Optimal placement of facts devices to reduce power system losses using evolutionary algorithm

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Article Info	ABSTRACT
	The rapid and enormous growths of the power electronics industries have made the flexible ac transmission system (FACTS) devices efficient and viable for utility application to increase power system operation controllability as well as flexibility. This research work presents the application of an evolutionary algorithm namely differential evolution (DE) approach to optimize the location and size of three main types of FACTS devices in order to minimize the power system losses as well as improving the network voltage profile. The utilized system has been reactively loaded beginning from the base to 150% and the system performance is analyzed with and without FACTS devices in order to confirm its importance within the power system. Thyristor controlled series capacitor (TCSC), unified power flow controller (UPFC) and static var compensator (SVC) are used in this research work to monitor the active and reactive power of the carried out system. The adopted algorithm has been examined on IEEE 30-bus test system. The obtained research findings are given with appropriate discussion and considered as quite encouraging that will be valuable in electrical grid restructuring.

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1. INTRODUCTION

Electricity production and distribution companies are undergoing a major transformation in the concept of electrical energy supply around the world. The change in the public market, the expansion of cities and the increasing demand for electricity in addition to the turmoil in the prices of natural resources are among the most important motives that make the companies looking for new technologies contribute to the best service to the consumers.

One of the technologies that have been used recently is the FACTS devices as an effective way to the further enhances in the capabilities of transmitting electrical energy without need to construction a new costly transmission lines [1-5]. The efficiency of current power transmission systems can be increased and made to operate with better reliability through the use of FASTS devices with flexible power flow. The flow of electrical power through an alternating current transmission line depends mainly on the line resistance, the size of the wires and the phase angle difference between the sending and receiving end of the transmission line [6]. Although adding FACTS devices with electric power transmission networks leads to additional flexibility of power flow, it leads to an increase in technological problems and adds new economic costs [7]. In recent years, many scientific studies and research have emerged discussing possible solutions to find the best use of the FACTS devises.

Choosing the best location in the electric power transmission network and modeling the possible solutions for installing FACTS devices has been discussed in [8]. In power systems suffering from congestion due to overloads, the site of FACTS devices are determined based on factors considered to be more sensitive and according to the nature of the load by solving the transmission problem In [9]. In [10], artificial intelligence methods of genetic algorithm were used to find the best place to install four types of FACTS devices-TCSC, UPFC, thyristor controlled voltage regulator (TCVR) and SVC. Various problems of improving the electrical power transmission systems are addressed by reducing system losses, improving line voltages, as well as increasing power transmission capacity using the particle swarm optimization (PSO) application is addressed in [11]. In [12] the main objective of the research was the economic cost of integrating the FACTS devices with the power transmission systems.

Annealing simulation to control the economic cost of power flow has been studied in [13]. Where the performance of the power transmission system was coupled without the use of FACTS devices and after adding several types of them, where the active power is controlled using a decoder to find the best location. The main objective behind this study is to reduce the losses and improve the voltage profile of the electrical power distribution system by finding the optimal location and sizing for three types of FACTS devices using one of the artificial intelligence (AI) techniques called (DE). In the Section 2, a brief overview of the FACTS devices techniques and types is presented. In the Section 3, the basic principles of the DE optimizing method is reviewed. In the Section 4, the methodology that used in this study is presented. In the Section 5, the results are collected. Finally, the results in the Section 6 are analyzed and discussed.

2. FACTS DEVICES

The use of FACTS devices has become common in modern electric power transmission and distribution systems to improve the stability and reliability of networks, in addition to increasing the fixed limits of transmission lines, which are often either thermal or insulated limits [14]. Basically, there are three main types of FACTS devices depending on the way of connection with the power transmission networks, which are series controllers, shunt controllers, combined series-shunt controller as shown in Figure 1 [15]. The serial controllers are injection of the series voltage at the connection point to deal with cases of the disturbance voltages Figure 1(a). In the shunt controllers, the electrical current is injected to the network through the contact point Figure 1(b) while the electric current is injected into the network by the shunt portion of the controllers and the series voltage is injected by the serial portion in the combined controller Figure 1(c) [16].

