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FACTS Devices Allocation Using a Novel Dedicated Improved PSO for Optimal Operation of Power System

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ABSTRACT

Flexible AC Transmission Systems (FACTS) controllers with its ability to directly control the power flow can offer great opportunities in modern power system, allowing better and safer operation of transmission network. In this paper, in order to find type, size and location of FACTS devices in a power system a Dedicated Improved Particle Swarm Optimization (DIPSO) algorithm is developed for decreasing the overall costs of power generation and maximizing of profit. Thyristor-Controlled Series Capacitor (TCSC) and Static VAr compensator (SVC) are two types of FACTS devices that are considered to be installed in power network. The purpose of this study is reducing the power generation costs and the costs of FACTS devices with considering different load levels. The main bases of this paper are using of Optimal Power Flow (OPF) and DIPSO algorithm to techno-economical analysis of the system for finding optimal operation. The Net Present Value (NPV) method is used to economic analysis of the system and power losses and maximum possibility load demand are considered for technical analysis. The proposed method is implemented on IEEE 57-bus test system and the achieved results are compared with genetic algorithm and particle swarm optimization methods to illustrate its effectiveness.

KEYWORDS: Dedicated Improved PSO, FACTs Allocation, NPV Index, Techno-economical Analysis, OPF.

1. INTRODUCTION

Recently, the electric power industry is changing to be more competitive. In this new environment, economical and technical operation of the power system is more important [1]. To achieve economic goals need to reduce power system operating costs.

FACTS devices are a recent technological development in electrical power systems [2] which are introduced by Electric Power Research Institute (EPRI) in 1980 [3]. These devices are subset of power electronic that can improve dynamic and static behavior of power system. Static VAr Compensator (SVC) and Thyristor-Controlled Series Capacitor (TCSC) are the most common elements of FACTS devices that inserted in series and parallel with the transmission line in power network, respectively [4]. In the last two decades, several researches have been done exploring FACTS impacts on the optimal operation of the power network. In these researches installation location, size and type of needed FACTS devices are determined by applying different methods for different reasons. In [5] by using of reactive power spot price index for contingency, an optimal allocation method for SVC has been reported. Meta-heuristic techniques such as Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) have been used to find optimal locations of FACTS devices in order to minimize installation cost and improve system load ability in [6] and [7], respectively. In [8], FACTS devices are optimally placed in 39-bus IEEE test network to reduce the costs of power generation by using of generation algorithm.

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Wibowo et al. [9] represented an optimal allocation method for FACTS devices by using of a two level hybrid PSO/SQP method for market-base power systems considering congestion relief and voltage stability. In [10], GAMS software used to find the location of installation of FACTS devices for reduction of operation cost, whereas load of system is constant. Mathematical modeling and sensitivity analysis had been reported in [11] to determine the TCSC location and its size. The results show that TCSC was comparably increased transmission capacity of the lines.

In this paper, FACTS devices are optimally placed by using of a hybrid Dedicated Improved PSO (DIPSO) algorithm and Optimal Power Flow (OPF) approach. The TCSC and SVC are two types of FACTS devices that are considered to install in power network to reduce power system generation costs and maximize operation economic profit. Thus, FACTS devices placement is formulated as an optimization problem for a wide range of load level in power network and it is solved using hybrid OPF and DIPSO methods. The allocation task, is based on cost function that includes the cost of both generated active and reactive power, cost of FACTS device, the cost of installation and annual maintenance. The annual Load Duration Curve (LDC) is considered to find a robust solution for a wide range of operating conditions.

It should be noted that the performance of the classical PSO greatly depends on its parameters adjustments, and it often suffers the problem of being trapped in the local optima so as to be premature convergence. Thus, some modification has been proposed for the classical PSO algorithm to improve its performance. The PSO with Time-Varying Acceleration Coefficients (PSO-TVAC) [12] is one the best technique for effectively improvements of the classical PSO performance in terms of robustness to control parameters and computational effort. All algorithm parameters including inertia weight and acceleration coefficients are varied with iterations to efficiently control the local search and convergence to the global optimum solution. Thus, in this paper, the idea of the PSO-TVAC optimizer is being used for the performance improvement of the proposed DIPSO algorithm to achieve desired level of techno-economical contribution of FACTs device in power system operation.

