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Application of HSA and GA in Optimal Placement of FACTS Devices Considering Voltage Stability and Losses

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Abstract- Voltage collapse is instability of heavily loaded electric power systems that cause to declining voltages and blackout. Power systems are predicated to become more heavily loaded in the future decade as the demand for electric power rises while economic and environmental concerns limit the construction of new transmission and generation capacity. Heavily loaded power systems are closer to their stability limits and voltage collapse blackouts will occur if suitable monitoring and control measures are not taken. To control transmission lines, it can be used from FACTS devices.

In this paper Harmony search algorithm (HSA) and Genetic Algorithm (GA) have applied to determine optimal location of FACTS devices in a power system to improve power system stability. Three types of FACTS devices (TCPAT, UPFS, and SVC) have been introduced. Bus under voltage has been solved by controlling reactive power of shunt compensator. Also a combined series-shunt compensators has been also used to control transmission power flow and bus voltage simultaneously.

Different scenarios have been considered. First TCPAT, UPFS, and SVC are placed solely in transmission lines and indices have been calculated. Then two types of above controller try to improve parameters randomly. The last scenario tries to make better voltage stability index and losses by implementation of three types controller simultaneously. These scenarios are executed on typical 34-bus test system and yields efficiency in improvement of voltage profile and reduction of power losses; it also may permit an increase in power transfer capacity, maximum loading, and voltage stability margin.

Keywords**—**FACTS Devices, Voltage Stability Index, optimal location, Heuristic methods, Harmony search, Genetic Algorithm.

I. INTRODUCTION

ELECTRIC utilities are forced to operate the system close to their thermal and stability limits due to major hurdles such as environmental, right-of-way and cost problems for power transmission network expansion [1].

The cost of transmission lines and losses, as well as difficulties encountered in building new transmission lines, would often limit the available transmission capacity. There are many cases where economic energy or reserve sharing is constrained by transmission capacity, and the situation is not getting better. Besides, in a deregulated electric service environment, an effective electric grid is vital to the competitive environment of reliable electric service. In recent years, greater demands have been placed on the transmission network and the increase in demands will rise because of the increasing number of nonutility generators and heightened competition among utilities themselves [2]. Increasing demands, lack of long-term planning, and the need to provide open access electricity market for Generating Companies (GenCo) and utility customers, all of them have created tendencies toward less security and reduced quality of supply.

The FACTS devices *(Flexible AC Transmission Systems)* could be a means to carry out this function without the drawbacks of the electromechanical devices such as slowness and wear.

FACTS can improve the stability of network, such as the transient and the small signal stability, and can reduce the flow of heavily loaded lines and support voltages by controlling their parameters including series impedance, shunt impedance, current, and voltage and phase angle.

Controlling the power flows in the network leads to reduce the flow of heavily loaded lines, increased system loadability, less system loss and improved security of the system.

The increased interest in these devices is essentially due to recently development in high power electronics that has made these devices cost effective and increased loading of power systems, combined with deregulation of power industry [3]. On account of considerable costs of FACTS devices, it is important to place them in optimal location.

There are several papers represented in literature, which deal with the optimal placement of FACTS controllers with heuristic methods. References [4, 5] deal with the location of FACTS devices from the security index point of view. And [1, 3] discusses the location of TCPAR, TCSC, UPFC for enhancement of power system security with real power flow performance index. In [6] three heuristic methods (Tabu search, Simulated annealing and Genetic algorithm) are applied to find the optimal location of FACTS devices in a power system.

The mentioned papers did not consider voltage stability.

As we know, Reliable assessment of voltage stability of an electric power system is essential for its operation and control. To accommodate the need for accurate analysis of voltage stability a number of analytical and computational tools have been developed [7], [10]. Typically, two voltage stability problems are analyzed:

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- Determination of the maximum loading problem;
- Computation of the critical loading of the power system [11].

In this paper a harmony search heuristic method and genetic algorithm have been suggested to optimally locate the UPFC, TCPAR and SVC to control voltage stability. The effectiveness of the proposed algorithm and voltage enhancement has been demonstrated on IEEE 30 bus network.