According to these classifications, there are many FACTS devices that are similar in their principle of work and differ in their design technique. In this study, three main types were used [17]:
a) TCSC (Thyristor controlled series capacitor). This type of device is used to increase line limits to transmit electrical power and to control the line overloads.
b) SVC (Static var compensator). This type of FACTS device is often used to compensate the low voltage of the line by injecting a reactive power directly or indirectly into the line contact bus.
c) UPFC (Unified power flow controller). This type is used to control and increase the power flow of the system and support system voltage profile.
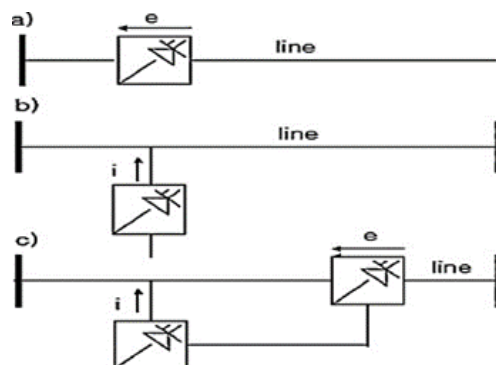

Figure 1. The basic patterns of FACTS devices, (a) series controller (b) shunt controller (c) combined series-shunt controller

3. DIFFERENTIAL EVOLUTION TECHNIQUE

Differential evolution technique (DE) is one of the evolutionary computation methods which has been utilized in many fields of engineering sciences. DE depends on stochastic real parameter optimization algorithms [18]. Practically, DE was applied in the operations of optimization by R. Storn and K. V. Price in 1995 to solve nonlinear, non-differentiable and multimodal objective functions. Furthermore, DE is characterized by its need for a less stochastic approach and uses rather a greedy selection than other classical evolution algorithms (EAs) to solve optimization problems. DE works through a simple cycle of stages that are presented in Figure 2 [19].
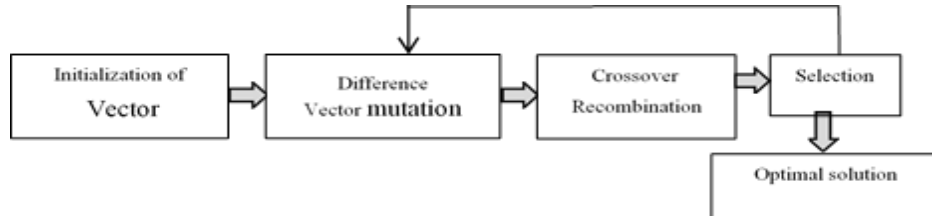

Figure 2. Cycle stages of the DE optimization method

DE method is a parallel direct search algorithm that uses size of the population (NP) and floating point for each individual solution as candidate solutions as in (1).

$$P^{(G)} = [X_1^{(G)}, \dots, X_i^{(G)}, \dots X_{NP}^{(G)}] \tag{1}$$

During the optimization process, the DE method maintains the population P $^{(G)}$ for each generation (NP) vector for each candidate solution (X_i) of the problem. The vector (X_i) is an integer-value of D-dimensional vector that depends on decision parameters (D) of the problem as given in (2).

$$X_i^{(G)} = \left[X_{1.i}^{(G)}, \dots, X_{j,i}^{(G)}, \dots, X_{D.i}^{(G)}\right], i = 1, \dots, N_p, j = 1, \dots, D \tag{2}$$

In recent years, DE methods have been widely used as a powerful tool in the field of optimization where it has many advantages like, straightforwardness and simplicity in application, speed in performance, contains fewer parameters and low complexity of search space. All these features have made the DE method one of the best and most popular methods [20].

4. THE PROPOSED APPROACH

To achieve the main objective of this study that is reduced system losses after adding the FACTS devices in suitable locations within a power system, the system considerations must be given at acceptable and desirable limits of voltage, active and reactive power of the entire power system [21]. These limits are considered as inequality constraints of the work as shown below:

$$P_{ni}^{min} \leq P_{ni} \leq P_{ni}^{max} \tag{3}$$

$$Q_{ni}^{min} \leq Q_{ni} \leq Q_{ni}^{max} \tag{4}$$

Where: P_{ni}, Q_{ni} and V_i assigned to active, reactive generated power and bus voltage magnitude respectively. P_{ni}^{min}, P_{ni}^{max} are min and max active power generated. Q_{ni}^{min}, Q_{ni}^{max} are min and max reactive power generated. V_i^{min}, V_i^{max} are min and max voltage limits at bus (*i*). When UPFC devices are integrated with the system, the series voltages are injected into the contact point at a maximum limit of (0.1)V max. Vmax is the maximum transmission line voltage, while the operating range belong to the angle is from -180° to +180°. TCSCs act as the load inductive or capacitive compensator by controlling the line reactance. The maximum capacitance magnitude is ranged at (-0.8 to 0.2) X_L, and X_L is considered as the line reactance [22].

