_i = \sum V_i V_j (B_{ij} \cos \delta_{ij} - G_{ij} \sin \delta_{ij})$$

3.3.2 Inequality constraints

The inequality constraints are the system operating limits. The inequality constraints that are real power outputs, reactive power outputs and generator outputs.

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \quad i \in N_g$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} \quad i \in N_g$$

$$|S_k| \leq S_k^{\max} \quad k \in N_E$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad i \in N_B$$

4. Solution methodology

4.1 Overview

GA is used to solve the OPF problem. The control variables modeled are generator active power outputs, voltage magnitudes, shunt devices, and transformer taps. To keep the GA chromosome size small, each control variable is encoded with different sizes. The continuous control variables include generator active power outputs, generator voltage magnitudes, and discrete control variables include transformer tap settings and switchable shunt devices.

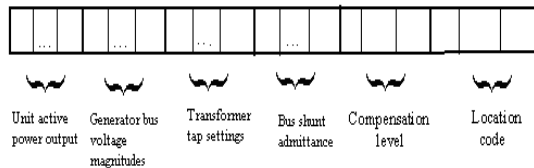


Fig .GA chromosome structure

4.2 The Proposed GA Algorithm

Typically it consist of three phases,

- (i) Generation
- (ii) Evaluation
- (iii) Genetic operation

4.1 Generation

In this phase number of chromosomes equal to population size is generated and each is of length equals to string length. The size of population is direct indication of effective representation of whole search space in one population. The population size affects both the ultimate performance and efficiency of GA. If it is too small it leads to local optimum solution. The selection of string length depends on the accuracy and resolution requirement of the optimization problem. The higher the string length, the better the accuracy and resolution. But this may lead to slow convergence

4.2 Evaluation

In the evaluation phase, suitability of each of the solutions from the initial set as the solution of the optimization problem is determined. For this function called “*fitness function*” is defined. This is used as a deterministic tool to evaluate the fitness of each chromosome. The optimization problem may be minimization or maximization type. In the case of maximization type, the fitness function can be a function of variables that bear direct proportionality relationship with the objective function. For minimization type

problems, fitness function can be function of variables that bear inverse proportionality relationship with the objective function or can be reciprocal of a function of variables with direct proportionality relation ship with the objective function. In either case, fitness function is so selected that the most fit solution is the nearest to the global optimum point. The programmer of GA is allowed to use any fitness function that adheres to the above requirements. This flexibility with the GA is one of its fortes.

4.3 Genetic operation

In this phase, the objective is the generation of new population from the existing population with the examination of fitness values of chromosomes and application of genetic operators. These genetic operators are *reproduction*, *crossover*, and *mutation*. This phase is carried out if we are not satisfied with the solution obtained earlier. The GA utilizes the notion of survival of the fittest by transferring the highly fit chromosomes to the next generation of strings and combining different strings to explore new search points.

(i)Reproduction

Reproduction is simply an operator where by an old chromosome is copied into a Mating pool according to its fitness value. Highly fit chromosomes receive higher number of copies in the next generation. Copying chromosomes according to their fitness means that the chromosomes with a higher fitness value have higher probability of contributing one or more offspring in the next generation.

(ii) Cross over

It is recombination operation. Here the gene information (information in a bit) contained in the two selected parents is utilized in certain fashion to generate two children who bear some of the useful characteristics of parents and expected to be more fit than parents.

Crossover is carried out using any of the following three methods

- (a) Simple or Single Point Crossover
- (b) Multi point crossover
- (c) Uniform crossover

(iii) Mutation

This operator is capable of creating new genetic material in the population to maintain the population diversity. It is nothing but random alteration of a bit value at a particular bit position in the chromosome. The following example illustrates the mutation operation.

Original String: 1011001

Mutation site: 4 (assumption)

String after mutation: 1010001

Some programmers prefer to choose random mutation 'or' alternate bit mutation. "*Mutation Probability (P_m)*" is a parameter used to control the mutation. For each string a random number between '0' and '1' is generated and compared with the P_m . If it is less than P_m mutation is performed on the string. Some times mutation is performed bit-by-bit also instead of strings. These results in substantial increase in CPU time but performance of GA will not increase to the recognizable extent. So this is usually not preferred.

Thus obviously mutation brings in some points from the regions of search space which otherwise may not be explored. Generally mutation probability will be in the range of 0.001 to 0.01. This concludes the description of Genetic Operators.

5. Results and discussions

The proposed approach has been tested on the standard IEEE 30-bus test system and 75 bus Indian practical system. The cost coefficients of IEEE 30 bus system and 75 bus system as shown below tables.

5.1 fuel cost minimization as objective

When fuel cost minimization taken as objective, fuel cost will be reduced but active power losses will be increased.

5.2 Active power loss minimization as objective

When active power loss minimization taken as objective, active power losses will be reduced but fuel cost will be increased.

To reduce both fuel cost and active power losses, both fuel cost and active power losses taken as objective.

5.3 fuel cost and active power loss minimization as objective.

