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Performance comparison of DE, PSO and GA approaches in Transmission Power Loss minimization using FACTS Devices

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ABSTRACT

This paper presents the performance comparison of meta–heuristics algorithms such as DE (Differential Evolution), PSO (Particle Swarm Optimization) and GA (Genetic Algorithm for the problem of Transmission Power Loss (TPL) minimization using Flexible AC Transmission System (FACTS) devices. In addition to that a novel power flow method is proposed using Broyden – Shamanski method with Sherman – Morrison formula (BSS) to reduce the computational time without loss of accuracy and the results are compared with the conventional Newton Raphson (NR) method. Simulation test are carried on WSCC 9 bus, New England 39 bus and IEEE 118 bus test systems. Results indicate that location of FACTS device using DE algorithm minimizes TPL better with higher computational efficacy when compared to PSO and GA.

General Terms

Electric Power Systems, Optimization Techniques.

Keywords

Differential Evolution, Genetic Algorithm, Particle Swarm Optimization, Transmission Power Loss, FACTS device.

1. INTRODUCTION

Power System operators continuously strive for the improvement in operation of power systems which is the need of present market conditions. One way of improving system operation is by reducing Transmission Power Loss (TPL) thereby, the cost of generation reduces, transmission capacity of existing system increases etc [1]. Though TPL minimization can be achieved by controlling system devices such as generators, synchronous condensers, capacitors, reactors and tap changing transformers, the state-of-the-art technology is to use the fast acting power electronic based Flexible AC Transmission System Devices (FACTS) such as TCSC (Thyristor Controlled Series Capacitor), SVC (Static Var Compensator) as controlling sources [2],[3]. It is well known that these devices are capable of controlling voltage magnitude, phase angle and circuit reactance. By controlling these, we can redistribute power flow and minimize TPL hence this method proves to be a promising one. The installation and operation cost of FACTS devices are very high, hence the number of devices required, optimal location and settings of these devices to minimize TPL should be found accurately to reduce the overall cost. This makes it a combinatorial analysis problem; hence modern heuristic methods such as Differential Evolution (DE), Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are more suitable for finding an optimal solution. Their performances in minimizing TPL using FACTS are compared in this paper. Further in this paper a novel power flow technique using Broyden – Shamanski method with Sherman – Morrison formula (BSS) to evaluate the TPL is proposed which reduces the computational time without loss of accuracy when compared to the conventional Newton Raphson (NR) method. The remaining paper is organized as follows: Section 2 deals with the description of DE, PSO and GA algorithms. Section 3 gives FACTS devices model and Section 4 gives TPL problem formulation. Results and Discussion are presented in Section 5. Finally conclusions are drawn in section 6.

2. OVERVIEW OF GA, DE AND PSO

All modern stochastic algorithms fall under the category of meta-heuristics. From the recent literatures [4]-[6] it is understood that these algorithms are the only practical solution to obtain global optimal for real world problems which are non linear, non differentiable, continuous and real valued. Of all these algorithms the most powerful ones are GA, DE and PSO. Hence in this paper these algorithms are tested and compared for the problem of TPL minimization using FACTS devices.

2.1 Genetic Algorithm

GA [7] is a search algorithm that depends on conjecture of natural selection and genetics. The general procedure of GA is to evaluate fitness (or objective function value) for a randomly generated initial population. Then based on fitness, selection is done on the individuals for reproduction. Upon selected individuals crossover and mutation is performed to create offspring which forms the population of next generation. This process is repeated until maximum number of generations or convergence is reached.

2.2 Differential Evolution

DE [8] uses the difference of randomly sampled pairs of object vectors to guide the mutation process which makes it relatively new when compared to other algorithms. Similar to GA a randomly generated initial population is created. For each individual three other individuals are selected in random. A new vector is created by adding a weighted (mutation factor) difference of two individual to the other. Cross over or recombination is one of the main operators for GA but it is complementary in DE. When the entire individuals are processed by this way then fitness is evaluated. If the fitness value of the new individual is better than that of old individual then replace the old individual with the new one. This process is repeated until maximum number of generations or convergence is reached.

2.3 Particle Swarm Optimization

PSO [9] algorithm is based on the social behavior of birds. In this algorithm, initially a random population is created. Every individual known as particle is assigned a velocity and a small social network. For all particles, fitness or objective function values are evaluated. Based on fitness unlike GA, PSO doesn't have crossover/mutation, but the personal optimal for each individual, global optimal in the complete population and neighborhood optimal found by the neighbors of each individual are saved to update velocity and position for each individual. This process is repeated until either maximum generations or convergence is reached.