II. Mathematical Model Of FACTS Devices

The power injected model is a good model for this study because it will handle the FACTS devices during power flow computations. This model would not affect the Y_BUS matrix and the Z_BUS matrix. In fact the power injection model is convenient and enough for power systems with FACTS devices. TCPAR and UPFC are modeled using the power injection method [12]. In a simple transmission line the parameters are connected between bus i and bus j. the voltages and angels at bus i are V_i and δi and at bus j are V_j and δj. Hence the real and reactive power from bus i to bus j could be written as:

$$Pij = Vi^2 Gij - ViVj\,[Gijcos\,(\delta ij) + Bijsin\,(\delta ij)] \quad (1)$$

$$Qij = -Vi^2\,(Bij+Bsh) - ViVj\,[Gijsin\,(\delta ij) - Bijcos\,(\delta ij)] \quad (2)$$

Where δij =δi-δj.

Similarly the active and reactive power from bus j to bus i is:

$$Pji = Vi^2 Gij - ViVj[Gijcos(\delta ij) - Bijsin(\delta ij)] \quad (3)$$

$$Qji = -Vi^{2}(Bij+Bsh) + ViVj\,[Gijsin\,(\delta ij) + Bijcos\,(\delta ij)] \quad (4)$$

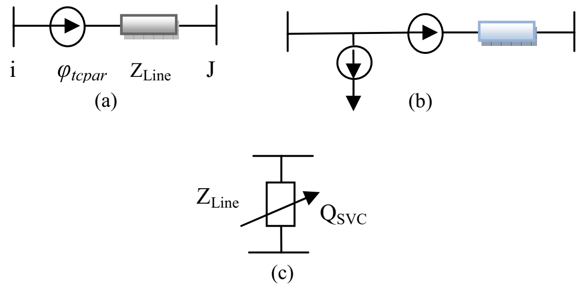

Fig. 1 Considered FACTS Devices: (a) TCPAR; (b) UPFC ;(c) SVC

A. TCPAR

The voltage angles between the buses i and j could be regulated by TCPAR. The model of TCPAR with transmission line is shown in Fig.1. The injected real and reactive power injected in buses i and j are:

$$Pi\,(com) = -Vi^2 S^2 Gij - ViVjS\,[Gijsin\,(\delta ij) - Bijcos\,(\delta ij)] \quad (5)$$

$$Pj\,(com) = -ViVjS\,[Gijsin\,(\delta ij) + Bijcos\,(\delta ij)] \quad (6)$$

$$Qi\,(com) = -Vi^2 S^2 Bij + ViVjS\,[Gijcos\,(\delta ij) + Bijsin\,(\delta ij)] \quad (7)$$

$$Qj\,(com) = -ViVjS\,[Gijcos\,(\delta ij) - Bijsin\,(\delta ij)] \quad (8)$$

Where $S = tan\varphi_{tcpar}$

B. UPFC

A series inserted voltage and phase angel of inserted voltage can model the affect of UPFC on the network. The inserted voltage has a maximum magnitude of $V_{T=}0.1Vm$, Where V_m is the rated voltage of the line, where the UPFC is connected. The real and reactive power injected at buses i and j are:

$$Pi(com) = -Vt^2 Gij \quad (9)$$
$$2ViVjGijcos(\varphi_{upfc}\delta ij) + ViVj[Gijcos\varphi_{upfc} + Bijsin\varphi_{upfc}]$$

$$Qi(com) = ViVj[Gijsin\,(\varphi_{upfc} - \delta ij) + Bijsin\varphi_{upfc}] \quad (10)$$

$$Pj\,(com) = VjVt\,[Gijcos\varphi_{upfc} - Bijsin\varphi_{upfc}] \quad (11)$$

$$Qj\,(com) = -VtVj\,[Gijsin\varphi_{upfc} + Bijcos\varphi_{upfc}] \quad (12)$$

C. SVC

SVC can be used for both inductive and capacitive compensation. In this paper SVC is modeled as an ideal reactive power injection at bus *i* :

