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Moth Flame Optimization based Reactive Power Planning

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Abstract: Reactive power planning is one of the challenges facing an integrated power network to operate efficiently. It requires optimal coordination of all the reactive power sources in the network. In this work, Moth flame optimization (MFO) based algorithm used for optimal location of flexible alternating current transmission system (FACTS) devices. In standard IEEE 30 and IEEE 57 test systems the proposed approach is examined. The static Var compensator (SVC) and thyristor controlled series capacitor (TCSC) are the two FACTS devices used. The load ability of the power system is enhanced by installing FACTS controllers considering both active and reactive loading. The reactive sources are placed optimally which is chosen by considering position and size of FACTS devices. The proposed method with FACTS devices is compared with other recent techniques like Particle swarm optimization (PSO) and gravitational search algorithm (GSA). It is observed that the MFO based approach is better as compared to other methods in terms of loss and the running cost at various loading conditions.

Keywords: *Active power loss, FACTS Controllerss, moth flame optimization*

I. INTRODUCTION

Power system networks are becoming complicated in the current scenario due to increased demand for power. Installation of new transmission lines to fulfill the current demand results in less safety and service quality degradation. It is essential to make effective use of established transmission lines after considering technical and economical aspects. Using the existing power system, the maximum transfer capacity of the power transmission line is achieved by set up of FACTS controllers. Depending upon the impedance of the line, the amplitude and sending and the receiving end voltage phase angle, power flows through an ac transmission line.

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The various types of FACTS controllers are explained in [1]. The operation of FACTS devices by controlling different parameters is discussed in [2]. In [3], the advantages of these controllers are discussed on the basis of their type, number, volume and position in the transmission system. The allotment technique of the FACTS devices are categorized in to heuristic and analytical techniques [4]. Optimal power flow model is discussed using FACTS devices [5]. A power flow control technique is addressed using a series compensator in [6]. Control of power flow using multi type FACTS devices is discussed in [7]. Reactive power planning (RPP) problem is discussed in [8]. Voltage stability along with RPP is discussed in [9]. The reduction in congestion cost using upfc is discussed in [10]. A novel scheme incorporating different FACTS controllers is discussed in [11]. In [12], control of power flow based on the steady state model of these devices is discussed. Selection of weak buses for installing reactive power source is discussed in [13]. Gravitational search algorithm based technique is discussed in [14] to optimize the allocation of FACTS controllers. The solution technique for reactive power control is explained in [16]. Improvement of voltage profile by reduction of the transmission loss is discussed in [17]. Voltage stability limit using bacteria foraging algorithm is discussed in [18]. A novel nature inspired optimization technique called MFO is discussed in [19]. Optimal placement of reactive sources using novel global harmony search algorithm is described in [20]. A methodology based on PSO for optimal placement of FACTS device is described in [21]. A loss sensitivity approach using evolutionary algorithms is discussed in [22]. Solution of optimal reactive power dispatch is discussed in [23]. Different bio-inspired algorithms for RPP are discussed in [24].

II. MATHEMATICAL MODEL OF FACTS CONTROLLERS

SVC and TCSC are being used as FACTS devices in the present work. SVC and TCSC must be mathematically modeled. The var flow can be reduced if the TCSC is placed on the line or if the SVC is located at the end of the line.

A. SVC

SVC's main goal is either to absorb or injection of reactive power to the bus where it is connected. The effective reactance of SVC is calculated by the parallel combination of inductive reactance (X_L) and capacitive reactance (X_C) and is given by,

$$X_{SVC} = \frac{\pi X_C X_L}{X_C[2(\pi-\alpha)+2\sin\alpha]-\pi X_L} \quad \text{......................} \; (1)$$

