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Optimal Allocation of Multiple Facts Devices with Hybrid Techniques for Improving Voltage Stability

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ABSTRACT: Now-a-days load configuration and load demand are increasing progressively, because of that power flows in the transmission lines are well over their normal limits and are not loaded up to their full capacity. For that reason, uneven load distribution occurs, so the voltage profile of the system gets declined which shows an insecurity of the power system. Likewise, voltage stability is one of the challenging issues developed by the services and it frequently occur on power systems that are severely overloaded, faulted or shortage of reactive power. Flexible Alternating Current Transmission Systems (FACTS) plays a significant role in enhancing the behavior of the system and it requires efficient primary financing. In this research, FACTS devices such as Static Var Compensator (SVC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controllers (UPFC) are applied on IEEE 30 system to validate the performance. The functions in this classes are difficult since there is a possibility of being stuck in various local optima while exploring the global optima. Also, improper placement in the system leads to high power loss, more deviation in voltage, etc. Therefore, a good hybrid meta-heuristic algorithm is one that can find an optimum solution. So, an efficient optimization technique called hybrid Kinetic Gas Molecule Optimization (KGMO) with Particle Swarm Optimization (PSO) is proposed for solving the allocation problem in this work. The performance measurement of the FACTS with KMGO-PSO is validated from MATLAB, which shows considerably superior results when compared with other techniques.

Keywords: FACTS (Flexible AC Transmission System), KGMO (Kinetic Gas Molecule Optimization), Particle Swarm Optimization (PSO), Static Var Compensator (SVC), Thyristor controlled Series Compensator (TCSC), UPFC (Unified Power Flow Controller).

Abbreviations: FACTS, Flexible Alternating Current Transmission Systems; SVC, Static Var Compensator; TCSC, Thyristor Controlled Series Compensator; UPFC, Unified Power Flow Controllers; KGMO, Kinetic Gas Molecule Optimization; PSO, Particle Swarm Optimization; GSA, Gravitational Search Algorithm; CKHA, Chaotic Krill Herd Algorithm; ICA, Imperialistic Competitive Algorithm; TCR, Thyristor Controlled Reactor; TSC, Thyristor Switched Capacitor.

I. INTRODUCTION

Furthermost the world's electric power supply systems are more widely interconnected with all networks to integrate overall capacity. This research is mainly implemented for economic reasons to reduce the cost of electricity and improve power system consistency [1]. As power transfers develop, the system becomes progressively more difficult to control and it turns out to be less protected for riding over the main outages. Some applications of FACTS devices show that they are proper and effective tools to control the technical parameters of power systems [2]. It can be similarly utilized to increase the transmission line capability to their maximum thermal limit, and to enhance the transmission system security with minimum infrastructure investment [3]. Rapid growth in power generation/transmission/distribution has come along with increased power supply quality challenges among the voltage profile [4]. One of the main issues which are related through a strained system that having either voltage collapse or instability. About the modeling and selection of possible locations for the installation of FACTS devices have been discussed in [5, 6]. During a strained situation, placing shunt FACTS regulators at suitable positions is the best manner to protect the network from voltage drop to deliver reactive power provision. Placing FACTS is the utmost way for services to enhance the voltage stability margin of the network. On the other hand, to achieve better performance from those controls, appropriate employment and sizing of above-mentioned devices are essential [7].

Due to the growth of electricity demands and transactions in power markets, existing power networks need to be improved to increase their load ability [8]. For confronting some significances, FACTS is the most familiar strategy. Conversely, some exclusive procedures must be located in an ideal position with finest settings [9]. From optimization viewpoint, optimum placement of FACTS is a most difficult issue, since it is extremely multi-modal and constrained one [10]. The efficiency of FACTS controls primarily be determined by the position of control devices. To assign the FACTS conferring to their features, numerous objectives have been measured [11].

The functions in this group are complex because there is a risk of being trapped in many local optima when finding the global optima. Therefore, a good metaheuristic algorithm is one that can find an optimum solution that is close to the actual global minimum with a high convergence rate and escapes from the local optima. The only option to keep the system free from the voltage failure is to scale down the reactive power load or attach added reactive power before arriving at the point of the voltage failure. To accomplish a safe and cost-effective function. FACTS controllers at suitable location are the most actual approach for services to enhance the voltage steadiness of the system. Global Harmonic Search Algorithm (HSA) [12], Particle Swarm Optimization [13], Sensitivity Analysis [14], Biogeography Based Optimization [15] is used to optimally place the FACTS (SVC, TCSC, UPFC and IPFC) for solving multi-objective problem. In the present development, voltage stability exploration has turn out to be vital for protecting power system operation and acceptable model. The voltage collapse is the procedure by which voltage uncertainty causes voltage loss in a substantial portion of the system. The process by which the structure of procedures attending voltage uncertainty leads to a shutdown or unusually low voltages in the power system. Meanwhile, optimization methods are playing a main part in producing more efficient outcome for such difficulties. So, a modest, quick and computationally achievable method to monitor the voltage stability which is proposed here termed as hybrid KGMO-PSO. Nowadays, only a few optimization techniques are developed with FACTS devices for solving above mentioned problems. KGMO with PSO is proposed for solving Multi objective problem. FACTS devices (SVC, TCSC, and UPFC) are allocated at optimal nodes to provide optimal RPD (Reactive Power Dispatch) that minimizes the power losses, total voltage deviation, L-index, cost and line loading with control variables of generator voltage, tap setting of the transformer and reactive power of shunt compensators.