$$\Delta Q_i = Q_{SVC} \quad (13)$$

III. Voltage Stability Index

A. Definition

Voltage stability is the ability of a system to maintain voltage so that when system nominal load is increased, the active power delivered to the load by the system will increase and both power and voltage are controllable. If the ability to maintain power transfer and voltage is lost, the system is voltage unstable. Voltage collapse is the process by which voltage instability leads to a loss of voltage in a significant part of the system. A power system will enter a period of voltage instability prior to a voltage collapse. During voltage instability, the power system is in grave danger and the system operators have lost control of system voltage and power flow. System reactive power reserve supplies will be exhausted and motors may begin to stall. If voltages decline any further, a voltage collapse may occur.

B. Review of Conventional Voltage Stability Indices

Reliable assessment of voltage stability of an electric power system is essential for its operation and control. To accommodate the need for accurate analysis of voltage stability a number of analytical and computational tools have been developed. It is important to assess voltage stability indices in the papers. Voltage stability is related to the feasibility of the power flow solution. Many voltage stability indices were proposed to measure a margin to the limitation of the power flow solution. Reference [13] presented a criterion that made use of the sensitivity of reactive power with respect to voltage. Determinant of the Jacobian matrix of the power flow equation has been presented by Afterwards in [14]. In particular, they focused on the sign of the determinant to judge if a power flow solution is stable or not. Tamura, *et al.* proposed an index that employed an angle between a pair of multiple power flow solutions [15]. That is based on the fact that a pair of multiple power flow solutions becomes closer and merges at the saddle bifurcation point as power system conditions get heavy-loaded gradually. Carpentier, *et al.* presented an index with the optimal power flow calculation [16]. The index shows that a power system lacks a large amount of reactive power if it is approaches voltage instability. Kessel and Glavitsch developed an index called *L* with the power flow calculation [17]. The index evaluates the power system conditions with the hybrid matrix. The advantage of the index is to require only one power flow calculation. Thomas and Tiranuchit presented a method that used the minimum singular value of the singular value decomposition technique [18]. Afterwards, Lof, *et al.* speeded up the method of Thomas and Tiranuchit with the sparse matrix technique [19,20].

P-V curves have been traditionally used as graphical tools for studying voltage stability in electric power systems. Fig. 2 conceptually shows the impact of a synchronous generator on voltage stability of a hypothetical node. In this paper, index *L* is used due to the computational efficiency.

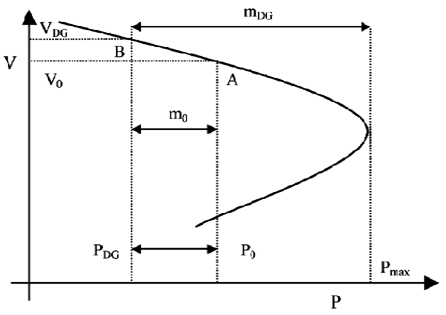

Fig. 2 P-V curves for studying voltage stability in power systems

C. Voltage Stability Index L

The voltage stability index *L* is based on the hybrid matrix of circuit theory. it is considered that nodes in a power network may be divided into α_L and α_G.

α_L :load nodes

α_G :generation nodes

The transmission system may be written as:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = [H] \begin{bmatrix} I_L \\ V_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \quad (14)$$

Where:

H: hybrid matrix

V_L (*IL*): voltage (current) at load node

V_G (*IG*): voltage (current) at generation node

Z_{LL}, F_{LG}, K_{GL}, Y_{GG}: sub-matrix of matrix *H*

The voltage stability index at load node *j* may be written as [21]:

$$L_j = \left| 1 + \frac{V_{0j}}{V_j} \right| \quad (15)$$

Where $V_{0j} = -\sum_{i \in \alpha_G} F_{ji} V_i$

Therefore, the voltage stability index for the whole network may be expressed as:

$$L = Max L_j \qquad j \in \alpha_L \quad (16)$$

Index *L* varies from 0 to 1, where *L*=0 means a power network without load and *L*=1 implies voltage collapse. The index above allows the system operator to evaluate a margin to voltage instability.