3. FACTS DEVICE MODEL

Though there are many FACTS devices, commercially available devices such as TCSC (Thyristor Controlled Series Capacitor) and SVC (Static Var Compensator) alone are considered in this paper. Steady state model of these devices from [10-13] are considered.

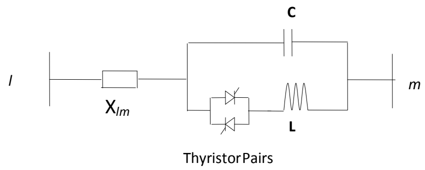

Fig 1.Schematic diagram of TCSC

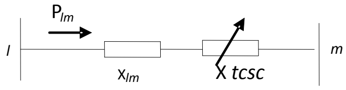

Fig 2.Variable Reactance representation of TCSC

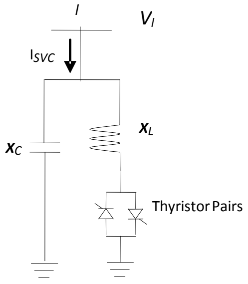

Fig 3. Schematic diagram of SVC

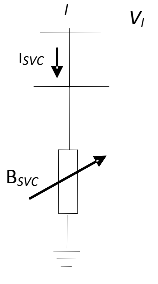

Fig 4. Variable Susceptance representation of SVC

Figure 1 shows the schematic diagram of TCSC. This device may have either inductive compensation or capacitive compensation with a limit of $-0.5X_L$ to $+0.5X_L$ respectively and is connected in series with the transmission line. Hence it is represented as a variable reactance representation of the transmission line as shown in Figure 2.

Figure 3 shows the schematic diagram of SVC. It is connected in shunt, generally to any load bus. It may have either inductive or capacitive compensation with a limit of -100 Mvar to $+100$ Mvar respectively. Figure 4 shows the variable susceptance representation of SVC.

4. PROBLEM FORMULATION

The objective function for minimizing TPL in a power system is given as

$$\min\left(P_{loss}\right) = \min\left(real\left(\sum_{k=1}^{NL}\left(S_{k,ij} + S_{k,ji}\right)\right)\right) \tag{1}$$

Where

$\left(S_{k,ij} + S_{k,ji}\right)$ is the total complex power flowing in the line 'k'

$S_{k,ij}$ is the complex power flowing from bus 'i' to 'j'

$S_{k,ji}$ is the complex power flowing from bus 'j' to 'i'

NL is the total number of transmission lines

Subject to

$$P_{G_i} - P_{D_i} - \sum_{j=1}^{n} P_{loss_{ij}} = 0 \tag{2}$$

$$Q_{G_i} - Q_{D_i} - \sum_{j=1}^{n} Q_{loss_{ij}} = 0 \tag{3}$$

$$V_{i\min} \le V_i \le V_{i\max} \tag{4}$$

$$S_{ij} = S_{ij\max} \tag{5}$$

$$P_{G_i} \le P_{G_i\max} \tag{6}$$

4.1 Power Flow using BSS method

In general, an NR method finds the value of $'x'$ iteratively such that

$$F(x) = 0 \tag{7}$$

In the iterative process, say in m^{th} iteration $'x'$ is updated as given below

$$x^{m+1} = x^m - \Delta x \tag{8}$$

and $$\Delta x = -(J^m)^{-1} F(x^m) \tag{9}$$

where J^m is the Jacobian matrix.

The Quasi–Newton BSS method [14] belongs to the class of two step iteration which differentiates it from the conventional Broyden's method [15]. Let us consider the (1) which has to be solved iteratively using BSS method. In the first iteration x^0 is chosen as in the case of NR method, then w^0 is calculated as given below

$$w^0 = -(J^0)^{-1} F(x^0) \tag{10}$$

Using (10) v^0 is updated as

$$v^0 = x^0 + w^0 \tag{11}$$

this is the first step iteration. Using (11) s^0 is computed as

$$s^0 = -(J^0)^{-1} F(v^0) \tag{12}$$

Then with the value of s^0 and v^0, x^1 is updated using

$$x^1 = v^0 + (M - C.\left\|s^0\right\|^{\alpha})s^0 \tag{13}$$

which is the second step iteration. Here M, C and α are the real variables defined in [15], where the role of M is to increase the rate of convergence, C and α keeps the new iteration in the convergence region.