II. LITERATURE REVIEW

The researchers have suggested several numbers of methods for optimal placement problem in the IEEE standard bus system. In this section, a brief review of a few significant contributions to the above mentioned issues is presented.

Jordehi [16] presented an Imperialistic Competitive Algorithm (ICA) for solving complex optimization issues in different fields. The proposed method is used to optimally allocate the FACTS to enhance security. Since the perspective of the standard deviation of surplus metrics, ICA delivers improved performance than previous meta-heuristics. In common, the fitter global solution will exist but it requires more search effort (higher number of function evaluations).

Prasad and Mukherjee [17] demonstrated novel symbiotic organisms search algorithm which is employed on modified IEEE-30 and IEEE-57 bus test system with FACTS devices installed at the specified location to comprehensively investigate the operation of the suggested method in solving the OPF issues. The proposed SOS based convergence profile of objective function for this system is found to be a promising one. One major limitation of the exact solution is that it is designed to solve some specific problems, which therefore limits its application area.

Mukherjee & Mukherjee [18] proposed Chaotic Krill Herd Algorithm (CKHA) for ORPD considering FACTS controller to enhance the scalability and robustness of the system. CKHA is executed and its presentation is verified effectively on standard IEEE 30-bus system. The measured system representations are prepared with two categories of FACTS controllers (namely, TCSC and thyristor controlled phase shifter). Although, the criteria of standard deviations and its proportional excluding of reactive power loss meant for the described procedures are not obtainable.

Inkollu & Kota [19] demonstrated a new method for enhancing the FACTS to preserve the voltage constancy in the transmission network. Here, PSO and adaptive Gravitational Search Algorithm (GSA) are projected for enhancing the stability of the network. In the suggested method, PSO is utilized for improving the gravitational constant and to enhance the searching operation of GSA. But, the proposed method was not suitable for a large system.

Safari *et al.*, [20] proposed an optimal setting and employment of FACTS controller using strength Pareto multi-objective evolutionary algorithm to reduce stability issues. This method approves the effectiveness of the suggested method which makes it favorable for the purpose of combinatorial issues of FACTS position and site in large scale system. But the exhaustive search is very time-consuming.

From the literature review, it concludes that growing power necessity influences the power systems to function at their determined operating settings. This precedes the system into voltage uncertainty and produces voltage drop. To eliminate this issues, FACTS devices have been utilized in power systems to improve stability with considerably minimized economical evaluations. To accomplish this objectives, FACTS devices must be positioned in definite position. This research proposed an efficient optimization algorithm (hybrid KGMO-PSO) to find these devices of proper sizing and minimum cost in the transmission system.

III. MODELLING OF FACTS DEVICES

A.SVC Modelling

The static VAR compensator is one of the shunt associated devices, which is installed in parallel with bus and can generate power at the point of connection. SVC is a shunt coupled static VAR absorber whose result is modified to convert inductive or capacitive current to maintain particular constraints of power systems. The SVC is a common term for a Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC). It performs in two different modes: inductive and capacitive mode. Absorbs reactive power in inductive mode and injects reactive power in capacitive mode. It is demonstrated as an optimal reactive power injection at the bus. The reactive power is limited as follows -100 MVAR ≤ QSVC≤ 100 MVAR [18].

Illustrating from Fig. 1, the location of SVC at a node is stated as follows

$$\Delta Q = Q_{SVC} \quad (1)$$

where, ΔQ is size of SVC which is existed at the assigned bus. At this instant, RPD issue with placement of SVC is stated as follows.

Cost function of SVC:

Cost-svc = $0.0003*s^2 – 0.3051*s + 127.38$ (2)

where s is the functional limits of facts devices

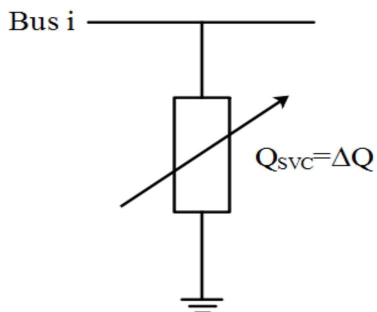

Fig. 1. The injections of Δ*Q* as size of SVC at Bus i.

B. TCSC Modelling

TCSC is significant FACTS device that is able to alter the value of the transmission line reactance by adding either a capacitive or inductive component to the main transmission line reactance. In this research, the reactance value of the feeder is tuned by T_{CSC} promptly. The evaluation of TCSC is based upon the reactance of the line where the TCSC is placed. It is expressed as follows.

$$X_{TCSC} = r_{TCSC} . X_{Line} \quad (3)$$

Here, X_{Line} denotes reactance of the transmission line and r_{TCSC} denotes the coefficient, it represents the degree of composition by TCSC. To eliminate overcompensation, the working range of TCSC is selected between –0.8*X* line and 0.2*X* line. By reducing the reactance amongst those ranges, the ideal position of reactance value can be attained [16].