here, α is the triggering angle

Fig (1) shows the mathematical model of SVC

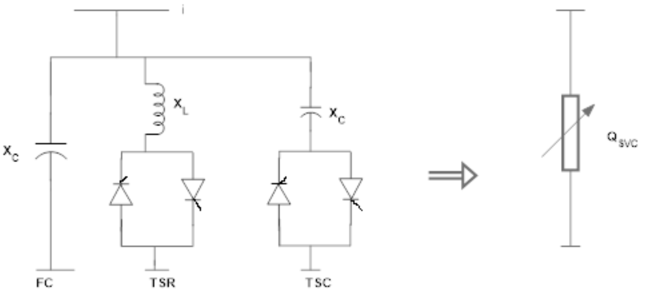

Fig. 1 : SVC module

B. TCSC

TCSC is a series capacitor connected to a thyristor-controlled reactor in parallel. It has the ability for quick and continuous regulation of the transmission line. TCSC serves as inductive or capacitive compensator by adjusting the line reactance.

The admittance of TCSC when it is connected to a specific line is given by,

The admittance of TCSC when it is connected to a particular line is given by,

$$G_T + jB_T = \frac{1}{R + j(X_L - X_T)} \quad \text{.....................} \quad (2)$$

Where, R is the resistance and X_L is the transmission line reactance without TCSC. X_T is TCSC's reactance.

Fig (2) shows theTCSC's mathematical model linked to the transmission lines.

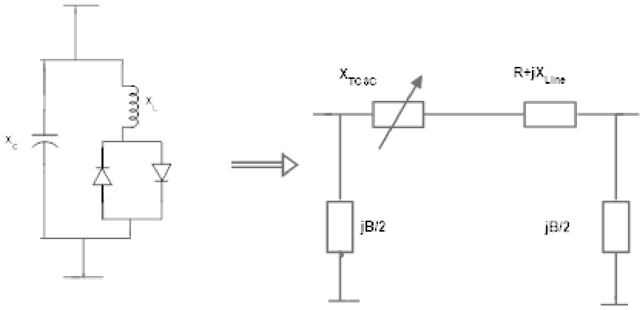

Fig 2: TCSC module

C. COST (C_{FACTS}):

The installation cost for FACTS devices are given as:

SVC: C_{SVC}=0.0003X^2-0.3051X+127.38 \$/KVar............ (3)

TCSC: C_{TCSC}=0.0015X^2–0.7130X+127.38 \$/KVar.......... (4)

Here, X is the FACTS devices operational range.

$C_{FACTS}=C_{SVC}+C_{TCSC}$ ……...(5)

Energy loss cost is expressed as

$C_{Energy}=P_{Loss}\times0.06\times100000\times365\times24$ ....(6)

The total running costs which are given by:

$Cost_{Total}=C_{Energy}+C_{FACTS}$. ....(7)

III. PROBLEM FORMULATION

A. Objective

The objective of the method used is the optimal placement of SVC and TCSC in order to reduce real power loss and running expense of the transmission network under various loading cases. The total cost is to be reduced by controlling different variables such as tap settings of transformer, reactive generation, shunt capacitors and TCSC reactance.

In a transmission network, the active power loss (APL) is given by,

$$P_L = \sum_{m=1}^{n} G_m[V_x^2 + V_y^2 - 2V_xV_y\cos(\delta_x - \delta_y)] \text{................} \quad (8)$$

Where, n is the number of lines, G_m is the conductance of the m^{th} line connected between buses x and y.

V_x , V_y denotes the voltage magnitudes and $\boldsymbol{\delta}_x$, $\boldsymbol{\delta}_y$ represents voltage phase angles of the buses x and y respectively.

The optimal power planning problems with different controlling variables have certain constraints defined as below.

Equality and inequality constraints which have to be satisfied are:

$$P_{G_x} - P_{D_x} - V_x\sum_{y=1}^{n_b} V_y[G_{xy}Cos(\delta_x - \delta_y) + B_{xy}Sin(\delta_x - \delta_y)] = 0, x = 1,2,...n_b \quad (9)$$

$$Q_{G_x} - Q_{D_x} - V_x\sum_{y=1}^{n_b} V_y[G_{xy}Sin(\delta_x - \delta_y) - B_{xy}Cos(\delta_x - \delta_y)] = 0, x = 1,2,...n_b \quad (10)$$

Where n_b is the bus number, P_{G_x} , Q_{G_x} are real and var generation at the x^{th} bus, P_{D_x} , Q_{D_x} are active and var reqirement at the x^{th} bus, G_{xy}, B_{xy} are the conductance and susceptance between x^{th} bus and y^{th} bus.