SVC can be worked within the system as either inductive or capacitive compensation. Consequently, it can be designed with two parallel perfect switched elements; capacitive and inductive [23]. The steps that have been adopted after the observance of the limits mentioned above in this research are as following:

Step 1: Calculate the active and reactive power of the test system in the base case, and determine the total power losses and voltage profiles.
Step 2: Determine the test system lines that have the highest active and reactive power as a candidate location to install the different types of FACTS devices.
Step 3: Apply the DE optimizing method for all candidate buses to detect the best size of FACTS devices and calculate the test system losses.
Step 4: Repeat the above steps after increasing the total load of the system by 100%, 125% and 150% from base case.

5. RESULTS AND DISCUSSION
5.1. The optimal location

In this study, the candidate locations for installing the FACTS devices are initially determined by evaluating the active and reactive power flowing in each line within the adopted IEEE 30 bus test system. The overall system load is increased to 150% from the base case in the same proportion for all buses. The overload is met by the generator connected to the slack bus. Table 1 illustrates the active and reactive power flow pattern excluding the FACTS devices. The work results were obtained using newton raphson method [24].

Table 1. Active and reactive power of the test system without FACTS devices

Line no.	Bus-bus	Base Case		Loading 100%		Loading 125%		Loading 150%	
		P	Q	P	Q	P	Q	P	Q
1	1-2	0.902	0.013	0.905	0.014	0.907	0.015	0.908	0.017
2	1-3	0.477	-0.003	0.479	-0.002	0.480	-0.002	0.484	-0.019
3	2-4	0.288	-0.058	0.290	-0.051	0.291	-0.047	0.292	-0.043
4	3-6	0.446	-0.027	0.446	-0.025	0.448	-0.024	0.451	-0.021
5	2-5	0.158	0.029	0.160	0.031	0.163	0.035	0.165	0.039
6	2-6	0.378	-0.051	0.380	-0.049	0.381	-0.047	0.383	-0.046
7	4-6	0.392	0.024	0.394	0.026	0.395	0.028	0.396	0.030
8	5-7	-0.130	0.029	-0.128	0.031	-0.126	0.034	-0.123	0.037
9	6-7	0.363	0.033	0.365	0.035	0.367	0.037	0.369	0.039
10	6-8	-0.027	0.013	-0.024	0.015	-0.023	0.017	-0.021	0.021
11	6-9	0.151	-0.110	0.154	-0.108	0.156	-0.105	0.159	-0.102
12	6-10	0.114	-0.031	0.117	-0.028	0.119	-0.024	0.123	-0.019
13	9-11	-0.179	-0.225	-0.175	-0.222	-0.172	-0.219	-0.169	-0.216
14	9-10	0.325	0.031	0.329	0.034	0.332	0.041	0.337	0. 044
15	4-12	0.268	-0.068	0.271	-0.065	0.274	-0.061	0.276	-0.057
16	12-13	-0.169	-0.301	-0.166	-0.298	-0.164	-0.295	-0.160	-0.293
17	12-14	0.076	0.019	0.079	0.023	0.082	0.027	0.085	0.030
18	12-15	0.175	0.041	0.178	0.045	0.179	0.048	0.183	0. 051
19	12-16	0.067	0.016	0.070	0.019	0.073	0.023	0.076	0.027
20	14-15	0.014	0.002	0.018	0.007	0.022	0.009	0.026	0.012
21	16-17	0.031	-0.042	0.034	-0.038	0.037	-0.035	0.040	-0.032
22	15-18	0.056	0.009	0.059	0.011	0.063	0.015	0.067	0.019
23	18-19	0.024	-0.010	0.027	-0.080	0.031	-0.004	0.036	-0.001
24	19-20	-0.070	-0.034	-0.068	-0.031	-0.065	-0.028	-0.061	-0.023
25	10-20	0.093	0.044	0.097	0.047	0.103	0.049	0.107	0.053
26	10-17	0.058	0.037	0.061	0.039	0.067	0.043	0.064	0.046
27	10-21	0.160	0.033	0.164	0.037	0.168	0.039	0.172	0.043
28	10-22	0.078	0.021	0.082	0.024	0.085	0.029	0.089	0.034
29	21-22	0.015	-0.020	0.018	-0.017	0.022	-0.014	0.026	-0.011
30	15-23	0.048	0.014	0.052	0.018	0.057	0.021	0.059	0.026
31	22-24	0.062	0.020	0.065	0.025	0.068	0.027	0.071	0.030
32	23-24	0.016	-0.001	0.019	-0.000	0.023	0.004	0.027	0.007
33	24-25	-0.009	-0.007	-0.005	-0.005	-0.003	-0.001	-0.001	0.001
34	25-26	0.035	0.022	0.039	0.027	0.043	0.029	0.047	0.033
35	25-27	-0.044	-0.031	-0.040	-0.028	-0.037	-0.024	-0.032	-0.025
36	28-27	0.163	-0.038	0.167	-0.034	0.172	-0.029	0.175	-0.024
37	27-29	0.061	0.015	0.067	0.012	0.073	0.009	0.075	0.005
38	27-30	0.070	0.016	0.073	0.020	0.077	0.023	0.080	0.025
39	29-30	0.037	0.006	0.040	0.009	0.042	0.012	0.045	0.019
40	8-28	0.042	0. 008	0.047	0. 011	0.049	0.017	0.053	0.023
41	6-28	0.135	0.052	0.139	0.057	0.142	0.060	0.145	0.064