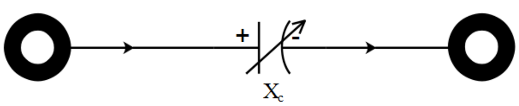

Fig. 2. Equivalent model of TCSC.

Stated from the Fig. 2, it is distinguished that, the corresponding TCSC is considered as a variable capacitive reactance which is adjusted as per the necessity of load requirement. The equivalent process will be presented in the projected study. Further kind of FACTS will present additional possibility for enhancing the RPD performance.

Cost function of TCSC:

Cost – $t_{csc} = 0.0015*s^2 – 0.7130*s + 153.75$ (4)

C. UPFC Modelling

UPFC is a versatile FACTS' device, which simultaneously controls the active power, reactive power, and bus voltage. The UPFC device combines the properties of series/shunt controller. It is two converter series-shunt FACT controller, which has better power flow and the voltage control capability compared to one converter FACTS controller. UPFC is one of the utmost favorable FACTS controller for load flow analysis. Meanwhile, it controls reactive and active power flow along with the lines and nodal voltage simultaneously. Power flow over the line essentially based on the following factors such as line reactance, phase angle and bus voltage, which is expressed in Eqn. (6).

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\delta_i - \delta_j) \quad (5)$$

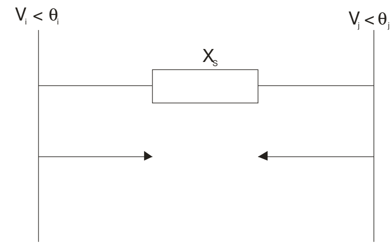

Fig. 3. UPFC model.

UPFC model is illustrated in Fig. 3. Considering the load flow program, UPFC model can be easily injected. If UPFC is placed in between the nodes i and j in the system, the admittance matrix is adjusted by injecting reactance value which is equivalent to X_S in amongst the two nodes. Jacobian matrix also changed by insertion of suitable injected power. The above figure implies that the net active power exchange of UPFC with the system is zero, as it is supposed to be UPFC with lossless one.

Cost function of UPFC :

Cost – UPFC = $0.0003*s^2 – 0.2691*s + 188.22$ (6)

IV. PROPOSED METHOD

Control strategy for FACTS controllers may be designed by using intelligent, adaptive digital controllers based on measured information obtained from wide-area networks. To confirm the safety for the operation of power-system by management of various FACTS devices in the same structure as well as in the adjacent structure too. It is important that the system is investigated extensively. Flowchart for the FACTS device allocation is shown in Fig. 4.

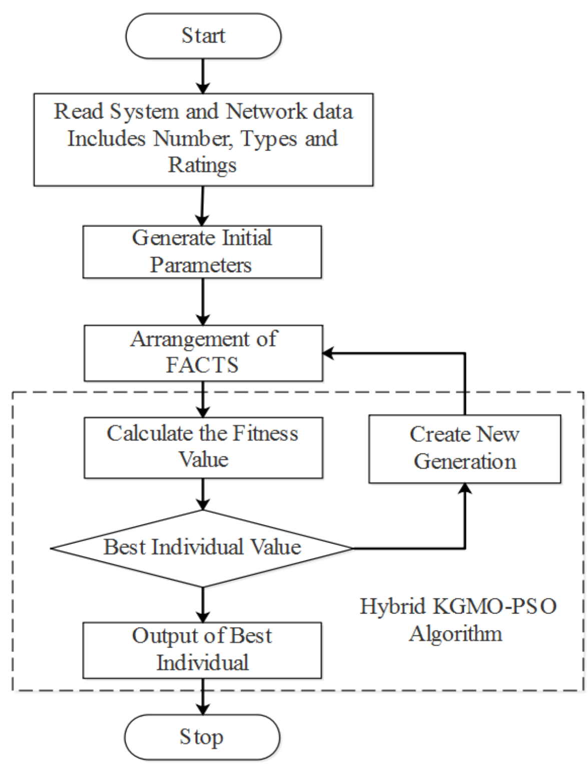

Fig. 4. Flowchart for FACTS allocation.

Step 1: Initialize the process with common control parameters that present inside the algorithm.
Step 2: Read the line data and bus data for IEEE-30 bus test system.
Step 3: In that data, at first random allocation of FACTS devices will be analyzed. For those particles, load flow analysis will also be checked.
Step 4: And then, run the fitness function (Power loss and Voltage profile) of this particular data.
Step 5: From the data, find the best fitness values that will be given to system data, which will be processed again for the next iteration.
Step 6: While considering the optimized algorithm (Hybrid KGMO-PSO), same load flow analysis will be checked with a proposed method to find the best fitness values.
Step 7: To find out the best fitness values, random location will be given primarily for placing the FACTS devices. In order to control the power loss and voltage stability values, best position and sizing of FACTS can be calculated.
Step 8: From the best values, FACTS devices will be optimally located with the help of the proposed method, and multi-objectives will be evaluated with proper placement of FACTS devices.

