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Economic Operation of Power System Using Facts

Ankit Kumar[1], Krushnachandra Sahoo[2], Sushantkumar Sethy[3], Vidit Prakash Rai[4]

M.Tech [EPS], Dept. of EEE, DRIEMS College, Tangi, Cuttack, India[1]

Assistant Professor, Dept. of EE and EEE, DRIEMS College, Tangi, Cuttack, India[2,3]

Lecturer, Dept. of EEE, KK Polytechnic, Dhanbad, India[4]

ABSTRACT:In the last two decades, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system steady state control problems. Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. This paper describes a developed differential evolutionary, symbiotic organisms search, Moth-Flame optimization algorithm to deal with optimal reactive power dispatch problem. The prime intention of reactive power dispatch problem is to curtail the real power loss and control the bus voltages in power system network. The Moth-Flame algorithm is one of the most powerful and robust new global optimization algorithms in engineering. This optimization algorithm employs a standard IEEE-57 bus system to attain the optimal settings of regulating variables from reactive power compensating components. As a result of the regulating variables, the prime intentions for system network can be achieved. The outcome solutions and results are notable in comparison with other well-known algorithms.

KEYWORDS:FACTS, optimization algorithm.

I.INTRODUCTION

The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents.

Flexible Alternating Current Transmission System (FACTS) is a static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability. It is generally a power electronics based device. Flexible AC Transmission Systems(FACTS) devices present an alternative method to reduce active losses occurring in the system. FACTS devices transform EPS into actively controlled system, whose parameters can be changed. Function of FACTS devices: Power flow control, Increase of transmission capability, Voltage control, Reactive power compensation, Minimization of transmission loss.. In this research, three FACTS devices, one shunt controller, SVC, and two series controllers, TCSC and TCPAR are deployed for the study.
Reactive power control using FACTS devices in transmission system also poses some challenging problems in power system operation. This is because, the need for most efficient operation of power system has increased with the price of fuel. For a given distribution of power, the losses in the system can be reduced by minimizing the flow of reactive power.
The optimal power flow and reactive power dispatch are the two major optimization problems in large scale power system network [1-2]. These two major optimization problems are interrelated with respect to the system operation & control in existing power system and restructured electric power system network. The foremost goal of optimization techniques is to determine the optimal setting of reactive output of generators, tap-setting of transformers, and settings

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of SVC, TCSC and TCPAR to minimize the operating cost of a power system by reducing the active power loss occurring in it.

The final objective is to compare the performance of the used optimization algorithms. The nature based optimization algorithms applied are Moth-flame based optimization algorithm (MFO), Symbiotic Organisms Search Optimization Algorithm (SOS) and Differential Evolution Algorithm (DE).

A. *SVC(Static Var Compensator)*

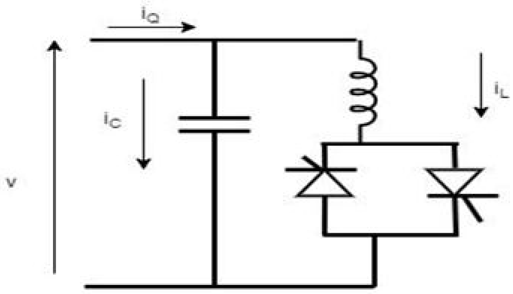

Fig. 1 FC-TCR type SVC

An SVC is connected to the bus through a step-downtransformer or through the tertiary winding of the transformer connected to the bus. It essentially consists of a capacitor connected in parallel to an inductor. As can be observed from the Fig. 1, a bidirectional valve is connected n series with the inductor.

B. *Thyristor-Controlled Series Capacitor (TCSC)*

A Thyristor-controlled series capacitor configuration consist of a capacitor connected in parallel with a thyristor-controlled inductor as shown in the Fig. 3.5.

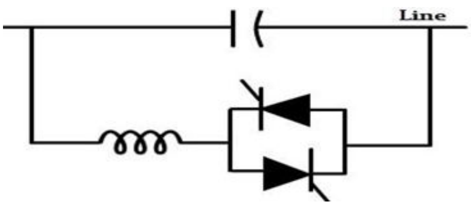

Fig. 2 Model of FC-TCR TCSC

This simple model utilizes the concept of a variable series reactance. The series reactance is adjusted automatically, within limits, to keep the specified amount of active power flow across the line. There are certain values of inductance and capacitance which causes steady-state resonance, as can be observed from the Fig.3.6.The TCSC can be continuously controlled either in capacitive or in inductive area, avoiding the steady-state resonance condition. The TCSC is assumed to be connected between buses i and j in a transmission line as shown in the Fig. 2, where the TCSC is presented simplified as a variable reactance (capacitive).