As is evident, the active power which is flowing in the lines 6, 7 and 4 is considered as very high, where these lines are connected between the buses (2,6), (4,6) and (3,6) respectively. Thus, these lines are identified as a candidate location to install UPFC devices. The lines 41, 25 and 18 have also been found to carry large reactive power flow, so they are identified as a candidate sites for installing TCSC devices since these are the top three reactive energy carriers. Finally, lines 27, 26 and 9 were found to have the highest, second and third highest reactive power flow in the test system respectively. Hence, the buses 17, 7 and 21which represent the end of the lines above are considered as the selective buses to install SVC devices where injection of reactive power in these buses can led to improve the system performance. Table 2 shows the candidate lines and buses for installing various types of FACTS devices.

Table 2. Location of different FACTS devices in the30 bus test system

Type of FACTS	Candidate position		
	1st position	2nd position	3ed position
TCSC	Line 41 (6-28)	Line 25 (10-20)	Line 18 (12-15)
UPFC	Line 6 (2-6)	Line 7 (4-6)	Line 4 (3-4)
SVC	Bus 17	Bus 7	Bus 21

5.2. The optimum size

The DE optimization method is applied to determine the optimum value of the various FACTS devices after they are installed on the candidate sites and then calculate the total power losses of the IEEE 30 Bus test system. IEEE 30-bus system consists of 6 generating units and 41 transmission lines. The total real power losses of base case when the system operates without FACTS devices is 17.5280 MW and the reactive power losses is attained at 68.8881MVar [25]. The DE technique is accomplished with several parameters that assigned in Table 3.

Table 4 shows the active and reactive power losses of the test system with UPFC devices in the candidate buses. It is clear that; line 4 (between buses 3-4) is the optimum location for UPFS devise with optimal sizing 9.854 MW. The total power losses of the system became 15.755, 16.198 and 16.743MW with % decreasing, while, reactive power losses become 61.227, 62.516 and 62.854 MVar when the test system is loaded 100%, 125% and 150% respectively. In Table 5, the results of the candidate lines power losses with TCSC devises are tabulated. Line 41 (between buses 6-28) is considered as the optimal location of TCSC with 9,640 MW size. The total real power losses becomes 15.531, 15.764 and 15.934 MW and the reactive power losses are 63.560, 63.865 and 64.706 MVar with increasing of the system load respectively. From Table 6, bus 21 is selected as the optimal location to install SVC device with optimum size is 9,720 MW. The overall active and reactive power losses of test system are 14.897, 15.674 and 15.864 MW and 62.015, 63.278 and 64.214 MVar respectively with different loaded.