A. Kinetic Gas Molecule Optimization

KGMO is a swarm-based algorithm for solving nonlinear problems, which works based on gas molecule theory. The gas molecules are the agents in the search space and kinetic energy is used as the basis of performance measurement and control [24, 25]. Considering a system with agents (gas molecules), the position of the i[th] agent is defined by:

$X_i = (x_i^1, \ldots, x_i^d, \ldots v_i^n)$ for $i = 1,2,\ldots,N$ (7)

where v_i^d represents the velocity of the i^{th} agent in the d^{th} dimension and the velocity of the ith agent is presented by:

$V_i = (v_i^1, \ldots v_i^d, \ldots, v_i^n)$, for $(i = 1,2,\ldots,N)$ (8)

where v_i^d represents the velocity of the ith agent in the dth dimension. Fundamental equations in KMGO are as below:

The kinetic energy, which is defined as *N*

$k_i^d(t) = \frac{3}{2} N b T_i^d(t)$, $K_i = (k_i^1, \ldots k_i^d, \ldots, k_i^n)$, for $(i = 1,2,\ldots,N)$ (9)

where b is the Boltzmann constant, N is the number of gas molecules and $T_i^d(t)$ is the temperature of ith agent in the dimension dth.

The velocity of the molecule is updated by:

$$v_i^d(t+1) = T_i^d(t) w v_i^d(t) + C_1 rand_i(t)\left(gbest^d - x_i^d(t)\right) + C_2 rand_i(t)(pbest_i^d(t) - x_i^d(t)) \quad (10)$$

where $T_i^d(t)$ for converging molecules reduces exponentially over time, calculated as:

$T_i^d(t) = 0.95 \times T_i^d(t-1)$ (11)

The minimum fitness function is found using:

$pbest_i = f(x_i)$ if $f(x_i) < f(pbest_i)$ (12)

$gbest_i = f(x_i)$ if $f(x_i) < f(gbest_i)$ (13)

Each gas molecule tries to modify its position (x_i^d) using the distance between the current position and $pbest_i^d$, and the distance between the current position and $gbest_i$

B. Particle Swarm Optimization

PSO has a group of individuals (swarm particles) moving in a search space to explore the best solution. A vector s of length n indicates each particle's position and velocity of particles is denoted as v. The particle's current position updated by velocity v in each iteration. In the solution space, each particle tracks its co-ordinates which relate to the best solution (fitness). This solution is denoted as $pbest$ that is personal best. Then one more best value is determined by comparing the each particle with its neighborhood particle and the value is denoted as $gbest$. The following formulations are used to modify each particle's position.
– The current positions,
– The current velocities,
– The distance between the current position and $pbest$,
– The distance between the current position and $gbest$.

The velocity updation of every particle is given in Eqn. (14) and the position updation is given in the Eqn. (15).

$v_i^{k+1} = w v_i^k + c_1 r_1 (pbest_i - s_i^k) + c_2 r_2 (gbest - s_i^k)$ (14)

$s_i^{k+1} = s_i^k + v_i^{k+1}$ (15)

where, the weighting factors are c_1 and c_2; the random numbers between 0 and 1 are r_1 and r_2; the weighting function is w; current velocity of particle i at iteration k is v_i^k; modified velocity of particle i is v_i^{k+1}; current position of particle i at iteration k is s_i^k; modified position of particle i is s_i^{k+1}; personal best of particle i is $pbest_i$ and global best of the group $gbest$.

C. Flowchart for Hybrid KGMO-PSO

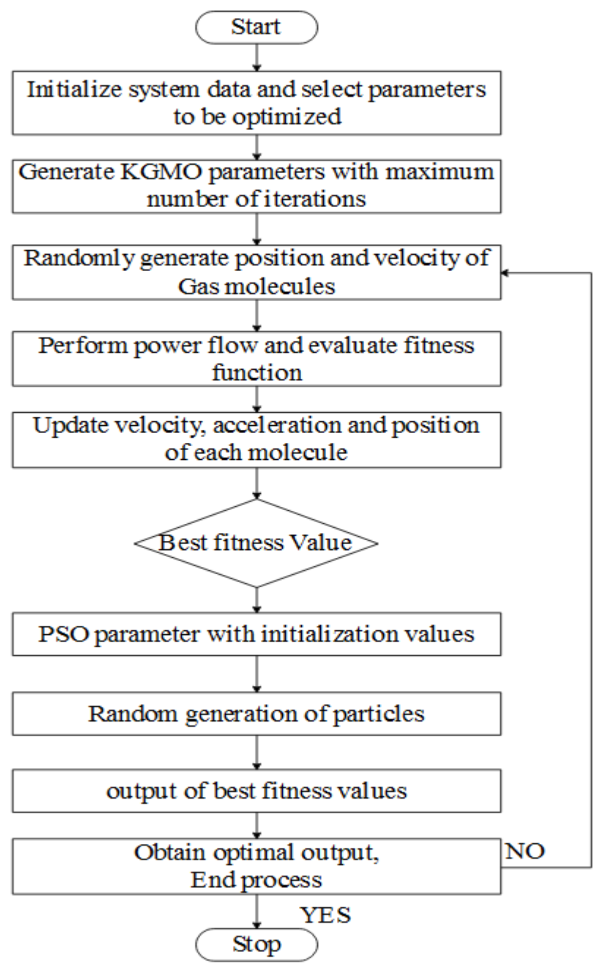

Fig. 5. Flowchart of Hybrid KGMO-PSO algorithm.