C. *Thyrisror-Controlled Phase Angle Regulator (TCPAR)*

TCPAR are equivalent of mechanical phase angle regulators (PARs) or phase shifting transformers (PSTs), which works on the principle of quadrature voltage injection using on-load tap-changers. The advantage of TCPAR over its mechanical counterparts is twofold. Firstly, it eliminates the need for costly maintenance and the other it provides the high speed response necessary for dynamic system control. They are used in conjunction with in-phase voltage injectors to control the flow of both the active and reactive power in the transmission lines. They provide a better alternative to control the power flow in transmission lines where the transmission angle is not compatible for the present requirement of power flow. Besides providing control of active power flow in lines, these are also used for transient stability improvement a, power oscillation damping, and minimization of post-disturbance overloads and the corresponding voltage dips.

D. Alternator

Alternators are the source of active and reactive power in a power system. However, the active power generation and reactive power generation of the alternators are independent of each other. These machines are rated in terms of the maximum MVA output at a specified voltage and power factor. The active power output is limited by the prime mover capability whereas reactive power output is limited by certain constraints as described in the next section, within the MVA rating of the machines. The reactive power generation of an alternator depends on the excitation system of the machine. Overexcited alternators delivers reactive power at lagging p.f. whereas under excited machines absorbs reactive power at leading p.f. Normally excited alternators neither absorb nor deliver reactive power to the power system. The reactive power generation or absorption of alternators depends on armature current limits, field current limits and end-region heating limit. Each of these limits are modelled as circles in the active-reactive output plane. The working range of reactive power output of alternators are decided by its Capability Curves or D-Curves. In conjunction with the reactive power limits of alternator, the generator must also operate within maximum and minimum active power limits imposed by the prime mover. The upper portion of the curve is the circle from the field current limit, the right portion of the curve is the circlefrom the armature current limit, and lower portion of the curve is the circle from the end region heating limit.

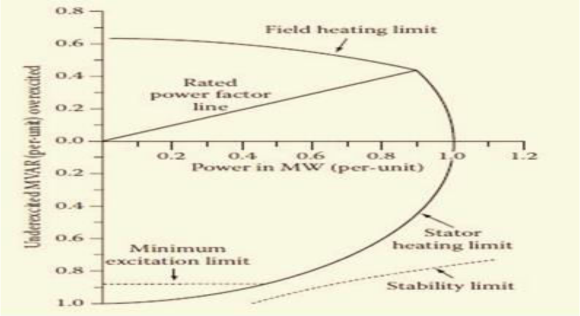

Fig. 3 Capability Curve of Alternator

E. On-load Tap-Changers (OLTC)

On-Load Tap-Changing transformers or Load-Tap Changing transformer are transformers provided with the taps on their windings either for voltage control of the buses to which they are connected or , for controlling the reactive power flow in transmission line to which they are connected in series with. Depending upon the function they perform in the power system, these transformers are classified as – No Automatic Control, Reactive Power Control, Voltage Control and Phase Control transformers. The tap positions of the No Automatic Control Transformers remains. fixed, unless changed externally. The reactive power control transformers modify the position of their tap to control the flow of reactive power through the transmission lines they are connected with. The voltage and phase control transformers change the position of their taps to regulate the voltage and phase of the regulated bus, respectively. OLTCs present in the system does not generate or absorb reactive power in the system. Rather, they modify the voltage of the regulated bus according to the work they are performing and the requirement of the needed reactive power is let to be fulfilled by the power system. As a result of which, their operation is fraught with the dangers of voltage instability in the system

II.SYSTEM MODEL AND ASSUMPTIONS

A. Problem formulation of OPF with FACTS

The objective of OPF is to minimize an objective function while satisfying all the equality and inequality constraints of the power system. The OPF problem may be formulated by (1) and (2) [3-5]

Minimize OF(x,y) (1)

$$\text{Subject to: } \begin{cases} e(x,y) = 0 \\ ie_1 \leq ie(x,y) \leq ie_u \end{cases} \quad (2)$$

Where, OF(x,y)objective function

$e(x,y)$: set of equality constraints;

$ie(x,y)$: set of inequality constraints;

ie_1, ie_u: set of lower and upper limits of the inequality constraints,respectively;

x : vector of dependent variables consisting of slack bus active power, load voltages, generators, reactive powers and transmission lines, loadings; and

y : vector of independent variables consisting of continuous and discrete variables.