After placing of FACTS devices by the proposed method, techno-economic effects of TCSC and SVC on power network operation are studied. The Net Present Value (NPV) method is used to economic analysis of results and power losses and maximum possibility load demand are considered to technical analysis. The effectiveness of the proposed method is tested on the IEEE 57-bus system to illustrate optimal operation of the power system. Also, to demonstrate the efficiency of the proposed method, the results is compared with obtained results of GA and classic PSO methods. The simulation results show that the proposed approach is efficient for determining type, size and location of FACTS devices in the power network and is superior to the GA and PSO algorithms. The rest of the paper is documented in the following headings. Dedicated improved PSO algorithm and method of investment analysis are explained in Secs. 2 and 3, respectively. Then the modeling of problem has been done in Sec. 4 and in Sec. 5 the allocation processing is developed. Section 6 provides the test network. Then the simulation results of the proposed method are presented in Sec. 7. Conclusion remarks have been focused in end section.

2. DEDICATED IMPROVED PSO

Particle swarm optimization is a population based, self-adaptive search optimization technique first introduced by Kennedy and Eberhart [13] in 1995. The simulation of simplified animal social behaviors such as fish schooling, bird flocking, etc was base of the motivation for the development of this method. The PSO method is becoming very popular due to its simplicity of implementation and ability to quickly converge to a reasonably good solution. In classical PSO, position vector and the velocity vector of the *i*th particle in the *d*-dimensional search space can be represented as $X_i = (x_{i1}, x_{i2}, x_{i3}, ..., x_{id})$ and $V_i = (v_{i1}, v_{i2}, v_{i3}, ..., v_{id})$, respectively. During a search in PSO all particles keep their personal best positions, $P_i = (p_{i1}, p_{i2}, p_{i3}, ..., p_{id})$ and their global best position, $P_{gb} = (p_{gb_1}, p_{gb_2}, p_{gb_3}, ..., p_{gb_d})$. Then, in the *t*th iteration, the velocities and the positions of the particles for the next fitness evaluation are updated using the following two equations:

$$V_i^{t+1} = W\,V_i^t + c_1.rand_1.(P_i - X_i^t) + c_2.rand_2.(P_{gb} - X_i^t) \quad (1)$$

$$X_i^{t+1} = X_i^t + V_i^t \quad (2)$$

where, c_1 and c_2 are constants known as acceleration coefficients, and $rand_1$ and $rand_2$ are two separately generated uniformly distributed random numbers in the range [0, 1]. The velocity and position of each individual particle must be in a certain limitations that these limitations determined according to (3) and (4), respectively.

$$X_i^{min} < X_i < X_i^{max} \quad (i = 1, 2, ..., N) \quad (3)$$

$$V_i^{min} < V_i < V_i^{max} \quad (i = 1, 2, ..., N) \quad (4)$$

In this study, a dedicated improved PSO algorithm that the population of this special PSO is consists of particles with binary, continuous and discrete parameters are proposed according to Fig. 1. In the proposed algorithm each parameters of a particle with respect to its type (continuous, binary or discrete) will be updated by using of the following methods.

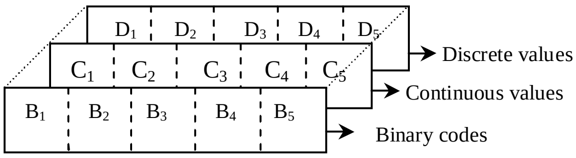

Fig. 1. Different section of each individual particle

2.1. Continues PSO with Time-Varying Acceleration Coefficients (CPSO-TVAC)

CPSO-TVAC is extended from PSO. In the PSO, proper control of the two stochastic acceleration components: the *cognitive* component (c_1) which corresponds to the personal thinking of each particle and the *social* component (c_2) which describes the collaborative effect of the particles, to obtain the global optimal solution is very important accurately and successfully. It should be noted that it is desirable that for cheering the particles to wander through the entire search space, without clustering around local optima during the early stages of the swarm-based optimization. On the other hand, in order to find the optimal solution effectively it is very important to enhancement convergence toward the global optima during the latter processes [12]. Thus, a novel parameter automation strategy for the PSO concept called PSO with time varying acceleration coefficients is considered, in this study. The motivation for using this method is enhancement the global search in the early stage of the optimization stages and cheering the particles to converge toward the global optima at the end of it. Thus, all coefficients including inertia weight and acceleration coefficients are varied with iterations [12]. The velocity updating equation of CPSO-TVAC can be expressed as:

$$V_i^{t+1} = C.\{W\,V_i^t + \left((c_{1f} - c_{1i})\frac{t}{t_{max}} + c_{1i}\right).rand_1.(P_i - X_i^t) + \left((c_{2f} - c_{2i})\frac{t}{t_{max}} + c_{2i}\right).rand_2.(P_{gb} - X_i^t)\} \quad (5)$$

$$\omega = (\omega_{max} - \omega_{min}).\frac{(t_{max} - t)}{t_{max}} + \omega_{min} \quad (6)$$

$$C = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}, \quad 4.1 < \varphi < 4.2 \quad (7)$$