The flowchart of proposed technique is shown in Fig. 5. and the step-wise process of Hybrid KGMO-PSO for eliminating RPD issues is as follows:

Step 1: Choose the constraints to be enhanced for every molecule.

In this research; five cases are considered;

1.1 Without FACTS = 19 {6 Generator, 4 Transformer taps & 9 Shunt compensators} 1.2 with SVC = 21 {along through above 19, SVC size & location}

1.3 Using TCSC = 21 {combined with above 19, TCSC location & size}

1.4 With UPFC = 23 {along with using the above 19, UPFC locations, voltage, angle and impedance}.

1.5 With all FACTS devices = 27 {combined using above 19, SVC, TCSC& UPFC size & locations}.

Step 2: Choose N number of molecules for find a search space in a container,

Step 3: Specify the Boltzmann constant, mass, temperature, coefficient of cognitive c1, Inertia weight, coefficient of social c2 and iteration count,

Step 4: Primarily set the velocity and position of every single molecule,

Step 5: Calculate the value of kinetic energy, update velocity and acceleration of each molecule,

Step 6: Calculate each molecule with its updated position.

Step 7: Calculate the fitness function of each molecule with multi-objective functions,

Step 8: Represent the global best and personal best positions of each molecule,

Step 9: The optimal values from the KGMO such as FACTS location and size are given as the input to PSO for finding the optimal location and size. Then randomly generates the swarm particles. PSO received the location and size from the KGMO to identify the quality of the solution. Step 10: Evaluate the best fitness from the randomly generated particles.

Step 11: If it provides the best location and size, it will display the optimal solution otherwise this process goes back to KGMO process again to get the best solution.

Step 12: In this study, the stopping criterion is set to the maximum generation of 100 iterations. The iteration stopped, when satisfying the stopping criterion, and the result of PSO is obtained.

The optimal FACTS location and size are evaluated from the hybrid KGMO-PSO methodology. The DG's are placed, when the bus has more power loss compared to other bus.

VI. SIMULATION RESULTS AND DISCUSSION

The hybrid KGMO-PSO optimization algorithm is concerned to resolve the multi-objective problem in IEEE 30 -BUS system for validating its efficiency in performance. In order to judge the effects of FACTS devices on system loss and voltage deviation, corresponding values of these parameters need to be determined. By carrying Newton Raphson load flow it is found that for uncompensated IEEE14 bus system transmission loss and voltage deviation stands at definite values. In the proposed technique, at particular population the control variables and velocity are produced within the limits. In spite of investigation, the extreme points of power losses, total voltage deviation, cost and line loading are minimized by using proposed algorithm as well as bus data, line data, generator data and control variable limits will be adapted. For considering in IEEE 30 -BUS system without FACTS device optimizing 19 control parameters, which incorporates Generator, Transformer taps and Shunt compensators. For including the FACTS devices (SVC, TCSC and UPFC), total of 27 control parameters to be optimized with the support of the proposed method.

One way of handling a multi-objective problem is to combine the specified goals of the optimization problem and construct a scalar function and so apply a common scalar optimization approach to solve the problem. The major superiority of this approach is unavailability of any straightforward methods for combining the objectives of the problem while they vary constantly. Though FACTS devices have many advantages as discussed above, its high cost due to incorporation of sophisticated power electronics devices is a matter of concern. In order to maximize the economic benefit optimal placement and sizing of FACTS devices is a must.

After finding the optimal location of various FACTS devices, optimal capacity of FACTS devices has been obtained using KGMO-PSO by placing various combinations of SVC, TCSC and UPFC at their suitable locations in both IEEE-14 and IEEE-30 bus system.

To analyze the proficiency of KGMO-PSO performance for SVC, TCSC and UPFC location in multi-objective problem. The facts of the bus structure are presented in below Table 1 as follows.

Table 1: IEEE 30 bus system data [21].

Item	Control parameters
Generators	6 buses {1, 2, 5, 8, 11, 13}
Transmission lines	41
Transformers	4 locations {6 –9, 6 –10, 4 –12 and 27 –28}
Shunt compensators	9 locations {10, 12, 15, 17, 20, 21, 23, 24 and 29}

In order to verify the performance, following scenarios are executed.

Scenario 1: Without FACTS devices

Scenario 2: Proposed Method with control variables

Scenario 3: Proposed Method with SVC

Scenario 4: Proposed Method with TCSC

Scenario 5: Proposed Method with UPFC

Scenario 6: Proposed Method with SVC, TCSC and UPFC.

For first scenario, only with control variables the above mentioned performances are measured, that are illustrated in the Table 2.

Scenario 1:

Table 2: Base case with Control Variables.

Control Variables	Initial Values
V1	1.0500
V2	1.0400
V5	1.0100
V8	1.0100
V11	1.0500
V13	1.0500
T11	1.0780
T12	1.0690
T15	1.0320
T36	1.0680
Qc10	0.0000
Qc12	0.0000
Qc13	0.0000
Qc17	0.0000
Qc20	0.0000
Qc21	0.0000
Qc23	0.0000
Qc24	0.0000
Qc29	0.0000
TVD	1.47
Ploss	5.74
LL	6.42

From Table 2, only 19 control parameters are considered. Base case value of TVD is obtained as 1.47, Ploss value is 5.74 MW and line loading is 6.42.