The continuous variables are generators, active powers except slack bus, generators, voltages and discrete variables are transformers, tap settings, reactive power injections of shunt regulators, reactance values of TCSC devices and phase shifting angles of TCPS devices. Hence, x and y may be expressed by (3) and (4), respectively,

$$x^T = [P_{G1}, V_{L1} \ldots V_{LNL}, Q_{C1} \ldots Q_{CNG}, S_{L1} \ldots S_{LNTL}] \quad (3)$$

$$y^T = [P_{G2} \ldots P_{CNG}, V_{G1} \ldots V_{CNG}, Q_{C1} \ldots Q_{CNG}] \quad (4)$$

where, NG : number of generator buses;
NL : number of load buses;
NTL : number of transmission lines;
NT : number of regulating transformers; and
NC : number of shunt compensators.

B. Constraints

The OPF with TCSC and TCPS are subjected to the constraints mentioned in the next two sub-sections.

B.1. Equality constraints

These constraints represent the load flow equations as stated in (5) [6]

$$\left.\begin{array}{l} \sum_{i=1}^{NB} (P_{GI} - P_{Li}) + \sum_{i=1}^{NB} P_{is} = \sum_{i=1}^{NB} \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} + \delta_i - \delta_j) \\ \sum_{i=1}^{NB} (Q_{GI} - Q_{Li}) + \sum_{i=1}^{NB} Q_{is} = \sum_{i=1}^{NB} \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} + \delta_i - \delta_j) \end{array}\right\} \quad (5)$$

Where,

P_{Li}, Q_{Li}:active and reactive power demands of i-th bus

P_{Gi}, Q_{Gi}:active and reactive power generations of i-th bus.

P_{is}, Q_{is}: injected active and reactive powers of TCPS at i-th bus,

Y_{ij}: admittance of transmission line connected between i-th and j-thbus;

θ_{ij}:admittance angle of transmission line connected between i-th and j-th bus;

NB : number of buses; and

NTCPS : number of TCPS devices in the power network.

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B.2. Inequality constraints

(i) Generator constraints: Generator voltage, active and reactivepower of the i-th bus should lie between their respectivemaximum and minimum limits as given by (6)

$$\left.\begin{array}{ll} V_{Gi\,min} \le V_i \le V_{Gi\,max} & i = 1,2,\ldots NG \\ P_{Gi\,min} \le P_i \le P_{Gi\,max} & i = 1,2,\ldots NG \\ Q_{Gi\,min} \le Q_i \le Q_{Gi\,max} & i = 1,2,\ldots NG \end{array}\right\} \quad (6)$$

V_{Gimin},$V_{Gi\,max}$:minimum and maximum generator voltage of the i-thgenerating unit, respectively
P_{Gimin},$P_{Gi\,max}$: minimum and maximum active power of the i-th generatingunit, respectively; and
Q_{Gimin},$Q_{Gi\,max}$:minimum and maximum reactive power of the i-thgenerating unit, respectively

(ii) Load bus constraints: Load bus voltage should lie between its respective maximum and minimum limits and may be represented by (7)

$$V_{Li\,min} \le V_i \le V_{Li\,max}, \quad i=1,2,\ldots NL \qquad (7)$$

where$V_{Li\,min}$ and $V_{Li\,max}$ are minimum and maximum load voltage of i-th generating unit, respectively.
(iii) Transmission line constraints: Line flow for each transmission line must be within its capacity limits and these limits may be, mathematically, expressed by (8)

$$S_{li} \le S_{li\,max} \qquad i= 1,2,\ldots..NTL \qquad (8)$$

where
S_{li}: apparent power flow of the *i*-th branch and
S_{limax} : maximum apparent power flow limit of the *i*-th branch.
(iv) Transformer tap constraints: Transformer tap settings are bounded between maximum and minimum limits by (9)