Under this situation, the inertia weight, ω, is linearly decreasing as time grows based on the equation as given in (5) and by changing the acceleration coefficients with time the cognitive component is reduced and the social component is increased [12]. The large and small value for cognitive and social component at the optimization process starting is permitted the particles to move around the search space, instead of moving toward the population best. In contrast, using a small and large cognitive and social component, respectively the particles are permitted to converge toward the global optima in the latter part of the optimization. Thus, CPSO-TVAC is easier to understand and implement and its parameters have more straightforward effects on the optimization performance in comparison with classic PSO.

Using the above concepts, the whole PSO-TVAC algorithm can be described as follows:

1. For each particle, the position and velocity vectors will be randomly initialized with the same size as the problem dimension within their allowable ranges.
2. Evaluate the fitness of each particle (P_{best}) and store the particle with the best fitness (G_{best}) value.
3. Update velocity and position vectors according to (5) and (2) for each particle.
4. Repeat steps 2 and 3 until a termination criterion is satisfied.

The main features of the PSO-TVAC algorithm are robustness to control parameters, easy implementation and high quality solutions. Also, it conducts both global search and local search in each iteration process, and as a result the probability of finding the optimal global solution is significantly increased. Thus, it has a flexible and well-balanced mechanism to enhance the global and local exploration abilities than the classical PSO one and other heuristic techniques.

2.2. Binary PSO with TVAC (BPSO-TVAC)

To tackle the binary optimization problems, Kennedy and Eberhart proposed the BPSO algorithm, where the particles take the values of binary vectors of length d and the velocity defined the probability of bit X_i to take the value 1 reserved the updating formula of the velocity (see (1)), while velocity was constrained to the interval [0, 1] by a limiting transformation function $S(v)$ [14]. Then the particle changes its bit value by (8-9) as follows:

$$sigmoid(V_i^{t+1}) = 1/(1+e^{-V_i^{t+1}}) \tag{8}$$

$$X_i^{t+1} = \begin{cases} 1, if \ \ rand < sigmoid(V_i^{t+1}) \\ 0, \qquad otherwise \end{cases} \tag{9}$$

In the BPSO-TVAC the velocity is updated according to (5) and then by calculating *sigmond(V)* using (8) the position is updated due to (9).

2.3. Discrete PSO with TVAC (DPSO-TVAC)

In discrete PSO with time-varying acceleration coefficients the parameters of each individual particle have a discrete value and the velocity updating equation can be expressed as:

$$V_i^{t+1} = \mathrm{fix}(C.\{\omega V_i^t + \left((c_{1f}-c_{1i})\frac{t}{t_{max}}+c_{1i}\right).rand_1.(P_i - X_i^t) + \left((c_{2f}-c_{2i})\frac{t}{t_{max}}+c_{2i}\right).rand_2.(P_{gb} - X_i^t)\}) \tag{10}$$

After updating the parameters, the parameters limits are checked and then the personal best positions particles and global best position of population following their finesses are updated. If the solution of the proposed algorithm get be convergent, the optimization has ended otherwise population will be update again.

3. INVESTMENT ANALYSIS

A suitable analysis method of the investment in FACTS devices must include the initial investment, the reduction in the generation cost resulting from the installation of FACTS devices (in this paper FACTS devices are TCSC and SVC), the operating and maintenance expenses and the economic life of the investment.

In this study, net present value method, which takes all cash flows during the lifetime of a project into account. The NPV method converts future costs and revenues to today’s values to allow comparison to internal cash cost, or required rate of return. A positive number indicates that the project will have a positive return [15]. The NPV can be calculated as:

$$NPV = (\sum_{t=1}^{T}\frac{CF_t}{(1+r)^t}) - CF_0 \tag{11}$$

where, T is the total period of the project (in years), CF_t is the net cash flow at time t, CF_0 is the initial investment and r is the discount rate. In this study, the discount rate is set to r = 10%, operating and the economic life of devices is 20 years, although many utility assets arguable have useful lifetime of 40-50 years [16].

The considered cash flows in the NPV method include:

Initial investment and maintenance on the negative side and the saving in the generation costs on the positive side.

The discount rate, *r*, on the capital investment has to be carefully chosen since the increase in the discount rate results in reduction of NPV value.

FACTS devices typically require a large initial capital outlay, however they could provide years of support with only reasonably small maintenance cost over their lifetime.