Scenario 2:

Table 3: Comparison for KGMO_PSO with Control Variables.

Control Variables	Initial Values	Optimal Values
V1	1.0500	1.0538
V2	1.0400	1.0110
V5	1.0100	1.0287
V8	1.0100	1.0471
V11	1.0500	1.0302
V13	1.0500	1.0408
T11	1.0780	0.9865
T12	1.0690	1.0050
T15	1.0320	1.0288
T36	1.0680	0.9791
Qc10	0.0000	3.3520
Qc12	0.0000	1.6031
Qc13	0.0000	2.0689
Qc17	0.0000	3.5121
Qc20	0.0000	4.1709
Qc21	0.0000	2.4442
Qc23	0.0000	2.0347
Qc24	0.0000	3.7086
Qc29	0.0000	1.8766
TVD	1.47	0.21442
Ploss	5.74	5.2105

From Table 3, KGMO with control parameters are considered. The value of TVD is obtained as 0.2144, P_{loss} value is 5.2105 MW. When compared with above mentioned base case scenario, proposed algorithm gives better results in all the performances. The fitness graph for proposed KGMO-PSO is shown in below Fig. 6.

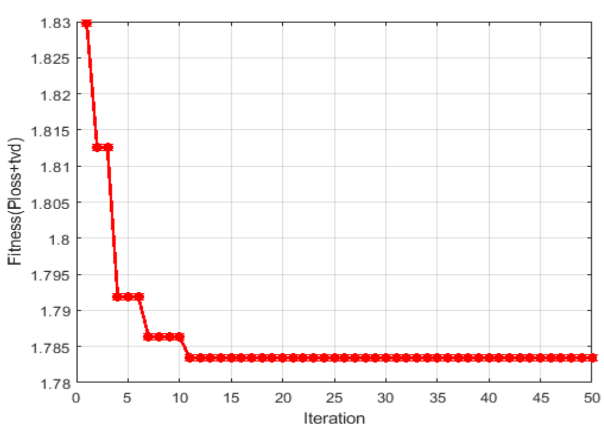

Fig. 6. Fitness graph for proposed method.

Scenario 3:

From Table 4, the proposed method with SVC device are considered. The value of TVD is obtained as 0.2144, P_{loss} value is 5.2105 MW and line loading value is 5.1284. In this scenario, when compared with excluding of FACTS, it provides better performance. With the assistance of proposed method, SVC is allocated in ideal position by providing less power loss and total voltage deviation. The fitness function graph is illustrated in Fig. 7.

Table 4: Comparison for KGMO_PSO with SVC.

Symbol	Initial values	Proposed Method with SVC
V1	1.0500	1.0321
V2	1.0400	1.0059
V5	1.0100	0.9898
V8	1.0100	1.0005
V11	1.0500	1.0527
V13	1.0500	1.0117
T11	1.0780	1.0067
T12	1.0690	0.9503
T15	1.0320	1.0314
T36	1.0680	0.9657
Qc10	0.0000	3.1151
Qc12	0.0000	1.9988
Qc13	0.0000	2.4809
Qc17	0.0000	2.9716
Qc20	0.0000	1.8070
Qc21	0.0000	1.3121
Qc23	0.0000	2.6071
Qc24	0.0000	2.2549
Qc29	0.0000	3.0175
SVC location	15.000	9.0000
SVC size	0.0000	21.1123
SVC cost	—	121.0745 $/MVAR
TVD	1.47	0.1460
Ploss (MW)	5.74	5.0231
LL	6.42	5.1284

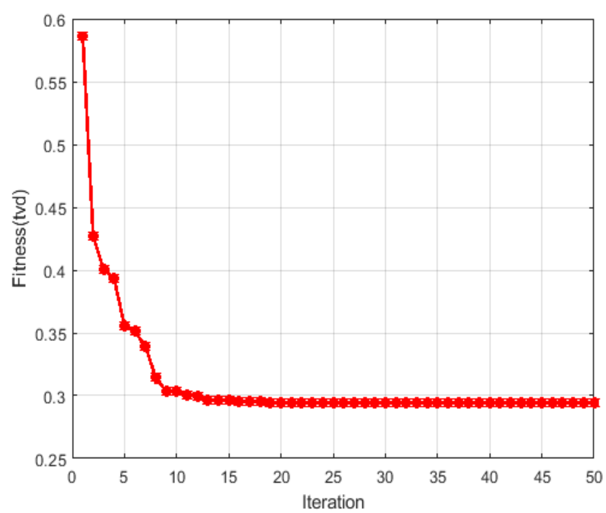

Fig. 7. Fitness graph for SVC.

Scenario 4:

From Table 5, KGMO with TCSC device are considered. The value of TVD is obtained as 0.1321, power loss value is 4.6214 MW and line loading value is 5.0354. By comparing with previous scenarios, it gives good performance in all the measurements. The fitness function graph is illustrated in Fig. 8.

Table 5: Comparison for KGMO_PSO with TCSC.