IV. Harmony Search Algorithm

Over the last four decades, a large number of algorithms have been developed to solve various engineering optimization problems. The computational drawbacks of existing numerical methods have forced researchers to rely on metaheuristic algorithms based on simulations to solve engineering optimization problems. The common factor in meta-heuristic algorithms is that they combine rules and randomness to imitate natural phenomena.

Recently, Geem et al. [22] developed a new Harmony Search (HS) meta-heuristic algorithm that is an optimization technique inspired by music phenomenon. Musical performances seek to find pleasing harmony as determined by an aesthetic standard, just as the optimization process seeks to find a global solution as determined by an objective function. In music improvisation, each player sounds any pitch within the possible range, together making one harmony vector. If all the pitches make a good harmony, that experience is stored in each player's memory, and the possibility to make a good harmony is increased next time. Similarly in engineering optimization, each decision variable initially chooses any value within the possible range, together making one solution vector [23-25].

In real optimization, each musician can be replaced with each decision variable, and its preferred sound pitches can be replaced with each variable‘s preferred values.

The steps in the procedure of harmony are as follows;

Step 1. Initialize the optimization problem and algorithm parameters.

Minimize F(x) s.t xi ∈ Xi , i=1,2,3,…..N.

f(x) : objective function

x : set of each design variable (xi)

Xi : set of the possible range of values for each design variable (Lxi <Xi < Uxi) .

N : is the number of design variables

The HS algorithm parameters are also specified in this step.

These are:

- HMS : harmony memory size or the number of solution vectors in the harmony memory;
- HMCR : harmony memory considering rate ;
- PAR : pitch adjusting rate ;

- N : number of decision variables ;
- NI :number of improvisations;
- Stopping criterion.

Step 2. Initialize the harmony memory (HM).

The harmony memory (HM) is a memory location where all the solution vectors (sets of decision variables) are stored. This HM is similar to the genetic pool in the GA. HM matrix is filled with as many randomly generated solution vectors as the HMS.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \dots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \dots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \dots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \quad (17)$$

Step 3. Improvise a new harmony

In this Step, a new harmony vector, $x' = (x'_1, x'_2, \dots x'_n)$, is generated based on three rules: (1) memory consideration, (2) pitch adjustment and (3) random selection. Generating a new harmony is called ‘improvisation’.

The value of the first decision variable (x'_1) for the new vector can be chosen from any value in the specified HM range $(x_1^1 - x_1^{HMS})$. Values of the other design variables $(x'_2, x'_3, \dots x'_n)$ are chosen in the same manner.

The HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while (1-HMCR) is the rate of randomly selecting one value from the possible range of values.

$$x'_i \leftarrow \begin{cases} x'_i \in \{x_i^1, x_i^2, \dots, x_i^{HMS}\} & \text{with probability } HMCR \\ x'_i \in X_i & \text{with probability } (1 - HMCR) \end{cases} \quad (18)$$

For instance, a HMCR of 0.90 indicates that the HS algorithm will choose the decision variable value from historically stored values in the HM with the 90% probability or from the entire possible range with the 100–90% probability. Every component of the new harmony vector, $x' = (x'_1, x'_2, \dots x'_n)$, is examined to determine whether it should be pitch-adjusted.

This operation uses the PAR parameter, which is the rate of pitch adjustment as follows:

$$x'_i \leftarrow \begin{cases} Yes & \text{with probability } PAR \\ No & \text{with probability } (1 - PAR) \end{cases} \quad (19)$$

The value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for x'_i is yes, x'_i is replaced as follows:

$$x'_i \leftarrow x' + bw \times U(-1,1) \quad (20)$$

bw: arbitrary distance bandwidth for the continuous design variable

U (-1, 1): uniform distribution between -1 and 1.

In Step 3, HM consideration, pitch adjustment or random selection is applied to each variable of the new harmony vector in turn.