4. MODELLING OF PROBLEM

In order to placement of FACTS devices in power network, the mathematical models of this devices should be appoint in the steady state condition for using in optimal power flow programming. Moreover, the purpose of FACTS devices installation in power system and the operational constraint of power network must be set.

4.1. Steady state model of FACTS devices

The FACTS devices that used in this study are TCSC and SVC that respectively inserted in series and parallel with the transmission line in power system.

a) Modelling Of TCSC

TCSC composed of a series and parallel branches that respectively are included a capacitive bank and inductive bank. LC circuit impedance is varied by changing the firing angle of thyristors. It is provided to impedance control, power oscillation damping and power flow control by using of TCSC. As shown in Fig. 2, the TCSC has been represented by a variable capacitive/inductive reactance inserted in series with the transmission line [17]. So, the reactance of the transmission line is adjusted by TCSC directly.

Let, Z_{new} is the new impedance of the transmission line after placing TCSC between bus *m* and *n*, X_{LINE} is the reactance of the line, R_{LINE} is the resistance of the line and X_{TCSC} the reactance of TCSC. Mathematically, the effective impedance of the transmission line with TCSC is given by:

$$\begin{aligned} Z_{\text{new}} &= R_{\text{Line}} + j(X_{\text{Line}} + X_{TCSC}) \\ &= R_{\text{Line}} + jX_{\text{Line}}(1+k) \end{aligned} \quad (12)$$

where, k is the ratio of X_{TCSC} to X_{Line} that calculated as follows:

$$k = \frac{X_{TCSC}}{X_{Line}} \qquad -1 < k < 1 \quad (13)$$

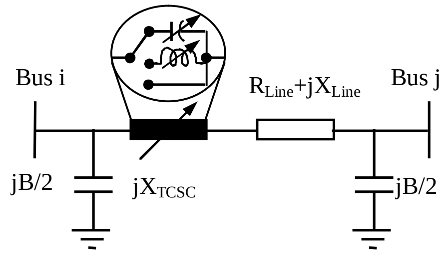

Fig. 2. TCSC steady state model

In this study, the minimum value of X_{TCSC} was set at -80% of the line reactance while the maximum value of X_{TCSC} was fixed at 20% of the line reactance.

b) Modelling Of SVC

The SVC is one of the useful shunt connected FACTS devices. It has the ability to generate or absorb reactive power at the point (bus) of connection. In this study, it is modeled as a variable susceptance that can generate 80 MVAr (capacitive mode) or absorb 80 MVAr (inductive mode) at rated voltage (1.0 p.u.) at the bus of interest. Figure 3 shows the steady state model of the SVC [18].

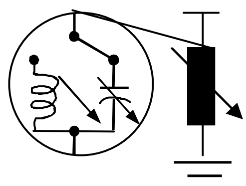

Fig. 3. SVC steady state model

Mathematically, it can be written:

$$Q_{\text{SVC}} - V_{\text{k}}^{2} B_{\text{e}} = 0 \quad (14)$$

$$B_{\text{e}} = 1 / X_{\text{e}} \quad (15)$$

4.2. Cost functions

The cost function considered here minimizes the generation cost while taking into consideration the cost of FACTS devices. The considered cost function is:

$$OF_C = \min(\sum_{k=1}^{OC}\sum_{i=1}^{n}(C_{P_i} + C_{Q_i}) + \sum_{j=1}^{m} C_{FACTS_i}) \quad (16)$$

where C_P, C_Q and C_{FACTS} are the costs of active and reactive power productions and the cost of allocated FACTS devices, respectively. The indices *n*, *m* and *OC* are the number of the generators and allocated FACTS devices and number of considered operating conditions, respectively.

The cost of the active power output of the generators calculated as follows:

$$C_P = \alpha_2 P^2 + \alpha_1 P + \alpha_0 \quad (\$/h) \quad (17)$$

The cost of the reactive power output of the generators is:

$$C_Q = \beta_1 Q + \beta_0 \quad (\$/h) \quad (18)$$

with $\beta_1 = 0.01\alpha_1$ and $\beta_0 = 0.1\alpha_0$ [19].

The cost of TCSC and SVC, respectively are [20]:

$$C_{TCSC} = 0.0015S^2 - 0.713S + 153.75 \text{ (\$/kVAr)} \quad (19)$$

$$C_{SVC} = 0.0003S^2 - 0.305S + 127.38 \text{ (\$/kVAr)} \quad (20)$$

where *S* is the size of the FACTS devices in MVAr. Since the power generation costs are given in \$/h and that requires the cost of FACTS devices to be converted to same units. The economic life of FACTS devices assumed 10 years and that they operate 24 *h*, 365 days per year. Thus, in order to get hourly cost, the total cost is divided by 20×365×24=175200 *h*.

