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Multi-Type Facts Placement For Voltage Stability Enhancement Using Harmony Search Optimization

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ABSTRACT

This paper presents a new method for optimal placement of multi-type FACTS devices with a view to enhance voltage stability using harmony search algorithm. The method uses three types of FACTS devices that includes static VAR compensator, thyristor controlled series compensator and unified power flow controller; and determines optimal locations for placement, type and parameters of the FACTS devices. Test results on IEEE 30 bus system exhibit the superiority of the developed algorithm

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INTRODUCTION

The present day power system is expanding everyday with increase in demand, and to meet this situation, either new installation of power generating stations and transmission lines are required or the operation of existing infrastructure has to be extended to its limits. Laying of new lines or installation of new generating stations imposes many environmental and economical constraints. As a result, the existing transmission lines are more heavily loaded than ever before. In steady state operation of heavily loaded power systems, the main problems are increased losses, poor voltage profile, unwanted loop flows and line overloads.

In addition, the system under such a state imbibes substantially different response to disturbances from that of non-stressed systems and therefore even a relatively smaller disturbance may upset the system. Besides progressive energy demands and depletion of the existing generation and transmission resources evolve a new type of problem, referred to as voltage instability or voltage collapse in power systems. The phenomenon of voltage instability in power systems is characterized by a monotonic voltage drop, which is slow at first, becomes abrupt after some time and generally triggered by some form of disturbance such as loss of generation, transmission lines or transformers or a change in the operating conditions, that create an increased demand for reactive power, which is in excess of what the system is capable of supplying. A large disturbance on a stressed system results in a loss of equilibrium, at which the generation and load do not meet, and the power system can no longer operate normally and leads to cascaded outages (Kundur, P., 1993).

The main factor causing voltage instability is the inability of the power system in meeting the reactive power demand at heavily stressed systems, and this prevents it from maintaining the desired voltages. The other factors contributing to voltage collapse are generator reactive power/voltage control limits, load characteristics, characteristics of reactive power compensating devices, the action of transformer with load tap changers, cutbacks in system maintenance, workforce downsizing and unpredicted power flow patterns.

The recent developments in power electronics have introduced Flexible AC Transmission Systems (FACTS) that include Thyristor Controlled Series Compensator (TCSC), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), Unified Power Flow Controller (UPFC), Static Synchronous Series Compensator (SSSC), Thyristor Controlled Phase Angle Regulator (TCPAR) etc., These devices can facilitate the control of power flow, increase the power transfer capability, decrease the generation cost, improve the security and enhance the stability of the power systems. They allow the operation of the power systems more flexible, secure and economical through controlling various electrical parameters of transmission circuits. However, the decision on the size, the locations and their parameters is of great significance in obtaining the benefits of the FACTS devices (Narain G. Hingorani and Laszio Gyugyi, 2000).

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The placement of FACTS devices can be described as an optimization problem with an objective of minimizing a cost function while satisfying system constraints. The objective may be power loss minimization, reduction of net voltage magnitude deviation and voltage stability enhancement. The constraints may include power flow and security limits under normal and contingent conditions. Due to rigorous constraints, the FACTS placement problem is a most challenging nonlinear optimization problem in power systems.

Several methods for obtaining the solution of FACTS placement problem have been developed in the recent years (Yoshida, H., 2000; Song S.H., 2003; Venkataramu, P.S., 2006; Tripathy, M., S. Mishra, 2007; Lin Jineng, 2008; Liu Hongchao, 2009; Bindeshwar, S.R., *et al*, 2010; Zhu, J., 2010; Subramanian, A., G. Ravi, 2011; Wibowo, R.S., 2011). An algorithm involving particle swarm optimization for reactive power and voltage control so as to ensure voltage security has been presented in (Yoshida, H., 2000). An UPOFC based methodology for ensuring security through line over load control and low voltage control has been suggested in (Song S.H., 2003). A strategy for placing UPFC in order to enhance VS margin under contingent conditions has been notified in (Venkataramu, P.S., 2006). A method using bacterial foraging algorithm for placing UPFC for loss minimization and voltage stability limit improvement has been outlined in (Tripathy, M., S. Mishra, 2007). An adoptive immune based methodology for the reactive power optimization has been outlined in (Lin Jineng, 2008). An procedure for minimizing voltage deviations so as to enhance VS through reactive power compensation has been suggested in (Liu Hongchao, 2009). Many methods for avoiding of voltage instability using FACTS devices in power systems have been surveyed in (Bindeshwar, S.R., *et al*, 2010). A strategy involving SVCs for enhancing voltage profile and reducing real power loss has been notified in (Zhu, J., 2010). A strategy for maintaining reactive power reserve so as to avoid voltage instability has been developed in (Subramanian, A., G. Ravi, 2011). An optimal allocation strategy for FACTS devices for relieving congestion and enhancing voltage stability has been presented in (Wibowo, R.S., 2011).

Recently, a Harmony Search Optimization (HSO) that was conceptualized using musical process of searching for a perfect state of harmony has been suggested for solving optimization problems (Geem, Z.W., 2001; Lee, K.S. and Z.W. Geem, 2005). The harmony in music is analogous to the optimization solution vector, and the musician's improvisations are analogous to local and global search schemes in optimization techniques. The HSA does not require initial values for the decision variables and uses a stochastic random search that is based on the harmony memory considering rate (HMCR) and pitch adjusting rate (PAR) so that the derivative information is unnecessary. It requires fewer mathematical computations compared to other meta-heuristic algorithms and can be easily adopted for various types of engineering optimization problems. It has been applied in solving EED problem in (Sivasubramani, S. and K.S. Swarup, 2011).