From the second iteration the above procedure is repeated by replacing the Jacobian matrix ‘ J ’ with an equivalent matrix ‘ A ’ which is defined at the mth iteration as given below

$$A^m = A^{(m-1)} + [\Delta F(x) - A^{m-1}(\Delta x)] \tag{14}$$

where

$$\Delta F(x) = F(x^m) - F(x^{m-1}) \tag{15}$$

$$\Delta x = x^m - x^{m-1} \tag{16}$$

This reduces the number of functional evaluations to ‘n’ from ‘n^2 + n’ when compared to the case of NR method but makes the convergence of BSS as super linear when compared to quadratic convergence of NR method.

Further in NR there are n^3 arithmetic operations for computing the inverse of A^m matrix. It can be reduced to n^2 operations in BSS method by using the Sherman Morrison formula as

$$(A^m)^{-1} = \frac{[A^{(m-1)}]^{-1} + U}{\Delta x^T [A^{m-1}]^{-1} \Delta F(x)} \tag{17}$$

Where

$$U = \{\Delta x - [A^{m-1}]^{-1} \Delta F(x)\} * \{\Delta x [A^{m-1}]^{-1}\} \tag{18}$$

In a normal power flow, the quadratic convergence and the implementation of sparsity technique in NR method proves to be superior to BSS method which has super linear convergence. When it comes to the problem of TPL minimization with FACTS using optimization algorithms, where power flow is solved repeatedly, which involves multiple Jacobian computations and inverses, in this process computation using BSS method is faster when compared to NR method.

The algorithm to minimize TPL with FACTS using the optimization algorithm is given below

Step 1: Read the population size, number of generations, power flow data etc.
Step 2: Initialize population.
Step 3: Set counter for number of generations.
Step 4: Set counter for number of individuals.
Step 5: From each individual obtain the values of settings and location of FACTS devices and incorporate these changes in the power flow data.
Step 6: Solve power flow using BSS method.
Step 7: Evaluate fitness using (1). Check whether fitness is evaluated for all individual If YES then GO TO *Step 8* else increment the counter for individuals and GO TO *Step 5*.
Step 8: Check for convergence or maximum generations reached. If YES then GO TO *Step 10* else GO TO *Step 9*.
Step 9: Perform operations on the individuals. Generate new populations. GO TO *Step 4*.
Step 10: Print the optimal values of decision variables and STOP.

5. RESULTS AND DISCUSSION

Comparison of the optimization methods DE, PSO and GA to minimize TPL in presence of FACTS device is presented in this section. The control parameter values [6] for all the optimization algorithms are given below

- DE: population=30, generations=300, differentiation factor randomly between=-1.5 to 1.5, crossover probability=0.95.
- PSO: population=30, generations=300, cognitive learning factor=2, cooperative factor=2, social learning factor=0.5, inertial constant=0.5 and number of neighbors=5.
- GA: real coded, population=30, generations=300, crossover probability=0.5, mutation probability=0.1.

Two different procedures for TPL evaluation are used, the conventional procedure with power flow using NR method with sparsity technique and the proposed method i.e. power flow using BSS method. The effectiveness of the proposed methodology is illustrated using the WSCC 9 bus, New England 39 bus and IEEE 118 bus test system. The power flow data for the test system are considered from [16]-[18]. The base MVA for the load flow is assumed to be 100. Only one TCSC and one SVC are considered for placement at a time. The limits X_{TCSC} of TCSC device is considered as -0.5X_L to +0.5X_L and Q_{SVC} of SVC device is -100 Mvar to +100 Mvar, where X_L is the reactance of the transmission line in which TCSC is installed. The values of M, C and α for BSS method [14] is taken as 2, 1 and 0.1 respectively for all the test system. Load flow programs are executed in MATLAB using modified MATPOWER [18] coding in INTEL core 2 Duo CPU T5500@ 1.66 GHz processor under Windows XP professional operating system.

5.1 WSCC 9 Bus test system

This test system consists of 3 generators and 9 transmission lines. The base load in the system is 335.33 MVA and the TPL without FACTS device is 4.954 MW.