4.3. Penalty function

Penalty functions are considered to prevent the placement more than of a device in a branch or in a bus. In this paper, it is considered for the following problem:

- Placement two TCSC in a same line
- Placement two SVC in a same bus
- Placement SVC in the generators bus

The penalty function increases the cost function and discards such solution from further consideration.

5. ALLOCTION PROCESSING

The bases of the proposed method for FACTS devices placement are using of the OPF and dedicated improved PSO optimization procedure to solve the allocation task. In addition, different load levels during a year and different operating constraints of the power network has been considered.

5.1. OPF

The major goal of a generic OPF is to minimize the costs of meeting the load demand for a power system while maintaining the security of the system [21]. In this study, in order to find maximum possibility demand power in a test network, the OPF run repeatedly with a gradual increase in the network loading factor, until it did not converge. The original loading factor of the network is one. The non-convergence is a consequence of the violation of one or more network constraints such as thermal limits of the lines, voltage limits of the buses, etc. For running OPF, the MATPOWER toolbox is used.

5.2. Allocation of FACTS devices

Due to the importance of finding the exact location, size and type of FACTS devices for power system operation, in this paper the combination of continuous, binary and discrete PSO-TVAC technique is proposed. For generation of initial population in DIPSO algorithm each particle consist of three independent section such that the number parameters of each section is equal with maximum possibility the number of FACTS devices that can be installed in power network. Here, the maximum possibility number of each FACTS devices and its type is considered 5 and 2, respectively. As a result, the parameters number of each section is 10. The different section of each individual particle for each type of FACTS devices is shown in Fig. 4.

The first section parameters of the each individual particle are continuous values that determine the size of FACTS devices. The second section parameters of each individual particle determine installation location of FACTS devices. Here, the locations that TCSC and SVC can be installing are 80 lines and 50 buses, respectively. The parameters of third section of each individual particle are binary codes that they determine the need or lack of need for any FACTS devices.

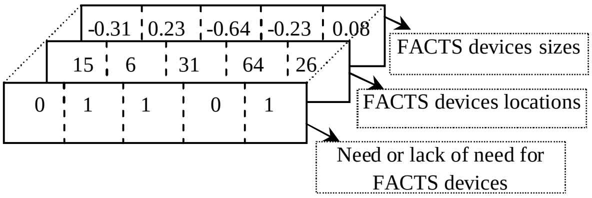

Fig. 4. Different section of each individual particle

5.3. Load duration curve

To ensure the efficiency of the proposed method, the Load Duration Curve (LDC) as shown in Fig. 5 is considered [22].

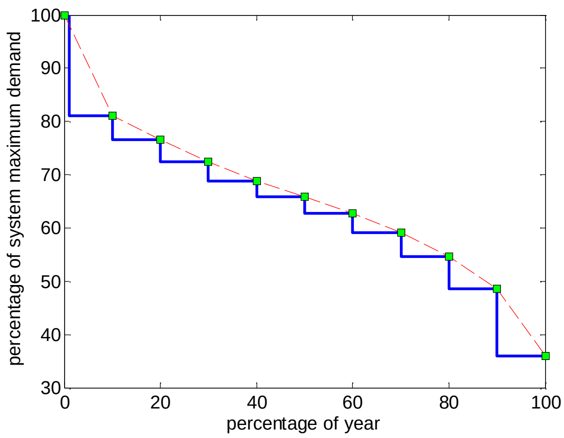

Fig. 5. Load duration curve

The vertical axis of this curve is consist of 11 load level that will start at 100% of the system maximum possibility load demand coming down to the minimum one as shown in Table 1. The horizontal axis shows percentage of year. Network constraints delineate the maximum possibility demand.

The FACTS devices placement procedure is explained in OPF section. Flowchart of the proposed DIPSO algorithm for the allocation of the FACTS devices in power network is shown in Fig. 6.