Symbol	Initial values	Proposed Method with TCSC
V1	1.0500	1.0175
V2	1.0400	1.0390
V5	1.0100	1.0138
V8	1.0100	0.9847
V11	1.0500	1.0205
V13	1.0500	1.0975
T11	1.0780	0.9814
T12	1.0690	0.9987
T15	1.0320	1.0127
T36	1.0680	0.9315
Qc10	0.0000	2.5897
Qc12	0.0000	2.8334
Qc13	0.0000	3.7273
Qc17	0.0000	3.5906
Qc20	0.0000	0.3687
Qc21	0.0000	3.0736
Qc23	0.0000	2.0993
Qc24	0.0000	1.5232
Qc29	0.0000	1.3579
TCSC location	15.000	14.0000
TCSC size	0.000	0.1979
TCSC cost	—	150.6063
TVD	1.47	0.1321
Ploss(MW)	5.74	4.6214
LL	6.42	5.0354

Scenario 5:

Table 6: Comparison for KGMO with UPFC.

Symbol	Initial values	Proposed Method with UPFC
V1	1.0500	1.0015
V2	1.0400	1.0193
V5	1.0100	1.0325
V8	1.0100	1.0607
V11	1.0500	1.0387
V13	1.0500	1.0217
T11	1.0780	0.9365
T12	1.0690	1.0153
T15	1.0320	1.0070
T36	1.0680	0.9672
Qc10	0.0000	1.9767
Qc12	0.0000	1.9585
Qc13	0.0000	3.5731
Qc17	0.0000	3.0166
Qc20	0.0000	2.0057
Qc21	0.0000	2.6892
Qc23	0.0000	3.4608
Qc24	0.0000	1.7988
Qc29	0.0000	3.5618
UPFC location	0.000	10.0000
UPFC size	0.000	0.9905
UPFC angle	0.0000	0.1051
UPFC cost	—	187.3790 $/MVAR
TVD	1.47	0.1303
Ploss(MW)	5.74	4.1284
LL	6.42	5.1345

From Table 6, the proposed method with UPFC device are considered. The value of TVD is obtained as 0.1303, power loss value is 4.1284 MW and line loading value is 4.5607. While comparing with the above mentioned scenarios like SVC and TCSC, this combination gives better results in all the performances except line loading factor. It should be observed that in case of minimum loss corresponding voltage deviation is higher than uncompensated system while for minimum voltage deviation scenario corresponding loss is higher than that of uncompensated system. However, while both are simultaneously optimized both values are found to be better than uncompensated system. Hence, it is prudent to simultaneously optimize both. The fitness function graph is illustrated in Fig. 9.

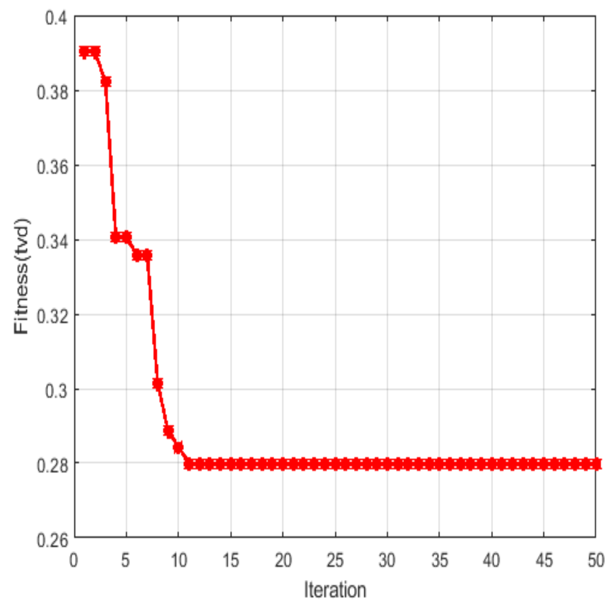

Fig. 8. Fitness graph for TCSC.

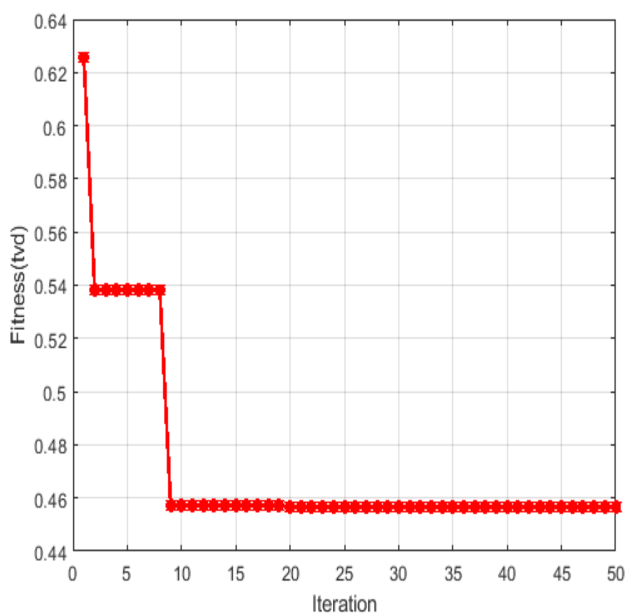

Fig. 9. Fitness graph for UPFC

Scenario 6:

Table 7: Comparison for KGMO withSVC_TCSC_UPFC.