The limits of voltage amplitude and the var otputs of the generator are mentioned below:

$$V_x^{\min} \le V_x \le V_x^{\max} \text{ ....} \quad (11)$$

$$Q_{g_x}^{\min} \le Q_{g_x} \le Q_{g_x}^{\max} \text{ ....} \quad (12)$$

The limits of transformer tap settings are mentioned below:

$$t_x^{\min} \le t_x \le t_x^{\max} \text{ ....} \quad (13)$$

The limit of Var output of shunt capacitors are mentioned below:

$$Q_{C_x}^{\min} \le Q_{C_x} \le Q_{C_x}^{\max} \text{ ....} (14)$$

The limit of TCSC is mentioned below:

$$Q_{TCSC_x}^{\min} \le Q_{TCSC_x} \le Q_{TCSC_x}^{\max} \text{ ....} (15)$$

The limit of SVC is mentioned below:

$$Q_{SVC_x}^{\min} \le Q_{SVC_x} \le Q_{SVC_x}^{\max} \text{ ....} (16)$$

B. Optimal positioning of FACTS controllers:-

The position of the FACTS controllers is calculated by measuring the power flow in the transmission lines. SVC location is chosen by selecting the weak buses at which effective reactive injection may boost overall performances of the system. The lines with high reactive power are chosen for TCSC placement.

In a standard IEEE 30 bus system, the positions of the SVC are selected on bus numbers 21, 7, 17 and 15 whereas lines 5, 25, 41 and 28 are chosen for TCSC location. In a standard IEEE 57 test system, bus number 25, 49, 38 are chosen for SVC's position whereas line number 39, 13, 61 and 57 are chosen for TCSC placement.

Table 1: Location of FACTS devices

System	Lines for TCSC position	Buses for SVC position
IEEE 30	25,41,28,5	21,7,17,15
IEEE 57	37,13,61,57	49,25,38

IV. PROPOSED METHOD:-

Moth Flame Optimization

In this method, the candidate solutions are moths and the problem variables are the location of moths in space. The moths can therefore fly in multidimensional space by changing their vectors of position. In each iteration, the difference between moth and flame will be updated. The moths are the true search agents that wander the search area, where moths are in the best position as flames.

For the MFO algorithm, a logarithmic spiral expressed as:

$$S(M_x, F_y) = D_x.e^{bt}.Cos(2\pi t) + F_y \quad .... \quad (17)$$

here, D_x refers to the x^{th} moth distance for the y^{th} flame, b is a constant to define the logarithmic spiral shape and t is a random number in [-1, 1]. D_x is calculated as $D_x = |F_y - M_x|$ where M_x indicate the x^{th} moth, F_y indicates the y^{th} flame.

In the spiral equation, the parameter l defines how close the moth's next position is to the flame (l= -1 is the nearest location to the flame and l=1 is the most distant position). A hyper-ellipse can therefore be assumed in all directions around the flame and within this space would be the next position of the moth. The spiral motion is the principal component of the method proposed as it investigates how moths change their positions around the flames. The spiral equation makes it possible for a moth to fly around a flame instead of in space. Therefore, the search space can be explored and exploited.

V. RESULTS AND DISCUSSIONS

Table-2: APL in IEEE 30 bus system in absence and presence of FACTS devices

Loading	APL without FACTS (p.u.)	APL with FACTS using MFO (p.u.)	APL with FACTS using PSO (p.u.)	APL with FACTS using GSA (p.u.)
100%	0.0711	0.0556	0.0445	0.039
110%	0.0974	0.0599	0.0639	0.0581
120%	0.1294	0.0825	0.0891	0.0824