Table 3. Parameters of the DE method

Differential evolution parameters	
Variable Size D*5	15
Maximum Generation (Gen max)	100
Crossover Probability (Ωc)	0.9
Mutation probability (Ωm)	0.2
Initial size range	0-10

Table 4. Total power losses of 30 bus system with UPFC device with different loading

UPFC Location	UPFC Size	Total losses Loading 100%		Total losses Loading 125%		Total losses Loading 150%	
	MW	MW	MVar	MW	MVar	MW	MVar
Line 6 (2-6)	9.8624	15.817	61.457	16.201	62.544	16.761	62.874
Line 7 (4-6)	9.7851	15.921	61.389	16.311	62.672	16.788	62.911
Line 4 (3-4)	9.8546	15.755	61.227	16.198	62.516	16.743	62.854

Table 5. Total power losses of 30 bus system with TCSC device with different loading

TCSC Location	TCSC Size	Total losses Loading 100%		Total losses Loading 125%		Total losses Loading 150%	
	MW	MW	MVar	MW	MVar	MW	MVar
Line 41 (6-28)	9.640	15.531	63.560	15.764	63.865	15.934	64.706
Line 25 (10-20)	9.476	15.592	63.578	15.772	63.893	16.247	64.844
Line 18 (12-15)	9.600	15.603	63.564	15.816	64.101	16.312	64.937

Table 6. Total power losses of 30 bus system with SVC device with deferent loading

SVC Location	SVC Size MW	Total losses Loading 100%		Total losses Loading 125%		Total losses Loading 150%	
		MW	MVar	MW	MVar	MW	MVar
Bus 17	9.632	15.756	62.456	15.954	63.475	16.018	63.871
Bus 7	9.648	15.369	62.315	15.841	63.435	15.971	63.977
Bus 21	9.720	14.897	62.015	15.674	63.278	15.864	64.214

The voltage profile of the whole test system has improved significantly after adding different types of FACTS devices as shown in Figure 3. It is clear; SVC achieves the greatest improvement in the level of voltages with deferent buses.
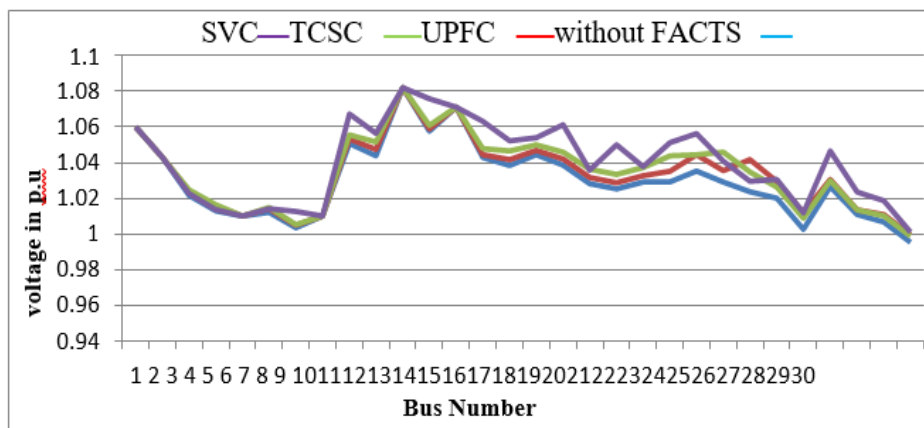

Figure 3. Comparison of voltage profiles with different FACTS devices

6. CONCLUSION

Recent studies have proven the importance of using FACTS devices within power networks to improve the performance and efficiency of electric power transmission networks. In this research, the addition of UPFC at the optimal location has led to a decrease in the system losses by percentage of 0.015%, 0.010% and 0.005% with different loading criteria. When installing the TCSC device in the line 44, the system losses are decreased by 0.017 %, 0.015% and 0.013%, while the bus 21 is the best place to install the SVC device in the test system, with reduced losses of 0.023%, 0.015% and 0.014%.

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