Power System Security Analysis Using FACTS Devices by Means of Intelligent and Hybrid Techniques Under Different Loading Conditions

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Abstract Power system security issue is a severe concern in restructured power market. In order to conserve the security of a system, flexible alternating current transmission system (FACTS) apparatus are one of the options. In this work, node voltage deviations and line apparent power flow factors are taken as the security indices and these are considered as objectives for security problems. The devices considered are thyristor-controlled series capacitors (TCSCs), static VAR compensators (SVCs), and unified power flow controllers (UPFCs). The main idea of this work is to compare distinct algorithms such as hybrid differential evolution (DEPSO) and fuzzy adaptive gravitational search algorithm (FAGSA) to attain the good location of the devices on IEEE 30 bus network with loading conditions.

Keywords DEPSO · FAGSA · FACTS · TCSC · SVC · UPFC

1 Introduction

Today's power network has become tortuous and less secure with increase of power demand. FACTS apparatus can augment power system transfer capacity and flexible line flow control [1]. These devices play a major task in power system security and can control the network parameters to influence the line power flows and voltages [2–4]. There are various types of FACTS controllers: SVC [5, 6], TCSC [7], UPFC [8], etc.

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Evolutionary and fuzzy adaptive methodologies are well-liked in current years. Some reputable techniques like DE were utilized to allocate the FACTS and improve the security [9], and PSO was introduced by 'John Kennedy and Eberhart' [10]. It is important to know, the better location for FACTS since their cost and to evade needless transmission loss, in [11] GA-based optimization technique was implemented to get the fine placements and sizing of the FACTS to augment the network loadability, in [12] multiobjective optimization process was utilized to get the better placement of FACTS to optimize the cost, line losses and loadability. In [13], GA to ask for the good placement of multi-type FACTS in a network; in [14], genetic algorithm is exercised to advance power system security; in [15, 16], hybrid differential evolution is presented to resolve the power flow trouble and system security; in [17, 18], GSA technique is implemented; in [19], FAGSA is applied to resolve bidding problem; in [20], reactive power planning is presented.

In this work, the main intention is to examine the various algorithms such as DEPSO and FAGSA to set the good location of FACTS and to get the lowest cost of FACTS apparatus, minimum loss and to improve the electrical power system security, which is obtained by bringing down the security index. These algorithms are tested using the standard IEEE 30 bus system. It is noticed that power system security is augmented by minimizing the system loss and security index.

2 FACTS Device Modelling

The three FACTS utilized in this work are TCSC, SVC, and UPFC models [1, 5, 6, 12], and constraints are considered as

$$\text{(i)} - 0.8X_L \leq X_{\text{TCSC}} \leq 0.2X_L \text{P.u} \tag{1}$$

$$\begin{aligned} &\text{(ii)} \ -100\,\text{MVAR} \leq Q_{\text{SVC}} \leq 100\text{MVAR} \\ &\text{(iii) both (1) and (2) for UPFC} \end{aligned} \tag{2}$$

where X_{TCSC} is reactance [7] added to the transmission line by employing TCSC, X_L is the reactance of line, and Q_{SVC} is the reactive power interjected [5, 6] at the node. The UPFC is used to control both parameters [8, 11].

3 Power System Security

The main intention of the security [2–4], [9] is to conserve the profile of voltage and line power flow within the limits. These are modelled as voltage and line apparent power security indices 'J_v' and 'J_s' [9]

$$J_S = \sum_{i}^{n} \sum_{i,j=1}^{n} W_i \left(\frac{S_{ij}}{S_{ij}^{\max}} \right)^2 \tag{3}$$

$$J_V = \sum_{i}^{n} W_i \left| V_i - V_{\text{ref},i} \right|^2 \tag{4}$$

where i, j: node numbers

W_i	Weighing factor and taken as 1
S_{ij}	Apparent power in the $i - j$ line
$S_{ij}^{\max}$	Apparent power limit in line $i - j$
$V_{\text{ref},i}$	Nominal voltage.