Table-3: APL in IEEE 57 bus system in absence and presence of FACTS devices

Loading	APL without FACTS (p.u.)	APL with FACTS using MFO (p.u.)	APL with FACTS using PSO (p.u.)	APL with FACTS using GSA (p.u.)
100%	0.2799	0.2172	0.2276	0.2145
110%	0.4168	0.2931	0.3155	0.2989
120%	0.6091	0.3093	0.3221	0.3012

Table-4: Analysis of running cost in absence and presence of FACTS controllers using PSO, GSA & MFO based approach in IEEE 30 bus system

Loading	Energy Loss Running Cost(A) in dollar	Algorithms with FACTS controllers	Running Cost (B) × 10^6 in dollar	Net Saving (A-B) in dollar
100 %	3737016	MFO	2.9223	814716
		PSO	2.4052	1331816
		GSA	2.1481	1588916
110 %	5120900	MFO	3.1483	1972556
		PSO	3.4361	1684800
		GSA	3.1224	1998500
120 %	6800100	MFO	4.3362	2463900
		PSO	4.7774	2022700
		GSA	4.4230	2377100

Table-5: Analysis of running cost in absence and presence of FACTS controllers using PSO, GSA & MFO based approach in IEEE 57 bus system

Loading	Energy Loss Running Cost(A) in dollar	Algorithms with FACTS controllers	Running Cost (B) × 10^6 in dollar	Net Saving (A-B) in dollar
100%	1.4711×10^7	MFO	1.141	3295968
		PSO	1.2059	2653000
		GSA	1.1429	3283000
110%	21907000	MFO	1.540	5691664
		PSO	1.6674	5233000
		GSA	1.5830	6077000
120%	32015000	MFO	1.6257	2463900
		PSO	1.7081	2022700
		GSA	1.5984	2377100

Table-6: Percentage reduction of APL at various loading using MFO, PSO & GSA techniques in IEEE 30 bus system

Algorithm	% reduction in losses for base loading	% reduction in losses for 110% base loading	% reduction in losses for 120% of base loading
MFO	27.88	62.60	56.84
PSO	59.78	52.43	45.23
GSA	82.31	63.97	52.77

Table-7: Percentage reduction of APL at various loading using MFO, PSO & GSA techniques in IEEE 57 bus system

Algorithm	% reduction in losses for base loading	% reduction in losses for 110% base loading	% reduction in losses for 120% of base loading
MFO	28.87	42.20	96.93
PSO	22.98	32.11	89.10
GSA	23.52	40.72	75.94

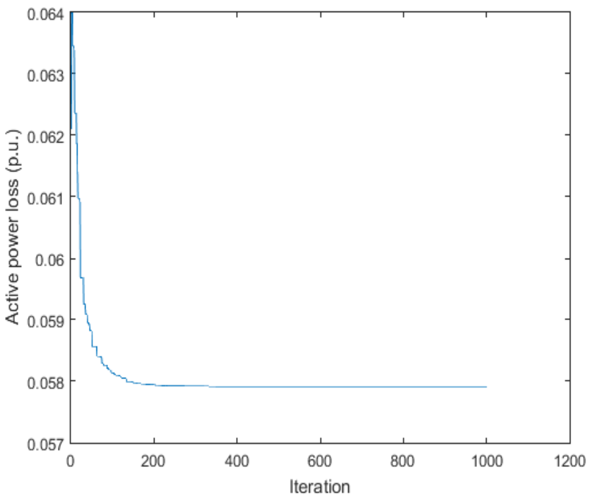

Fig 3(a) Active power loss variations for base loading using MFO for IEEE 30 bus system

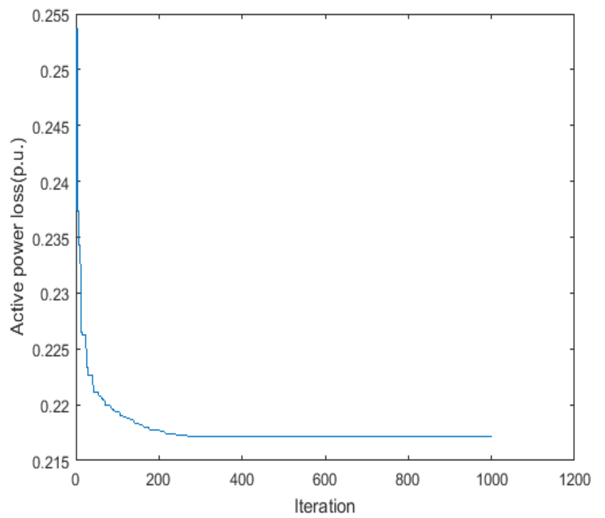

Fig.4 (a) Active power loss variations for base loading using MFO for IEEE 57 bus system