Table 1. Load levels

Operating condition	Loading factor	Yearly operating hours
1	1.0819	87.6
2	0.8771	788.4
3	0.8279	876
4	0.7831	876
5	0.7438	876
6	0.7128	876
7	0.6798	876
8	0.6399	876
9	0.5915	876
10	0.5254	876
11	0.3895	876

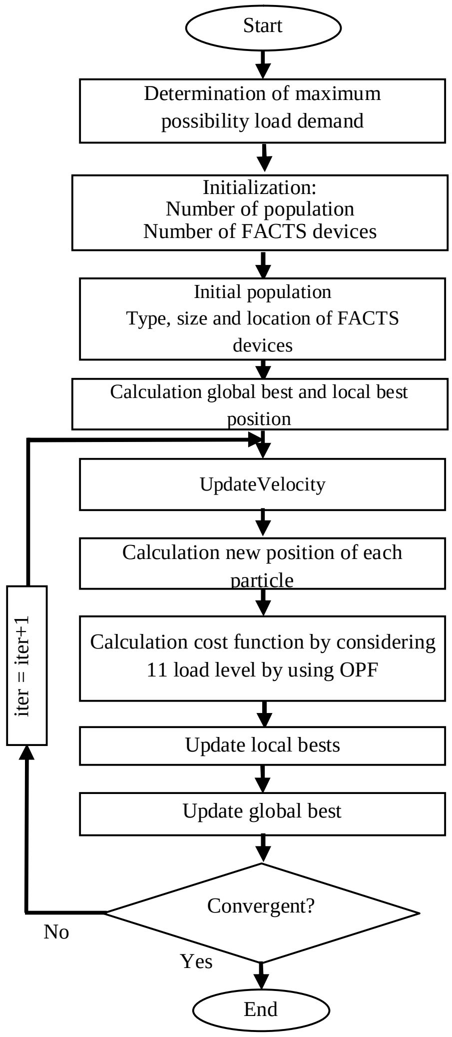

Fig. 6. Allocation process of FACTS devices

6. TEST NETWORK

The test network used in this study is a portion of the American electric power system, AEP, used in the Midwest in the early 1960's and is better known as IEEE 57-bus system. The system data are available in MATPOWER toolbox [23]. The network as shown in Fig. 7 consists of 57 buses, 7 generators, and 80 lines. The generators are located at bus 1, 2, 3, 6, 8, 9, and 12. The voltage limits are set between 0.94 p.u. and 1.06 p.u.

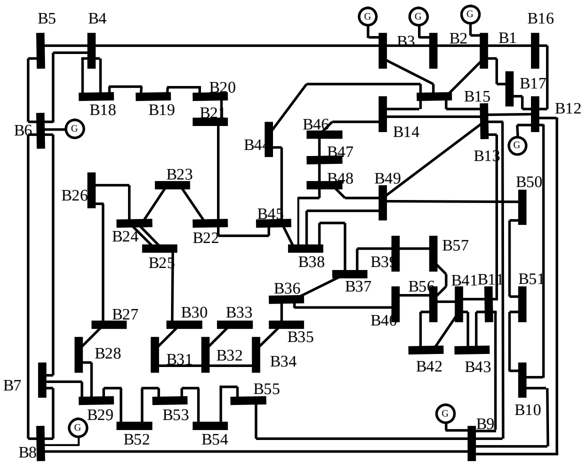

Fig. 7. IEEE 57 bus system

7. SIMULATION RESULTS

The proposed method is implemented in MATLAB 7.1 software. To analyze the effects of various FACTS devices on the power system operation, the following scenarios are studied:

- Scenario 1: Only SVC allocation.
- Scenario 2: Only TCSC allocation.
- Scenario 3: Simultaneously SVC and TCSC allocation.

In the simulation study, parameters of dedicated improved PSO algorithm are chosen according to Table 2. The maximum number of each type of FACTS devices for the allocation five devices are considered in this study.

Table 2. Dedicated improved PSO parameters

c_{1i}	c_{1f}	C_{2i}	C_{2f}	$W_{\min}$	$W_{\max}$	φ
2.5	0.2	0.2	2.5	0.6	0.9	4.1

The results obtained after simulating according to proposed method for each scenario are shown in Table 3. The results include type, location and size of needed FACTS devices. Also, the simulation results by using of GA [19] and classic PSO method for scenario 3 is presented in Table 3.

Table 3. Locations and sizes of FACTS devices by using of DIPSO

Method	Scenario	FACTS type	Location	Size
DIPSO	1	SVC	Bus 31	-307 Kvar
	2	TCSC	Line 47 (bus 34-bus 35)	-37.85 %
			Line 59 (bus 14-bus 46)	20.00 %
	3	SVC	Bus 31	-245 Kvar
		TCSC	Line 59 (bus 14-bus 46)	20.00 %
			Line 55 (bus 41-bus 42)	-27.09 %
Classic PSO	3	TCSC	Line 63 (bus 49-bus 50)	-70.73 %
			Line 43 (bus 30-bus 31)	-38.03%
GA	3	TCSC	Line 33 (bus 22-bus 23)	-64.22%
			Line 35 (bus 24-bus 25)	-2.03%
			Line 47 (bus 34-bus 35)	-22.55%

The obtained results of GA and classic PSO methods in scenario 3 is indicated that it not required to make use of SVC for optimal operation of the power system. However, from the results of the proposed method, it can be seen that the optimal operation of the power system is achieved for simultaneously installation of TCSC and SVC.