4 Problem Formulation

The proposed work is to diminish the installation cost of FACTS, loss, and security indices. By combining all, objective (Objfn) or fitness function is created.

$$\text{Objfn} = F = a_1(J_S) + a_2(J_v) + a_3(\text{Total Investment Cost}) + a_4(\text{Losses}) \tag{5}$$

The cost functions in (US$/KVAR) of devices are expressed in Eqs. (6)–(8).
For TCSC

$$C_{\text{TCSC}} = 0.0015S^2 - 0.713S + 153.75 \tag{6}$$

For SVC

$$C_{\text{SVC}} = 0.0003S^2 - 0.3051S + 127.38 \tag{7}$$

For UPFC

$$C_{\text{UPFC}} = 0.0003S^2 - 0.2691S + 188. \tag{8}$$

where S is the operating range of the FACTS in MVAR [20, 21]. The coefficients a_1–a_4 will be equal to 0.25.

5 Overview of Algorithms and Its Implementation

5.1 Hybrid Differential Evolution (DEPSO)

In the DEPSO, one-to-one competition is initiated which will provide rapid convergence swiftness towards optimum. It uses fewer populations in the evolutionary procedure to get the global result [15, 16]. To get rid of the problems in DE and PSO technique [22, 23] and to get the advantages of both, the DEPSO method is developed.

The procedure is as follows:

- First produce random values of population (*N*).This is taken as parent vector.
- Determine the fitness function F_1 (*i*) for each of the particles in the parent vector, for $i = 1, 2, 3, \ldots, N$.
- Now, do the operations like selection, crossover, and mutation. The consequent vector is the target vector.
- Find the fitness value F_2 (*i*) for each agent in the target vector.
- Obtain the *G*best up to this iteration.
- Evaluate each particle or agent velocity in the parent vector using these Pbest and Gbest values.
- By using the PSO algorithm, update the positions the particles.
- By using these values, evaluate the fitness value F_3 (*i*) and compare the three fitness values.
- Now, these selected set of particles become parent vector for subsequent iteration.

5.2 Fuzzy Adaptive Gravitational Search Algorithm (FAGSA)

It is a good method for controlling the parameter and to overcome the problems of GSA [19, 24], which is used to tune the 'gravitational constant (*G*)' using 'IF/THEN' rules of fuzzy. Proper selection of '*G*' provides a brace between the global and local exploration and exploitation [8, 19]. The inputs for FIS are the current best performance evaluation as 'normalized fitness value (NFV)' and the recent '*G*'. The outputs are 'ΔG'. The membership functions are considered as triangular.

$$\mathrm{NFV} = \frac{\mathrm{objfn} - \mathrm{objfn}_{\mathrm{min}}}{\mathrm{objfn}_{\mathrm{max}} - \mathrm{objfn}_{\mathrm{min}}} \tag{9}$$

Here, the poorer value of NFV gives the superior result. Objfn is calculated from Eq. (5). The limit of 'G' is considered between 0.4 and 1.0, and NFV is considered between 0 and 1.0 and 'ΔG' range in between −0.1 and +0.1.

$$G^{t+1} = G^{t} + \Delta G \tag{10}$$

5.3 Initialization

Using the algorithms, the primary particles' population is produced haphazardly between the prearranged limits and calculated the fitness function. The FACTS variables are their placement and setting. By using these values, the objective function shown in Eq. (5) is calculated.

6 Results and Discussion

The functioning of these algorithms is examined on the IEEE-30 [25] bus, and the solutions are obtained. The FACTS apparatus setting, cost, security indices, loss were found by means of these algorithms. The FACTS are installed in a particular location to lessen the loadings of active and reactive powers by regulating the powers in other directions, and the better locations are obtained by these algorithms. This is observed from security indices J_s, J_v which are reduced by using these optimization techniques with loading conditions.

Fuzzy rules, PSO, DE, and GSA parameters are shown in Tables 1, 2, 3, and 4. The security objectives for 40% light load, 60% over load and device location, and ratings are given in Tables 5, 6, 7, and 8 and observed that the security indices and loss are lessened, and hence, security has been progressed.