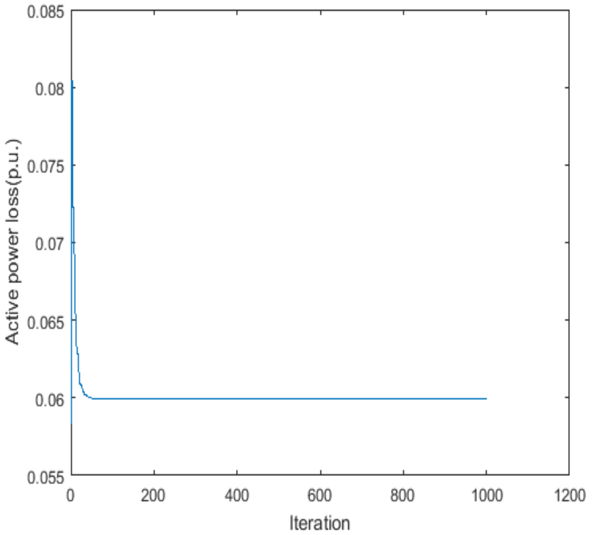

Fig.3 (b) Active power loss variations for 110% base loading using MFO for IEEE 30 bus system

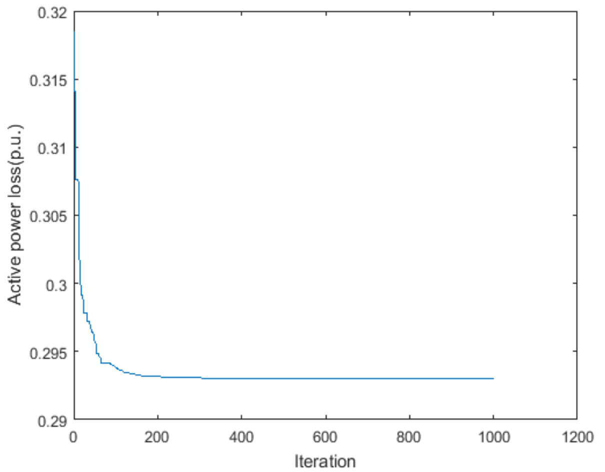

Fig.4 (b) Active power loss variations for 110% base loading using MFO for IEEE 57 bus system

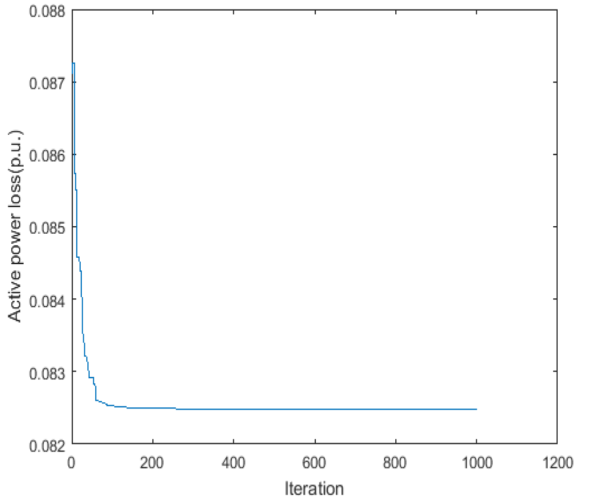

Fig.3 (c) Active power loss variations for 120% base loading using MFO for IEEE 30 bus system