7.1. Economic analysis of the results

According to simulation results, the generation cost without FACTS devices and the saving cost for all 11 loading factors relevant each scenario are shown in Table 4.

The saving cost represents the difference between generation cost before and after of installation FACTS devices. However, based on the LDC, each loading factor lasts only for a limited number of hours during the year. Thus, in order to find the annual saving, firstly the saving cost for each loading factor is multiplied by the hours that represent the occurrence of this load level over the year and then gather all these values. The total annual saving cost for each scenario is shown in the last row of Table 4.

The annual saving cost using the GA and classic PSO techniques are calculated by using of the same method and represented in Table 5.

Table 4. Power generator costs

Operation Condition	Generators Costs Without FACTS	Saving cost ($/h)		
		Scenario 1	Scenario 2	Scenario 3
1	49033.96	2767.4586	2769.8424	2772.4736
2	35283.38	0.7132	3.1016	4.2386
3	32717.73	0.6422	2.7451	3.7449
4	30407.24	0.5810	2.4652	3.3492
5	28399.92	0.5286	2.2467	3.0356
6	26831.81	0.4894	2.0824	2.8016
7	25182.82	0.4452	1.8574	2.4999
8	23246.87	0.3951	1.6087	2.1646
9	20971.41	0.3391	1.3454	1.8064
10	18005.21	0.2702	1.0476	1.3961
11	12402.68	0.0000	0.5254	0.4724
Annual saving cost ($)		246226	259033	264843

Table 5. Annual saving cost

Scenario 3	DIPSO	Classic PSO	GA
Annual saving cost ($)	264843	242054	244873

According to Table 5 it is clear that maximum annual saving cost achieved when that the allocated FACTS devices by using of DIPSO method be installed in test network.

In order to economic analysis of application of FACTS devices, the NPV index that described in section 3 is considered. The total cost (cost of devices and installation costs) of FACTS devices and the annual maintenance cost (5% of the cost of the device) for each scenario are calculated based on the FACTS cost curves and represented in Table 6.

Table 6. FACTS cost

Scenario	1	2	3
FACTS cost ($)	40000	56500	105500
Maintenance cost ($)	2000	2800	5200

According to Table 6 it can be seen that to simultaneous install of SVC and TCSC in power network, maximum investment is required and the SVC installing in power network need minimum investment.

It is assumed that the economic life of devices and discount rate are 20 years and 10 percent, respectively. The total profit for company from installation of FACTS devices is calculated by using of (11) and is depicted in Fig. 8.

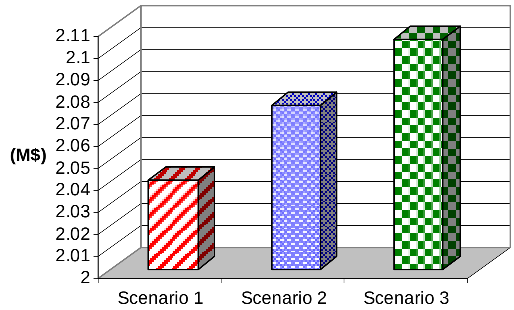

Fig. 8. Total profit from installation FACTS devices by using of DIPSO

According to Fig. 8 it is evident that the maximum provided profit after end of the economic life of project is obtained in scenario 3. Although, this scenario requires the maximum capital investment.

The total profit after installation of the allocated FACTS devices using the classic PSO, GA and DIPSO algorithms is shown in Fig. 9 for scenario 3. This results show that by installation of allocated FACTS devices using the proposed method, maximum profit is achieved.

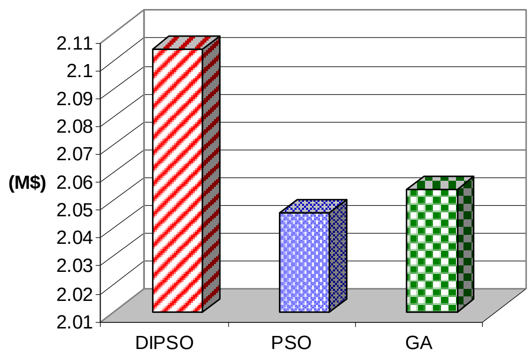

Fig. 9. Total profit from installation FACTS devices

In order to demonstrate of the discount rate influence on the NPV, its curve for three discount rates (5%. 10% and 15%) are shown in Fig. 10 for scenario 3 using the DIPSO technique. It can be seen that the lower discount rate will increase reversal of capital investment and will increase total profit for the company.