$$T_{i\,min} \le T_i \le T_{imax} i=1,2,\ldots NT \qquad (9)$$

where $T_{i\,min}$ and $T_{i\,max}$ are minimum and maximum tap setting limits of the i-th transformer, respectively.
(v) Shunt compensator constraints: Shunt compensation are restricted by their maximum and minimum limits as in (10)

$$Q_{Ci\,min} \le Q_{Ci} \le Q_{Ci\,max} \qquad i=1,2,\ldots,NC \qquad (10)$$

where$Q_{ci\,min}$ and $Q_{ci\,max}$ are minimum and maximum VAR injection limits of the i-th shunt capacitor, respectively.
(vi) TCSC reactance constraints: TCSC reactance are restricted bytheir maximum and minimum limits as in (11)

$$X_{ti\,min} \le X_{ci} \le X_{timax}, \qquad i=1,2\ldots,NTCSC \qquad (11)$$

where
$X_{ti\,min}$, X_{timax} : minimum and maximum reactance of the i-th TCSC, respectively, and
NTCSC : number of TCSC devices installed in the power network.
(vii) TCPS phase shift constraints: TCPS phase shifts are restricted by their maximum and minimum limits as in (12)

$$\emptyset_{ti\,min} \le \emptyset_{ti} \le \emptyset_{ti\,max} \qquad i=1,2,\ldots.NTCPS \qquad (12)$$

where$\emptyset_{ti\,min}$ and $\emptyset_{ti\,max}$ are minimum and maximum phase shift angle of the i-th TCPS, respectively.

C. Symbiotic Organism Search (SOS) Optimization Algorithm

Symbiotic Organisms Search Algorithm is proposed by Cheng and Pragyo [7]. It is inspired by the variety in nature of interaction among different organisms in an ecosystem. Symbiotic Organisms Search (SOS) have become popular due to its simplicity and effectiveness in wide range of applications with low computational cost. Some of the applications of congestion management, scheduling of hydrothermal generators, cloud computing etc [8].

D. Moth-flame Optimization (MFO)

Moth-flame Optimization algorithm (MFO) is a nature-inspired approach for obtaining the global or the near global optimum solution of optimization problems. SyedaliMirjalili proposed this algorithm in 2015 [9]. Due to its robustness and proven capability to attain optimal solutions, it is deployed to solve numerous engineering problems in different streams of engineering, including power system operation [10], among others. This methodology of obtaining optimum solutions mimics the movement of moths. Their behaviour of converging towards flames is exploited to develop this algorithm.

E. Differential Evolution (DE)

Differential Evolution starts with an initial population. The dimension of the controlling variables in the problem decides the dimension of the initiated population. The number of individuals in the problem is decided according to the computational effort to be committed. There are three operators in DE- Mutation, Crossover and Selection.

Mutation:

Mutation is the chief operator present in the DE. This operator essentially provides the magnitude and direction of perturbation to an individual so that a new individual can be generate I the population. There are several methods available to induce mutation in the population of the DE. However, the method as described below used to induce mutation. Three different individuals are selected randomly from the population except the current individual which is to be perturbed. The difference between any of the two is then added to the remaining individual to obtain the perturbed individual.

Let Xi is the individual to be perturbed. Then Xa, Xb and Xc are chose among the remaining individuals of the population.

A new individual is generated as follows:

Xi'= Xa+rand*(Xb-Xc); where Xa,Xb and Xc are the randomly selected individuals from the population except Xi.

Generation

Generation is the next operator of DE. This operator combines the existing individual and the new individual generated in the mutation stage to produce a new individual. The existing individual is modified in certain dimension by replacing its values in those dimensions by the new individual values in the same dimensions.InDE, there is a threshold value of allowing crossover between individuals called crossover probability. Every dimension of the existing individual is assigned with a crossover probability. If the crossover probability of the existing individual is found more than the crossover threshold, then the crossover takes place. Let U_{ij} be the individual generated during the mutation phase for the existing individual of the population Xi during the generation G. The modified individual $X_{i,j,G+1}$ generated is given by:

$X_{i,j,G+}1$ ={$X_{i,j,G}$if crossover probability is less than crossover threshold
$U_{ij,G}$if crossover probability is more than the crossover threshold}

Selection:

Select ion is the last operator of the Differential Evolution. In this stage, the fitness of the newly generated individual is compared with that if the existing individual $X_{i,G}$. If the fitness of $X_{i,G+1}$ is found better than the fitness of the existing individual X_i, then the new individual replaces the existing individual in the population.