Step 4.Update harmony memory

If the new harmony vector, $x' = (x'_1, x'_2, \dots x'_n)$, is better than the worst harmony in the HM, from the point of view objective function value, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

Step 5.Check stopping criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated.

V. Genetic Algorithm

GA is an evolutionary computing method in the area of artificial intelligence. It was pioneered by Holland in the 60's and 70's and his work is comprehensively presented in [26]. It is a global search algorithm that is based on concepts from natural genetics and the Darwinian survival-of-the-fittest code. Meta-heuristic algorithm-based engineering optimization methods, including GA, have occasionally overcome several deficiencies of conventional numerical methods. Genetics is usually used to reach to a near global optimum solution. In each iteration of GA (referred as generation), a new set of string (.i.e. chromosomes) with improved fitness is produced using genetic operators (i.e. selection, crossover and mutation). Useful practical details of genetic algorithms are available in [27] and [28].

A. Binary Encoding

The most common way of encoding is a binary string, which would be represented as in Fig. 3.

Chromosome 1	1	1	0	1	0	0	0	0	1	1	0
Chromosome 2	0	1	0	1	1	1	1	1	1	0	0
:											
Chromosome n	1	1	0	1	1	1	0	0	1	0	1

Fig. 3. Typical Chromosome for binary encoding

Each chromosome encodes a binary (bit) string. Each bit in the string can represent some characteristics of the solution. Every bit string therefore is a solution but not necessarily the best solution. Another possibility is that the whole string can represent a number. The way bit strings can code differs from problem to problem. Binary encoding gives many possible chromosomes with a smaller number of alleles. On the other hand this encoding is not natural for many problems and sometimes corrections must be made after genetic operation is completed. Binary coded strings with 1s and 0s are mostly used. The length of the string depends on the accuracy [29].

B. Selection

Selection is the process of choosing two parents from the population for crossing. In proposed GA, method of tournament selection is used for selection.

C. Cross Over

Crossover is the process of taking two parent solutions and producing from them a child. After the selection process, the population is enriched with better individuals. Reproduction makes clones of good strings but does not create new ones. Crossover operator is applied to the mating pool with the hope that it creates a better offspring. There are various crossover techniques. In this paper single point crossover has been used where the two mating chromosomes are cut once at corresponding points.

E. Mutation

After crossover, the strings are subjected to mutation. Mutation prevents the algorithm to be trapped in a local minimum. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information. It is an insurance policy against the irreversible loss of genetic material. In this paper, a random vector from a Gaussian distribution to the parents. For each chromosome, random number is selected.

F. Fitness Function

The goal of optimization algorithm is to place FACTS devices in order to enhance power system stability level (Section III) considering models of FACTS devices. So these devices should be placed to prevent instability in transmission lines and transformers and maintain bus voltages close to their reference value.
In most of the nonlinear optimization problems constraints are considered by defining the object function using penalty terms. In this problem the voltages of PV buses, tap of transformers, and the amount of reactive power installation are controlled variables which are self constrained. Voltages of PQ buses and injected reactive powers of PV buses are constraints that are add to the object function as a penalty term. The initial object function is expressed as:

$$F_Q = f_Q + \sum_{i \in N_V^{\lim}} \lambda_{Vi}(V_i - V_i^{\lim})^2 + \sum_{i \in N_Q^{\lim}} \lambda_{Gi}(Q_{Gi} - Q_{Gi}^{\lim})^2 + L_{\max} \quad (21)$$

λ_{Gi} : Penalty factor

λ_{Vi} : Penalty factor

$$V_i^{\lim} = \begin{cases} V_i^{\max}; V_i > V_i^{\max} \\ V_i^{\min}; V_i < V_i^{\min} \end{cases} \quad (22)$$

$$Q_i^{\lim} = \begin{cases} Q_i^{\max}; Q_i > Q_i^{\max} \\ Q_i^{\min}; Q_i < Q_i^{\min} \end{cases} \quad (23)$$

VI. Simulation Results

A. Considerations

In this part of the research optimal placement of three types of FACTS devices in a IEEE 30 bus power system (Fig. 4) are investigated and seven scenarios have been considered. This problem has been solved by the Genetic algorithm (GA) and harmony search algorithm (HSA).
In this study below cases have been considered.