If both fuel cost and active power loss minimization taken as objective, both will be reduced.

5.3.1 Case study (i)-IEEE 30 bus system

The GA parameters are

Population size = 40

Maximum number of generations = 100

Elitism probability = 0.15

Cross over probability = 0.95

Mutation probability = 0.001

Table 1 OPF results for IEEE 30 bus system with fuel cost and active power loss minimization as objective

Generat or bus no	Active power outputs (with out TCSC)	Active power outputs (with TCSC)	Fuel cost (with out TCSC)	Fuel cost with (TCSC)
1	108.62	92.23	261.48	216.35
2	48.26	46.94	125.21	120.70
5	34.91	34.84	111.07	110.70
8	29.37	27.46	97.24	90.80
11	15.36	16.51	52.44	56.34
13	52.45	50.18	226.12	213.49

From the analysis of above results, both fuel cost and active power losses taken as objective, due to the influence of TCSC fuel cost reduced from 872.667\$/hr to 829.40 \$/hr, and active power losses are reduced from 5.7255MW to 5.422 MW.

P_{gmax} and P_{gmin} for generators

Generator bus no	P_{gmin}	P_{gmax}
1	0.5	2.0
2	0.2	0.8
5	0.15	0.5
8	0.1	0.35
11	0.1	0.3
13	0.2	0.8

a, b, c constants for generators

Generator No	a	b	c
1	0	2	0.00375
2	0	1.75	0.0175
3	0	1	0.0625

4	0	3.25	0.002075
5	0	3	0.025
6	0	3	0.025

Fig shows the single line diagram of 75 bus Indian system, and table shows the a.b.c coefficients of 75 bus system.

Fig. Single line diagram of 75-bus Indian system

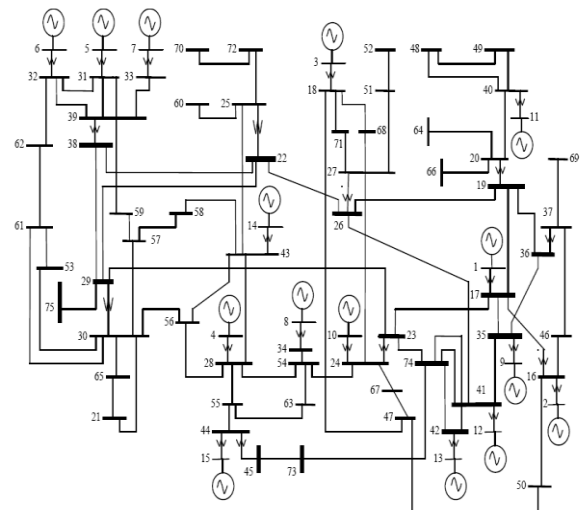


Table .a,b,c coefficients for 75 –bus Indian practical system

Generator bus no	Active power outputs (with out TCSC)	Active power outputs (with TCSC)
2	1.903	0.805
3	1.633	1.460
4	0.838	1.983
5	0.872	0.987

6	0.941	0.710
7	0.887	0.982
8	5.148	5.443
9	2.306	1.774
10	1.924	1.025
11	2.152	1.937
12	8.520	8.751
13	1.386	1.090
14	3.287	3.472
15	7.841	7.938

from the analysis of above results, both fuel cost and active power losses taken as objective, due to the influence of TCSC fuel cost reduced from 8044.8\$/hr to 7896.7\$/hr, and active power losses are reduced from 176.07MW to 155.97 MW.

The effect of TCSC in a system will minimize total fuel cost or active power losses or both fuel cost and active power losses.

6. CONCLUSIONS

In this paper Optimal power flow (OPF) has been solved using genetic algorithm (GA) to obtain the optimal fuel cost and active power losses. To reduce the total fuel cost and active power losses further, OPF has been solved with FACTS device like TCSC.

Case 1: IEEE 30 bus system

- Fuel cost minimization taken as objective, due to the influence of TCSC the fuel cost reduced from 849.41\$/hr to 828.332\$/hr.
- Active power loss minimization taken as objective, due to the influence of TCSC the active power losses are reduced from 4.3285MW to 3.4925MW.

- Both fuel cost and active power losses taken as objective, due to the influence of TCSC fuel cost reduced from 872.667\$/hr to 829.40 \$/hr, and active power losses are reduced from 5.7255MW to 5.422 MW.

Case 2: 75 bus Indian system

- Fuel cost minimization taken as objective, due to the influence of TCSC the fuel cost reduced from 7986.9\$/hr to 7947.7\$/hr.
- Active power loss minimization taken as objective, due to the influence of TCSC the active power losses are reduced from 142.73MW to 141.16MW.
- Both fuel cost and active power losses taken as objective, due to the influence of TCSC fuel cost reduced from 8044.8\$/hr to 7896.7\$/hr, and active power losses are reduced from 176.07MW to 155.97 MW.

From the analysis of above results, the effect of TCSC in a system will minimize total fuel cost or active power losses or both fuel cost and active power losses

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