III.RESULT AND DISCUSSION

The simulation study of the heuristic techniques on the IEEE 57-bus test system. The three heuristic techniques, namely Moth-Flame Optimization, Symbiotic Organisms Search Optimization and Differential Evolution are tested at different reactive loading. The system data for the system is obtained from the [55]. The performance of these heuristic techniques is tested at different reactive loading conditions- base reactive loading. 130% of base reactive loading and 150% of base reactive loading.

A. *Placement of FACTS Devices*

The positions of SVC is decided by modal analysis. SVC are placed at weaker buses

Device	**SVC-1**	**SVC-2**	**SVC-3**
Location	25	38	49

Table 1 Position of SVC in the System

The positions of TCSC is decided by the flow of reactive power in the lines. The lines with higher reactive power is chosen for placement of TCSC.

Device	**SVC-1**	**SVC-2**	**SVC-3**
Location	25	38	49

Table 2 Position of TCSC in the System

The position of TCPAR is decided by loss sensitivity of a line with phase injection [1]. Line 33 is found to be most suitable for placing TCPAR.

B. *Performance Analysis of Moth-Flame Optimization (MFO)*

From Fig 4, it can be observed that the voltage profile of the system has improved due to implementation of FACTS in the system using MFO. The voltage improvement is attributed to the re-distribution of reactive power flow in the system. The buses 31, 32, 33 are far from any generator in the system, resulting in the poor voltage profile at these buses. However the FACTS along with other reactive controllers have improved the reactive power flow and provide the reactive support to these buses resulting in the improvement of voltages at these buses. Fig. 4 demonstrates the convergence characteristic of the MFO when applied for the test system at base reactive loading. From the Fig. 4 it can be examined that the MFO has converged fast for the given system. Though 500 iterations are performed, the process of convergence saturated before 100 iterations, showing the fast convergence property of MFO.

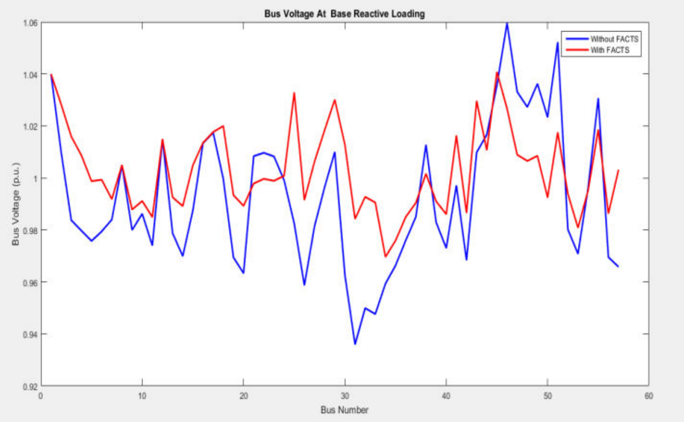

Fig. 4 Voltage profile of the system with and without FACTS Using MFO at 100% of Base reactive Loading

TABLE 3 Active Power Loss Without and With FACTS at Different Reactive Loading Conditions Using MFO

Reactive Loading(% of Base Loading)	Active Power Loss (p.u.)	
	Without FACTS	With FACTS
100	0.2789	0.2532
130	0.2941	0.2615
150	0.3013	0.2718

From Table 3, it is clear that the implementation of FACTS has resulted in the considerable reduction of active power loss occurring in the system at various loading conditions

From Table 4, it can be inferred that the reactive power flow in transmission lines has reduced considerably. The operating cost of system, which includes the cost of active power loss occurring in the system and the operating cost of FACTS devices, is provided in Table 5. It can be inferred from the Table 5 that the operating cost of the system has reduced at all loading condition.