Table 1. WSCC 9 bus system with FACTS device

Parameters		DE	PSO	GA
FACTS device	TCSC	Line 3-6	Line 3-6	Line 7-8
	SVC	Bus 9	Bus 9	Bus 9
CPU time (sec)	**NR**	**88.705**	**93.929**	**91.482**
	BSS	**86.052**	**92.198**	**89.559**
TPL (MW)		**4.7220**	**4.7220**	**4.7287**

The TPL with FACTS device using DE, PSO and GA is shown in Table 1. As shown in Table 1, for a given optimization method the value of TPL is same either with NR or with BSS method but the CPU time for BSS method is less when compared to NR method. Using DE or PSO the FACTS device SVC is placed at Bus 9 with Q_{svc}=46.85 Mvar and TCSC in line 3-6 with X_{tcsc}=0.5 p.u. hence the TPL is 4.722 MW which is 4.91 % less than the base TPL. Whereas using GA, SVC is placed at Bus 9 with Q_{svc}=46.85 Mvar and TCSC in line 7-8 with X_{tcsc}=-0.1 p.u and the TPL is 4.7287 MW which is only 4.78 % less than the base TPL value. From Table 1 it is also understood that the CPU time for DE (BSS method) is 7.14 % and 4.07 % less when compared to PSO (BSS method) and GA (BSS method) respectively.

5.2 New England 39 Bus test system

This test system consists of 10 generators and 46 transmission lines. The base load in the system is 6310 MVA and the TPL without FACTS device is 42.74MW.

Table 2. New England 39 bus system with FACTS device

Parameters		DE	PSO	GA
FACTS	TCSC	Line 26-27	Line 26-27	Line 26-27

device	SVC	Bus 15	Bus 15	Bus 8
CPU time (sec)	**NR**	**135.281**	**145.762**	**143.692**
	BSS	**122.456**	**128.301**	**126.74**
TPL (MW)		**41.823**	**41.823**	**41.842**

The TPL with FACTS device using DE, PSO and GA is shown in Table 2. As shown in Table 2, for a given optimization method the value of TPL is same either with NR or with BSS method but the CPU time for BSS method is less when compared to NR method. DE locates SVC at Bus 15 with Q_{svc} =100 Mvar and TCSC at line 26-27 with X_{tcsc}=-0.5 p.u. hence the TPL value is 41.823 MW which is 2.192 % less when compared to the base TPL value. PSO finds the same global optimal point similar to DE as shown in Table 2, but the CPU time for DE (BSS method) is 4.77 % less when compared to PSO (BSS method). Whereas using GA, SVC is placed at Bus 8 with Q_{svc} =100 Mvar and TCSC at line 26-27 with X_{tcsc}=-0.5 p.u. and the TPL is 41.842 MW which is only 2.146 % less than the base TPL value. Further from Table 2 it is evident that the CPU time for DE (BSS method) is 3.5 % less when compared to GA (BSS method).

5.3 IEEE 118 Bus test system

This test system consists of 54 generators and 186 transmission lines. The base load in the system is 4479.1 MVA and the TPL without FACTS device is 132.862 MW.

Table 3. IEEE 118 bus system with FACTS device

Parameters		DE	PSO	GA
FACTS device	TCSC	Line 38-65	Line 38-65	Line 38-65
	SVC	Bus 102	Bus 51	Bus 17
CPU time (sec)	**NR**	**460.96**	**493.67**	**484.06**
	BSS	**264.51**	**287.72**	**281.31**
TPL (MW)		**130.38**	**130.53**	**130.55**

The TPL with FACTS device using DE, PSO and GA is shown in Table 3. Using DE, SVC at Bus 102 with Q_{svc} =40 Mvar and TCSC at line 38-65 with X_{tcsc}=-0.5 p.u. are placed which gives a TPL value of 130.38 MW which is 2.192 % less when compared to the base TPL value. Similarly PSO places SVC at Bus 51 with Q_{svc} =17.85 Mvar and TCSC at line 38-65 with X_{tcsc}=-0.5 p.u hence with a TPL of 130.53 MW. Whereas using GA, SVC is placed at Bus 17 with Q_{svc} =-47.79 Mvar and TCSC at line 38-65 with X_{tcsc}=-0.5 p.u. with TPL as 130.55 MW. From Table 3 it is evident that DE fetches global optimal value when compared to PSO or GA. Further the CPU time of DE is 8.77 % and 6.35 % less when compared to the CPU times of PSO and GA respectively.

6. CONCLUSION

The overall comparison of DE, PSO and GA for the problem of TPL minimization using FACTS devices is presented. The comparison is done based on the location of FACTS devices in standard test systems such as WSCC 9 bus, New England 39 bus and IEEE 118 bus. Results indicate that with the placement of FACTS device using DE, PSO or GA there is a considerable reduction in TPL and the CPU time reduces when BSS method is used with the optimization algorithm when compared to NR method. In all the test systems considered DE outperforms PSO and GA in finding optimal value as well as in computational efficacy. Further the percentage reduction in CPU time using DE (BSS method) increases with the increase in size of power system.

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