Symbol	Initial values	Proposed Method with SVC_TCSC_UPFC
V1	1.0500	1.0361
V2	1.0400	1.0436
V5	1.0100	1.0433
V8	1.0100	1.0412
V11	1.0500	1.0602
V13	1.0500	0.9716
T11	1.0780	1.0264
T12	1.0690	0.9950
T15	1.0320	1.0141
T36	1.0680	0.9515
Qc10	0.0000	1.5605
Qc12	0.0000	2.8599
Qc13	0.0000	3.7958
Qc17	0.0000	2.2847
Qc20	0.0000	3.1794
Qc21	0.0000	1.6088
Qc23	0.0000	0.8007
Qc24	0.0000	2.7894
Qc29	0.0000	2.5274
SVC location	15.000	18.0000
SVC size	0.0000	4.5472
SVC cost	—	126.9268 $/MVAR
TCSC location	15.000	8.0000
TCSC size	0.000	0.0121
TCSC cost	—	153.1090 $/MVAR
UPFC location	0.000	8.0000
UPFC size	0.000	0.9900
UPFC cost	—	187.9779 $/MVAR
Total cost	—	468.0137 $/MVA
TVD	1.47	0.1167
Ploss(MW)	5.74	3.8786
LL	6.42	3.9729

From Table 7, the proposed method with all above mentioned FACTS devices are considered. The value of TVD is obtained as 0.1167, Ploss value is 3.8786 MW and line loading value is 3.9729. While comparing with the above mentioned scenarios like SVC, TCSC and UPFC, this combination gives better results in all the performances. The fitness function graph is shown in below Fig. 10. The figures clearly depict the impact of line loading with the optimal placement of various FACTS devices. The FACTS device placement significantly minimizes the line loading when compared with line loading without FACTS devices. This shows that the system is improved after the placement of FACTS devices. Optimal placement of UPFC minimizes the overall line loading and gives excellent security enhancement when compared with other FACTS devices. Likewise, the optimal placement of TCSC gives relatively good performance comparable with UPFC in minimizing line loading.

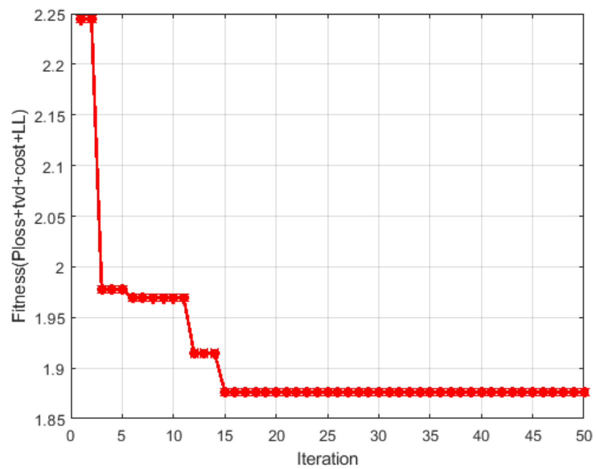

Fig. 10. Fitness graph for Multiple Devices.

The results from the hybrid KGMO-PSO algorithm is compared with the other technique which is mentioned comparison Table 8 and 9.

Table 8: Comparison of power loss for proposed method.

Parameter	PSO [22]	ABC [22]	TLBO [22]	BBO [23]	CRO [23]	QOCRO [23]	Proposed Method
Power loss	4.7883	4.7883	4.7143	4.5674	4.5521	4.5303	3.8786

Table 9: Comparison of voltage profile for proposed method.

Parameter	BBO [23]	CRO [23]	QOCRO [23]	Proposed Method
TVD	0.256	0.251	0.236	0.1167

From the above Table (8 and 9), it concluded that the proposed method gives better performance in reducing the power losses and voltage deviation. The power loss and voltage stability of the hybrid KGMO-PSO methodology is less compared to PSO, Artificial Bee Colony (ABC) and Teaching Learning Based Optimization methodology [22] and Chemical Reaction Optimization, Biogeography Based Optimization and Quasi-Oppositional Chemical Reaction Optimization [23]. Because, the combination of KGMO-PSO gives optimized location and size for the FACTS devices. Based on this optimal placement with an effective size, the power loss and reliability are improved in the transmission system. From the result it is observed that installing FACTS devices at proper magnitude at locations identified by the proposed technique will reduce the transmission loss considerably while improving the voltage profile.

VI. CONCLUSION

The conventional method is not used for getting the optimal results of the searching capability, as it takes more processing time. Therefore, it is usually hard to find the nearest optimal location for fixing the FACTS device. For this reason, in this research, the hybrid KGMO-PSO methodology is introduced to solve the location and sizing problems of FACTS devices. The hybrid KGMO-PSO methodology is implemented in IEEE 30 bus systems for decreasing the losses and improving the voltage stability. This methodology is rapid and accurate in determining the sizes and locations. The main benefit of using the hybrid technique is that it does not need more time for tuning the control parameters. The results of various test cases revealed that the proposed technique with optimal FACTS devices achieved better performance in all scenarios when compared with base case.

The power loss of proposed methodology improved for that is 3.8786 MW, it is less compared to the TLBO methodology of 4.7143 MW and QOCRO method of 4.5303 MW. Also, the voltage deviation of the proposed method is 0.1167 which is less than QOCRO [23] of 0.236. In the future, this research can be extended for large bus system with other constraints like emission and load factor. Furthermore, the effect of various FACTS devices for voltage stability enhancement can also be analyzed and compared.

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