TABLE 4 Reactive Power Flow in Lines at Different Loading Conditions Using MFO

lines	Reactive Power Flow (p.u.)					
	100% Loading		130% Loading		150% Loading	
	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS
37	0.8189	0.4801	0.7479	0.5324	0.9142	0.5400
59	0.9825	0.7327	1.2038	0.8229	1.1514	0.7439
65	1.0128	0.4000	0.9035	0.3144	0.9635	0.4553
$\sum$	2.8142	1.6128	2.8552	1.6693	3.0291	1.7372

TABLE 5 Operating Cost of System Without and With FACTS at Different Loading Conditions Using MFO

Reactive Loading (% of Base Loading)	Operating Cost (M $)		
	Without FACTS	With FACTS	Net Saving (M $)
100	14.65	13.37	1.28
130	15.45	13.81	1.64
150	15.83	14.36	1.47

C. Performance analysis of Symbiotic Organisms Search Optimization (SOS)

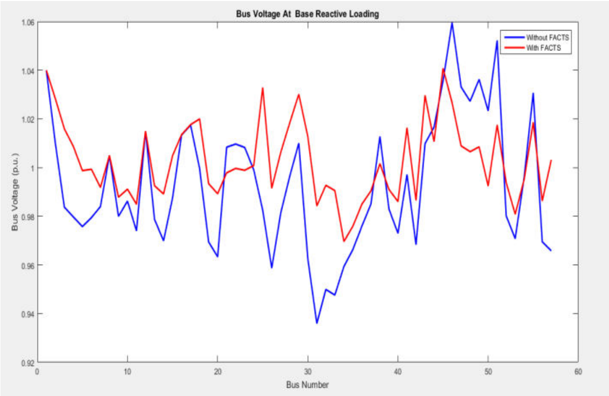

Fig 5. Voltage Profile of the system at Base Reactive Loading using SOS at 100% of Base Reactive Loading

Fig. 5 presents the voltage profile of the system, without and with FACTS devices using Symbiotic Organisms Search (SOS) as the optimization approach at base reactive loading of the system.

From Table 6, it can be inferred that SOS has successfully reduced the active power loss occurring in the system at different loading conditions of the system. The considerable reduction in operating losses of the system has resulted in the reduced operating cost of the system, which is presented in the Table 7. The reduction in operating cost of the system is due to the reallocation of reactive power flow through lines, which is brought about by allocating FACTS to reduce reactive power flow through the system. The benefits accrued over due to FACTS implementation has resulted into annual savings of 1.34, 1.75 and 1.60 million dollars for the present test system. Using this analysis, it can be inferred that the implementation of FACTS results in economic benefit to the power system operator. However, the benefits accrued over the time of study depends greatly on the working condition of the system. A heavily loaded system presents a better alternative to saving of the operating expense. It can beinferred that the operation of FACTS is advisable in power system with heavily loaded transmission system.

TABLE 6 Active Power Loss With and Without FACTS at Different Reactive Loading Using SOS

Reactive Loading (% of Base Loading)	Active Power Loss (p.u.)	
	Without FACTS	With FACTS
100	0.2789	0.2547
130	0.2941	0.2621
150	0.3013	0.2765

TABLE 7 Operating Cost of System Without and With FACTS at Different Reactive Loading Conditions Using SOS

Reactive Loading (% of Base Loading)	Operating Cost (M $)		
	Without FACTS	With FACTS	Net Saving (M $)
100	14.65	13.47	1.18
130	15.45	13.86	1.59
150	15.83	14.64	1.19

TABLE 8 Reactive Power Flow in Transmission Lines With and Without Using FACTS at Different Loading Conditions Using SOS

	100% Loading		130% Loading		150% Loading	
Lines	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS
37	0.8189	0.6776	0.7479	0.5999	0.9142	0.7049
59	0.9825	0.7108	1.2038	0.8887	1.1514	0.7650
65	1.0128	0.7515	0.9035	0.7235	0.9635	0.8653
∑	2.8142	2.1399	2.8552	2.2121	3.0291	2.3352