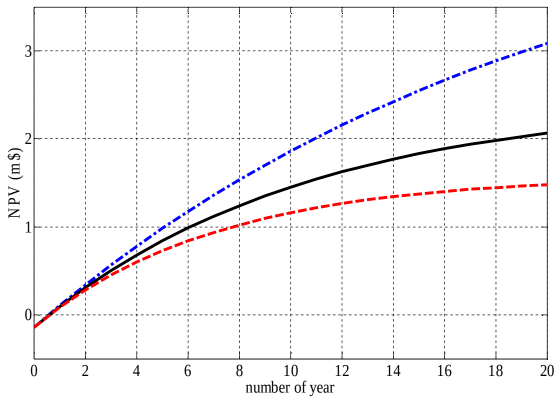

Fig. 10. The influence of different discount rates on the NPV; Solid (*r*=10%), Dashed (*r*=5%) and Dashed dotted *r*=15%)

7.2. Technical analysis

In order to technical analysis of the FACTS devices application in power network, active power losses and maximum possibility demand power is studied. Annual power losses before and after the installation of FACTS devices can be calculated as follows:

$$W_{\text{loss}} = \sum_{i=1}^{oc} P_{\text{loss}_i} . h_i \qquad (MWh) \tag{21}$$

The amount of annual active power losses before and after the installation of FACTS devices is shown in Fig. 11. According to this figure, in scenario one with installation of SVC not only annual active power losses did not decrease but also increased. Because, in this study the aim of installation of FACTS devices is achievement of maximum profit and losses reducing not considered. In other words, the cost of power generated depends on how demand power that can be produced by generators.

In scenario 2 and 3 the annual active power losses decreased and maximum reduction of losses is when TCSC and SVC are installed in power network, simultaneously.

The amount of maximum possibility power demand is derived by using of the proposed method in section OPF and is given in Table 7. The results show that maximum possibility load demand is increased after installation of the FACTS devices and the maximum increasing is achieved in scenario 3. In other word, the simultaneous installation of the SVC and TCSC in power network has a better ability to increase maximum possibility load, although the initial cost is higher than the required cost in this scenario.

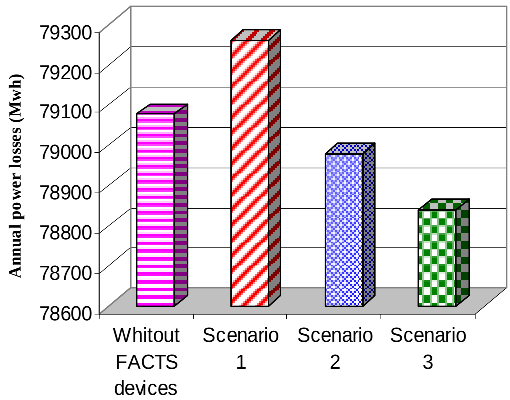

Fig. 11. Annual active power losses

The voltages of load buses in the power network with and without FACTS devices are compared in three different loading factors such as namely maximum loading, base loading (loading factor 1) and minimum loading. It is found that the voltages in the network do not change significantly after the installation of FACTS devices.

Table 7. Maximum possibility load demand

Rate of nominal load demand			
Without FACTS	With FACTS		
	Scenario 1	Scenario 2	Scenario 3
1.0819	1.0990	1.0941	1.1063

8. CONCLUSION

This paper presents a simple and effective optimization algorithm to determine type, size and location of FACTS devices in power network. For this reason, a dedicated improved particle swarm optimization algorithm was developed for optimal placement of FACTS devices to decrease the overall costs of power generation and maximize operation economic profit. In addition, the idea of the PSO-TVAC optimizer was considered for the performance improvement of the proposed DIPSO algorithm to achieve desired level of techno-economical contribution of FACTs device in power system operation. To guarantee the robustness of the proposed method the load duration curve was considered in optimization process. Comparison the achieved results using the proposed method with results of GA and classic PSO approaches, show that the proposed DIPSO algorithm is efficient for optimal placement of FACTS devices in the power network.

In addition, it was indicated that selected FACTS devices donate significantly to savings in generation costs and that the payback period of investment is less than economic life of devices. Moreover, to savings in generation costs installed FACTS devices also donated to the increase in power flow across the network. This contribution is more importance in case of more heavily loaded network. Also, it can be said the technical behavior of the power network after optimal installation of FACTS devices is improved that these improvements include the reduction of annual power loss and increasing maximum possibility load demand.

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