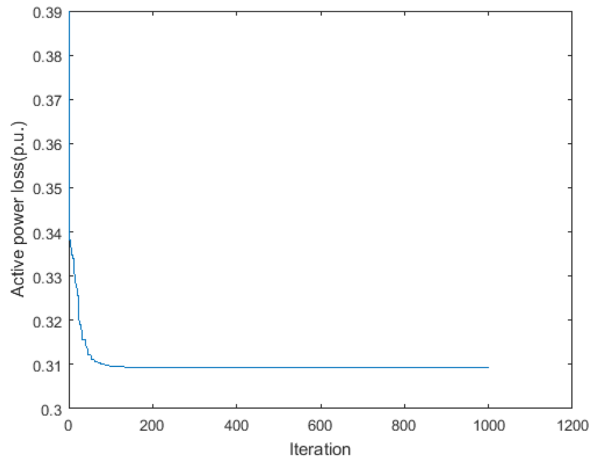

Fig.4 (c) Active power loss variations for 120% base loading using MFO for IEEE 57 bus system

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Table-8: Control variable settings using MFO, PSO & GSA at various loading in IEEE-30 bus system

Control variables	Control variable setting using various algorithms at base loading			Control variable settings using various algorithms at 110% base loading			Control variable settings using various algorithms at 120% of base loadings		
	MFO	PSO	GSA	MFO	PSO	GSA	MFO	PSO	GSA
$Q_g(2)$	0.4160	0.6000	0.6000	0.4759	0.1463	0.4886	0.4235	0.1463	0.3784
$Q_g(5)$	0.4848	0.0000	0.6250	0.4106	0.0419	0.4534	0.4257	0.0419	0.4614
$Q_g(8)$	0.3359	0.0000	0.1491	0.3692	0.1049	0.3452	0.3507	0.1049	0.3652
$Q_g(11)$	0.2766	0.4000	0.4000	0.2998	0.1388	0.2561	0.2918	0.1388	0.2847
$Q_g(13)$	0.2858	0.0000	0.2736	0.3805	0.0000	0.3077	0.2878	0.2129	0.3339
SVC(7)	0.1163	0.0000	0.0000	0.1143	0.0000	0.1097	0.1087	0.0000	0.1171
SVC(15)	0.1086	0.0000	0.0120	0.1123	0.0000	0.1175	0.1108	0.0000	0.1009
SVC(17)	0.1210	0.0000	0.0000	0.1188	0.0965	0.1184	0.1141	0.0000	0.1163
SVC(21)	0.1047	0.0000	0.0000	0.1185	0.0000	0.1136	0.1207	0.0000	0.1224
tap(11)	1.0213	0.9000	1.1000	1.0185	0.9000	1.0130	1.0234	0.9000	1.0226
tap(12)	1.0052	0.9000	0.9000	1.0257	0.9704	1.0168	1.0181	1.0609	1.0212
tap(15)	1.0060	0.9200	1.1000	1.0189	0.9242	1.0102	1.0185	0.9765	1.0121
tap(36)	1.0180	0.9000	0.9000	1.0059	0.9000	1.0218	1.0183	0.9000	1.0030
$X_{TCSC}(5)$	0.0479	0.1463	0.0600	0.0492	0.0000	0.0456	0.0464	0.6000	0.0421
$X_{TCSC}(25)$	0.0441	0.0419	0.0600	0.0440	0.0000	0.0486	0.0519	0.0000	0.0434
$X_{TCSC}(28)$	0.0508	0.1049	0.0600	0.0488	0.5000	0.0556	0.0499	0.5000	0.0480
$X_{TCSC}(41)$	0.0477	0.1388	0.0600	0.0478	0.0478	0.4000	0.0451	0.4000	0.0451

Table-9: Control variable settings using MFO, PSO & GSA at various loading in IEEE-57 bus system