D. Performance Analysis of Differential Evolution (DE)

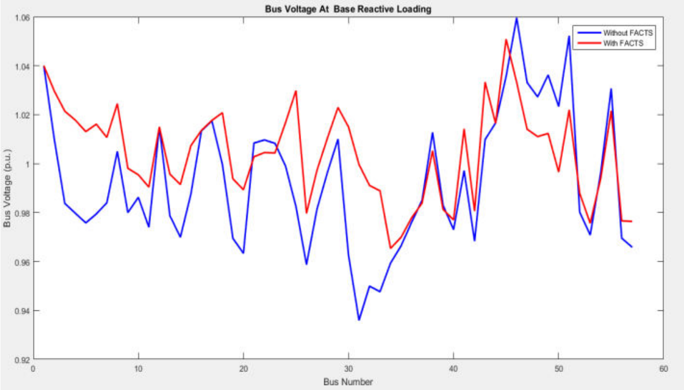

Fig 6. Voltage Profile of the System at Base Reactive Loading Using DE at 100% of Base Reactive Loading

Fig. 6 provides the information about the voltage profile of the system at base reactive loading using DE. It can be observed from the Fig. 6 that the voltage profile of the system has improved due to the optimal placement of FACTS devices. The buses with poor voltage conditions without FACTS devices have improved voltage with FACTS devices. This is essentially due to the setting of FACTS and other reactive controllers have resulted into the more efficient reactive power flow in the system. Table 9 provides the values of active power losses as obtained at different loading conditions using DE. From the table it is evident that the DE has successfully reduced the active power losses occurring in the system, by modifying the control parameters of the system. There is a considerable reduction in the active power losses occurring in the system even at 150% of base reactive loading, thus, making it suitable for optimization purposes.

TABLE 9 Active Power Loss With and Without FACTS at Different Reactive Loading Using DE

Reactive Loading (% of Base Loading)	Active Power Loss (p.u.)	
	Without FACTS	With FACTS
100	0.2789	0.2559
130	0.2941	0.2635
150	0.3013	0.2749

TABLE 10 Operating Cost of System Without and With FACTS at Different Loading Conditions Using DE

Reactive Loading(% of Base Loading)	Operating Cost (M $)		Net Saving (M $)
	Without FACTS	With FACTS	
100	14.65	13.55	1.55
130	15.45	13.96	1.49
150	15.83	14.56	1.27

Table 10 presents the saving in operating expenses of the system due to the optimal allocation of FACTS and other reactive controllers present in the system at different reactive loading conditions.

Table 11 provides the change in reactive power in transmission lines provided with series compensation, using TCSC.

TABLE 11. Reactive Power Flow in Transmission Lines with and without Using FACTS at Different Loading Conditions Using DE

lines	100% Loading		130% Loading		150% Loading	
	Without FACTS	With FACTS	Without FACTS	With FACTS	Without FACTS	With FACTS
37	0.8189	0.4708	0.7479	0.5478	0.9142	0.5390
59	0.9825	0.6147	1.2038	0.7344	1.1514	0.7500
65	1.0128	0.3809	0.9035	0.3276	0.9635	0.6551
∑	2.8142	1.4664	2.8552	1.6098	3.0291	1.9441

E. *Comparison of MFO, SOS and DE*

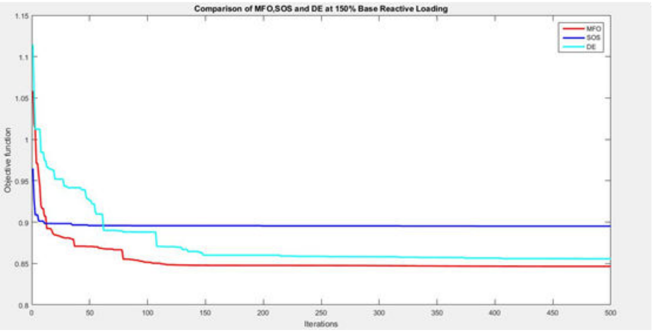

Fig. 7 Convergence Curve of MFO, SOS and DE at 150% base reactive loading

Fig. 7, 8 and 9 presents the convergence curve of MFO, SOS and DE at 150%, 130% and base reactive loading conditions, respectively. It can be observed from the figures, that the MFO outperforms the other two approaches for obtaining the optimal solution of a large scale optimization problem like allocation of reactive controllers in power system with FACTS devices. DE performs better than SOS at different conditions. It can be inferred from these figures that the MFO is the best algorithm among these three approaches. The better performance of the MFO is attributed to the better exploitation and exploration of the search space.