Table 1 Fuzzy rules

Rule no.	NFV	G	ΔG
1	S	S	ZE
2	S	M	NE
3	S	L	NE
4	M	S	PE
5	M	M	ZE
6	M	L	NE
7	L	S	PE
8	L	M	ZE
9	L	L	NE

Table 2 Parameters of PSO

C_1, C_2	1.5
W_{max}	0.9
W_{min}	0.4
No. of swarm being	50
No. of iterations	100

Table 3 DE parameters

NP	*D*	*F*	CR	Iterations
30	2	1.2	0.5	100

Table 4 GSA parameters

NP	G_o	Iterations
30	100	100

Table 5 Security objectives under 40% light load at bus 7

	J_S			J_V			Loss			Cost ($) * 10^6	
Techniques	Base case	DEPSO	FA GSA	Base case	DEPSO	FA GSA	Base case	DEPSO	FA GSA	DEPSO	FA GSA
Without FACTS	9.7	–	–	0.0263	–	–	15.7	–	–	–	–
TCSC	–	9.28	9.23	–	0.0215	0.0205	–	15.21	15.14	2.66613	2.9784
SVC	–	9.46	9.42	–	0.0154	0.0148	–	15.24	15.19	1.9376	1.5212
UPFC	–	8.98	8.94	–	0.0143	0.0140	–	15.09	15.02	4.3664	2.7637

Table 6 FACTS placement and the ratings

	Line/bus		Rating	
Techniques	DEPSO	FA GSA	DEPSO	FA GSA
TCSC (X_{tcsc})	2–4	3–4	0.0421	0.0210
SVC (Q_{svc})	21	8	15.8	12.3
UPFC (X_{tcsc} & Q_{svc})	2–4	6–8	0.0236	−0.054
			13	9.8

Table 7 Security objectives under 60% over load at bus 7

	J_S			J_V			Loss			Cost($) * 10^6	
Techniques	Base case	DEPSO	FA GSA	Base case	DEPSO	FA GSA	Base Case	DEPSO	FA GSA	DEPSO	FA GSA
Without FACTS	11.3	–	–	0.0259	–	–	19.7	–	–	–	–
TCSC	–	10.65	10.56	–	0.0192	0.0186	–	19.18	19.14	4.2953	3.9305
SVC	–	10.79	10.74	–	0.0191	0.0169	–	19.24	19.20	2.6350	2.3701
UPFC	–	10.54	10.48	–	0.0181	0.0172	–	18.76	18.69	6.9996	7.5196

Table 8 FACTS placement and the ratings

Techniques	Line/bus		Rating	
	DEPSO	FA GSA	DEPSO	FA GSA
TCSC (X_{tcsc})	3–4	12–16	0.2441	−0.0107
SVC (Q_{svc})	3	21	21.8	19.5
UPFC (X_{tcsc} &Q_{svc})	4–6	2–4	0.0209	0.0810
			24.5	21.2

7 Conclusions

In this work, placement of FACTS apparatus is inexorable, because the utmost capacity of the system is utilized by means of establishing FACTS. Here, the problem of device placement is analysed using DEPSO and FAGSA methodology, and the gained results are compared. The effectiveness of the installation of these devices in advancement the security is measured in terms of diminishing the indices, loss, and cost. The study shows after the proper positioning of devices, security indices are lessened, thus progressing the system security. Further, analysis discloses that FAGSA shows better performance. Henceforth, the FAGSA yields a competent result which considerably diminishes security indices. The acquired results clearly depict that

1. The appropriate installation TCSC successfully lessens the loading of line when contrasted to SVC.
2. The fixing of SVC in good location raises the profile of voltage as contrasted to TCSC.
3. Appropriate UPFC incorporation furnishes better presentation in reducing both loading of line and voltage difference when contrasted to other FACTS controllers. Another significant practical problem considered for installing FACTS is the cost. UPFC is a costly device when contrasted with TCSC and SVC devices.

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