- Finding the optimal location of three types of FACTS devices consisting TCPAR, UPFC and SVC by genetic algorithm and harmony search algorithm in different states.
- Studding the impact of FACTS devices settings on the power loss transmission and stability considering there optimal placement.

The configuration of FACTS devices have been obtained by two parameters: the location of devices and rate value. Each individual represents a string which the first value of each string represents the location of the FACTS device in the network and the second value represents the rated value of the FACTS device. According to the model of the FACTS devices, the rated values (RV) of each FACTS device is converted in to the real compensation as follow:
TCPAR: The working range of the TCPAR is between the −5 degrees to +5 degrees.

$$\varphi tcpar = RV \times 5(degree) \quad (24)$$

UPFC: The working range of the UPFC is between -180 degrees to +180 degrees.

$$\varphi upfc = RV \times 180(degree) \quad (25)$$

It should be noticed that the RV parameter is between -1 and 1 and also the power sytem transmission loss in the absence of FACTS devices is 17.557 MW.

B. Network data

The 30_bus IEEE power system has been selected for this study that is shown in Fig. 4. Consists of 48 branches, six generator buses and 20 load buses. Four branches, (6,9), (6,10), (4,12) and (27,28) are under load tap setting transformer branches. The possible reactive power source installation buses are 3, 10 and 24. Six buses are selected as PV buses as follow: 2, 5, 8, 11 and 13. The bus No.1 is the swing bus. The variable limits have been given in Table.I. It has assumed that the transformer taps and the reactive power source installation are continuous variables. Also the other parameters limits are represented in Table.II. The generations of G1-G6 are shown in Table.III.

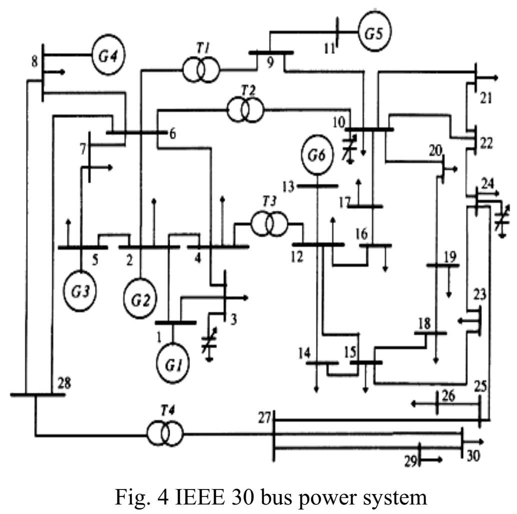

Fig. 4 IEEE 30 bus power system

TABLE.I
VARIABLE LIMITS (P.U)

Variables	V_G	V_{PQ}	T	Q_C
Max	1.1	1.05	1.1	0.3
Min	0.9	0.95	0.9	-0.3

TABLE.I
LIMITATION OF THE PV REACTIVE POWER GENERATION

Bus	1	2	5	8	11	13
Q_C^{Max}	2.0	1.0	0.8	0.6	0.5	0.6
Q_C^{Min}	-0.2	-0.2	-0.15	-0.15	-0.1	-.15

TABLE.III
GENERATIONS of G_1-G_6

P_1	P_2	P_3	P_4	P_5	P_6
99.2MW	80 MW	50 MW	20 MW	20 MW	20 MW

C. Considered scenarios

Three scenarios have been considered and in each scenarios GA and HSA have been implemented for finding optimal placement and best rate values for FACTS devices.

Case 1: one-type FACTS allocation using GA and HSA

In this case, allocation of one-type FACTS devices has been performed using GA and HSA. Three different kinds of FACTS devices (TCPAR, UPFC, and SVC) have been used to be placed in optimal location solely to enhance power system stability index and reduce losses.

Results for one-type FACTS allocation using GA and HSA have been compared and presented in Tables IV-VI.