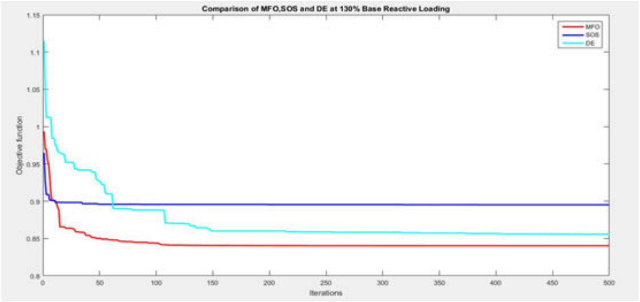

Fig. 8. Convergence Curve of MFO, SOS and DE at 130% of Base Reactive Loading

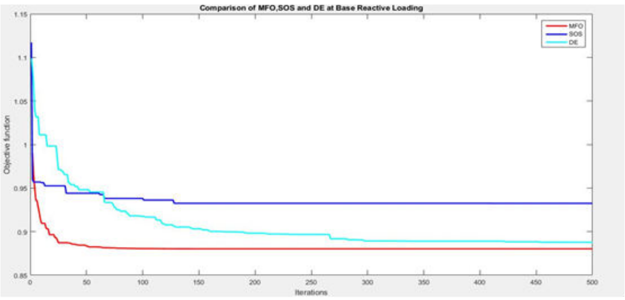

Fig. 9. Convergence Curve of MFO, SOS and DE at Base Reactive Loading

TABLE 12. Comparison of Active Losses at Different Loading Using Different Optimization Approaches

	Active Power Loss (p.u.)			
	Without	With FACTS		
lines	FACTS	MFO	SOS	DE
100	0.2789	0.2532	0.2547	0.2559
130	0.2941	0.2615	0.2621	0.2635
150	0.3013	0.2718	0.2765	0.2749

Table 12 just poses the values of active power losses obtained by different optimization techniques with the case where, no FACTS devices were used. From the table it is evident that the use of FACTS, results in reduction of active power losses occurring in the network. Among all the optimization approaches used in the work, the results obtained from the MFO is found to be the most promising. It provided the minimum amount of losses under different operating conditions. Table 13 provides the comparison of operating cost of the system obtained by the different heuristic approaches under different loading conditions. The results makes it clear that the MFO determines minimum cost of operation among all the approaches used in this work. The minimum operating cost of the system as obtained by the MFO ,under base loading condition, 130% of base loading and 150% of base loading , is found to be 13.37, 13.81 and 14.36 million dollars respectively. In comparison to MFO, the values obtained by SOS 13.47, 13.86 and 14.64, for the respective conditions. The performance of MFO is also better than the DE.

TABLE 13 Comparison of Operating Cost at Different Loading Using Different Optimization Approaches

Loading	Initial Operating Cost (M $)	Optimization Approach	Operating Cost After Optimization (M $)	Cost of FACTS Devices (‘000 $)	Net Saving (M $)
100	14.65	MFO	13.37	70.51	1.28
		SOS	13.47	90.22	1.18
		DE	13.55	105.65	1.15
130	15.45	MFO	13.81	71.46	1.64
		SOS	13.86	90.82	1.59
		DE	13.96	112.79	1.49
150	15.83	MFO	14.36	80.11	1.47
		SOS	14.64	107.84	1.19
		DE	14.56	114.59	1.27

IV.CONCLUSION

Three heuristic approaches for optimization purposes namely, Moth-flame optimization, Differential Evolution and Symbiotic Organisms Search has been given. In this paper, the performance analysis of these heuristic techniques for reducing the operating cost of IEEE 57-bus system along with obtaining acceptable voltage profile in the system, has been done. The voltage profile obtained, reduction in active power loss and operating cost of the system obtained by these techniques has been examined. Moreover, the influence of the FACTS along with other reactive power controllers on the reactive power flow in the system is investigated. The convergence characteristic of the given heuristic approaches to optimization is studied and the influence of initial solution provided to the methodology and the optimal result provided is analysed.In the later part of this chapter, the performance of these techniques are under different operating conditions is compared on the basis of convergence characteristics, and reduction in operating cost of the system. From the comparison, it can be observed that the MFO is more favourable and efficient technique than DE and SOS. The results obtained by MFO are found to be better than those obtained by remaining two methodologies.

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