Control variables	Control variable setting using various algorithms at base loading			Control variable settings using various algorithms at 110% base loading			Control variable settings using various algorithms at 120% of base loadings		
	MFO	PSO	GSA	MFO	PSO	GSA	MFO	PSO	GSA
$Q_g(2)$	0.3997	0.4338	0.0141	0.3562	0.0000	0.3997	0.3545	0.0331	0.3564
$Q_g(3)$	0.4669	0.5313	0.4836	0.4487	0.0000	0.4669	0.3990	0.0304	0.4488
$Q_g(6)$	0.1732	0.2500	0.1017	0.1582	0.0163	0.1732	0.1551	0.0163	0.1583
$Q_g(8)$	1.4170	0.2000	1.1694	1.5677	0.0000	1.4170	1.4342	0.0410	1.5675
$Q_g(9)$	0.0634	0.0900	0.0614	0.0607	0.2872	0.0634	0.0748	0.3039	0.0607
$Q_g(12)$	0.9972	0.3809	0.3918	0.9053	0.0937	0.9972	1.1825	0.1027	0.9055
SVC (49)	0.1218	0.2246	0.2987	0.1223	0.3211	0.1218	0.1304	0.7092	0.1223
SVC (25)	0.1189	0.0169	0.2347	0.1127	0.9000	0.1189	0.1212	0.9000	0.1126
SVC (38)	0.1153	0.4064	0.2067	0.1155	0.9000	0.1153	0.1195	0.9000	0.1156
tap(19)	1.0110	0.9763	1.0197	1.0185	0.9001	1.0110	1.0209	0.9000	1.0186
tap(20)	1.0153	0.9016	0.9505	1.0279	0.9000	1.0153	1.0128	0.9000	1.0280
tap(31)	1.0110	0.9486	0.9519	1.0271	0.9026	1.0110	1.0010	0.9000	1.0272
tap(37)	1.0211	0.9808	1.0460	1.0148	0.9000	1.0211	1.0281	1.1000	1.0150
tap(41)	1.0126	0.9387	0.9567	1.0128	0.9000	1.0126	1.0179	1.1000	1.0127
tap(46)	1.0212	0.9572	1.0280	1.0238	0.9251	1.0212	1.0281	0.9000	1.0237
tap(54)	1.0359	0.9374	0.9829	1.0128	0.9000	1.0359	1.0126	0.9000	1.0128
tap(58)	1.0043	0.9234	0.9822	1.0095	0.9000	1.0043	1.0194	0.9000	1.0096
tap(59)	1.0208	0.9626	0.9800	1.0150	1.0125	1.0208	1.0185	1.1000	1.0150
tap(65)	1.0001	0.9414	0.9776	1.0110	0.9173	1.0001	1.0000	0.9000	1.0109
tap(66)	1.0158	0.9584	0.9554	1.0101	0.9424	1.0158	1.0184	0.9000	1.0101
tap(71)	1.0076	0.9264	1.0041	1.0182	1.0187	1.0076	1.0046	1.0116	1.0181
tap(73)	1.0086	0.9129	1.0158	1.0213	0.9000	1.0086	1.0117	0.9000	1.0213
tap(76)	1.0088	0.9285	0.9523	1.0105	0.9228	1.0088	1.0149	0.9000	1.0106
tap(80)	1.0161	0.9580	1.0232	1.0100	1.0078	1.0161	1.0023	1.1000	1.0099
$X_{TCSC}(39)$	0.0505	0.0331	0.0597	0.0485	0.0000	0.0505	0.0528	0.0000	0.0485
$X_{TCSC}(13)$	0.0483	0.0410	0.0025	0.0490	0.0000	0.0483	0.0458	0.2500	0.0490
$X_{TCSC}(61)$	0.0501	0.0163	0.0002	0.0519	0.2000	0.0501	0.0498	0.2000	0.0519

VI. CONCLUSION

The efficacy of the MFO-based algorithm is based on IEEE 30 and IEEE 57 bus system for power system planning in this research work. The results of optimization methods based on PSO and GSA are compared with results obtained by MFO based approach. It is found that MFO yields better results than PSO, more comparable to GSA in IEEE 30 bus system and it gives better result as compared to PSO and GSA in IEEE 57 bus system for base, 110% and 120% loading. In both the IEEE 30 and the IEEE 57 bus system the active power loss and therefore running costs are significantly reduced. It can therefore be concluded that MFO can be regarded as a better technique of optimization for VAR planning of power systems.

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