TABLE.IV
OPTIMAL LOCATION AND RELATED PARAMETES FOR SVC

Algorithm	SVC			
	Location (Bus No.)	Size (MVA)	Losses (MW)	L (stability index)
GA	32	21.23	5.28	0.1431
HSA	12	12	5.22	0.1400

TABLE.V
OPTIMAL LOCATION AND RELATED PARAMETES FOR UPFC

Algorithm	UPFC			
	Location (Branch)	Rate	Losses (MW)	L (stability index)
GA	9	-0.6	5.21	0.140
HSA	6	-0.8	5.1	0.138

TABLE.VI
OPTIMAL LOCATION AND RELATED PARAMETES FOR TCPAR

Algorithm	TCPAR			
	Location (Branch)	Rate	Losses (MW)	L (stability index)
GA	10	-0.341	5.36	0.1464
HSA	23	-0.435	5.30	0.1412

Case 2: two-type FACTS allocation using GA and HSA

In this case, allocation of two-type FACTS devices has been performed using GA and HSA. Two different kinds of FACTS devices among TCPAR, UPFC, and SVC have been selected and are located in optimal location two by two to enhance power system stability index and reduce losses.

Consequences for two-type FACTS allocation by GA and HSA have been assessed and presented in Tables VII-VII.

TABLE.VII
OPTIMAL LOCATION AND RELATED PARAMETES FOR TWO TYPES OF FACTS DEVICES (SVC+TCPAR)

	SVC		TCPAR			
	Location (Bus No.)	Size (MVA)	Location (Branch)	Rate	Losses (MW)	L (Stability Index)
GA	17	-2	15	0.6453	5.201	0.1382
HSA	8	-22	33	0.7810	5.180	0.1422

TABLE.VIII
OPTIMAL LOCATION AND RELATED PARAMETES FOR TWO TYPES OF FACTS DEVICES (SVC+UPFC)

	SVC		UPFC			
	Location (Bus No.)	Size (MVA)	Location (Branch)	Rate	Losses (MW)	L (Stability Index)
GA	17	-2	17	0.4223	5.278	0.1401
HSA	18	-13	21	-0.6681	5.1765	0.1444

Case 3: multi-type FACTS allocation using GA and HSA

In the last scenario, three types controller simultaneously have been implemented to improve voltage stability index and losses. Table IX shows optimal location of devices in this scenario.

This results show that installation of multi-type FACTS devices can lead to improve in voltage stability index and reduce in power system losses simultaneously. So multi-type FACTS devices should be placed in optimal location to both improve stability margins and reduce losses in the network.

VI. CONCLUSION

In this paper, a method for placement of multi-type FACTS devices based on Harmony Search (HS) and Genetic Algorithm (GA) has been presented. Three types of FACTS devices (SVC, TCPAR, and UPFC) have been modeled. The criteria for optimization were considered as the voltage stability index and the minimization of losses. For investigation of the purposes, Different scenarios have been considered. In the first scenario TCPAT, UPFS, and SVC are placed exclusively in transmission lines and indices have been calculated. Then two types of above controller try to improve parameters randomly. Next three types controller simultaneously have been implemented to improve voltage stability index and losses.

The results of execution of these scenarios on a typical 30-bus test system were clarified robustness of this method in optimal and fast placement of FACTS devices. The results showed efficiency of this method for improvement of voltage profile, reduction of power losses and also an increase in power transfer capacity, maximum loading and voltage stability margin.

TABLE.IX
OPTIMAL LOCATION AND RELATED PARAMETES FOR THREE TYPES OF FACTS DEVICES (SVC+UPFC+TCPAR)

Algorithm	SVC		TCPAR		UPFC		Losses (MW)	L (stability index)
	Location (Bus No.)	Size(MVA)	Location (Branch)	Size (MVA)	Location (Branch)	Size (MVA)		
GA	16	17.121	9	0.769	7	-1	5.211	0.1333
HSA	25	29.21	6	0.879	12	-0.8453	5.120	0.1301

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