An improved HSO based method for optimal placement of multi-type FACTS devices for enhancing the voltage stability is suggested in this paper. The algorithm is tested on IEEE 30 bus test system and the results are presented. The paper is divided into six sections. Section 1 presents the introduction, section 2 overviews the improved HSO, section 3 explains the proposed method, section 4 discusses the results and section 6 concludes.

Improved Harmony Search Optimization:

The HSO is based on the musical process of searching for the perfect state of harmony. Musicians, during a rehearsal or a performance, try to create pleasing sounds and approach the ideal state of harmony. HSA is inspired from the improvisation process of music players. Just as the musicians try to improve their music, the HSA seeks for certain values for the decision variables that optimize the objective function while at the same time satisfying the problem constraints. It improves the optimal solution iteration after iteration in the same way as a music band improves rehearsal after rehearsal. It is simple in concept, few in parameters and easy for implementation with theoretical background of stochastic derivative.

In this approach, a Harmony Memory (HM), comprising a number of candidate solutions of the problem at hand, is defined. The HM is initialized with random guesses in the problem space as:

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_N^1 \\ x_1^2 & x_2^2 & \cdots & x_N^2 \\ x_1^3 & x_2^3 & \cdots & x_N^3 \\ \vdots & \vdots & & \vdots \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_N^{HMS} \end{bmatrix} \tag{1}$$

Generating a new harmony is known as "improvisation". A new harmony vector $\vec{x}' = (x_1', x_2', \cdots, x_N')$ is generated based on the following mechanisms

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Memory considerations:

The value for the first decision variable $x_1^{'}$ for the new vector is chosen from any of the values in the specified HM range $(x_1^{'} - x_1^{HMS})$. Values for other decision variables $(x_2^{'}, x_3^{'}, \cdots, x_N^{'})$ are chosen in the same manner. The HMCR that varies between 0 and 1 is the rate of choosing a value from HM, while (1-HMCR) is the rate of randomly selecting a value from the possible range of values as shown in (2)

```
if (rand ( ) < HMCR)
        x_i' ← x_i' = (x_i^1, x_i^2, ..., x_i^HMS)
else
        x_i' ← x_i' ∈ X_i
end
```

(2)

where rand ( ) is a uniform random number between 0 and 1 and X_i is the set possible range of values for each decision variable, that is $x_i(\min) \le X_i \le x_i(\max)$

Pitch adjustment:

Every component obtained by memory consideration is pitch adjusted based on the PAR as

```
if (rand ( ) < PAR)
        x_i' ← x_i' ± rand() × BW
else
        x_i' ← x_i'
end
```

(3)

Where BW is an arbitrary distance bandwidth.

Update harmony memory:

If the new harmony vector $\vec{x}' = (x_1^{'}, x_2^{'}, \cdots, x_N^{'})$ is better than the worst harmony in the HM, then the worst harmony is replaced by the new harmony.

Convergence Check:

The process of generating new harmony vector can be terminated when the number of iterations reaches the maximum number of iterations.

Proposed Method:

Appropriate FACTS devices should be installed at the best possible locations with optimal parameter settings in order to enhance the VS. The VS index (VSI), also called L-index that varies in the range between 0 (no load of the system) and 1 (voltage collapse) for each load bus, is popular among the researchers in assessing the VS (Kessel, P. and H. Glavitsch, 1986). The control against voltage collapse is based on minimizing the sum of L-indices for a given operating condition as

Minimize $\Phi = \max\,(L_j)$ (4)

Subject to

FACTS device constraints

$-0.8 \le \eta_k \le 0.2$ for TCSC (5)

$-100\,MVAR \le Q_{Fi} \le +100\,MVAR$ for SVC (6)

Eqs. (5) and (6) for UPFC (7)

Power Flow Constraints

$P(V,\delta) - P^{sp} = 0$ for PV and PQ buses (8)

$Q(V,\delta) - Q^{sp} = 0$ for PQ buses (9)

Where

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$$L_j = \left| 1 - \sum_{i=\Omega} F_{ij} \frac{V_i}{V_j} \right| \tag{10}$$

The values of F_{ij} are obtained from the bus admittance matrix.

$$[F] = -[Y_{LL}]^{-1}[Y_{LG}] \tag{11}$$

$[Y_{LL}]$ and $[Y_{LG}]$ are submatrices of the Y-bus matrix.

The FACTS placement problem, represented through Eqs. 4-11 offers a solution that enhances the VS through placing FACTS devices at appropriate transmission lines with optimal parameter settings. This is achieved by altering the network parameters and injecting or absorbing reactive power at appropriate lines.

Representation of HSO variables:

Each harmony in the proposed strategy is defined to denote the type of the devices, their locations and parameters. Integer numbers in the range of (1, 3) are used to denote the type of the FACTS devices. In this formulation, 1 represents SVC, 2 denotes TCSC and 3 indicates UPFC. The location also contains integer numbers. The other parameters are denoted by real numbers. The HSO generates real numbers and hence to obtain values for type and location, the real numbers are rounded off to the nearest integer values.

Repair Algorithm:

It is disagreeable to fix two or more FACTS devices at a line/bus. During the iterative process, there is a chance that a solution point contains same line numbers. If this happens, it may be corrected by the following repair algorithm.

- Change any one line number by generating a random number to represent another line.
- Repeat the above step till no two numbers representing the location is same.

Solution Process:

The process of generating a new harmony from the HM, which is generated randomly through memory considerations, pitch adjustment and memory update, may be called an iteration. The iterations are continued till the number of iterations reaches the MI. The iterative process is continued till convergence. The flow of the Proposed Method (PM) is shown in Fig. 1.

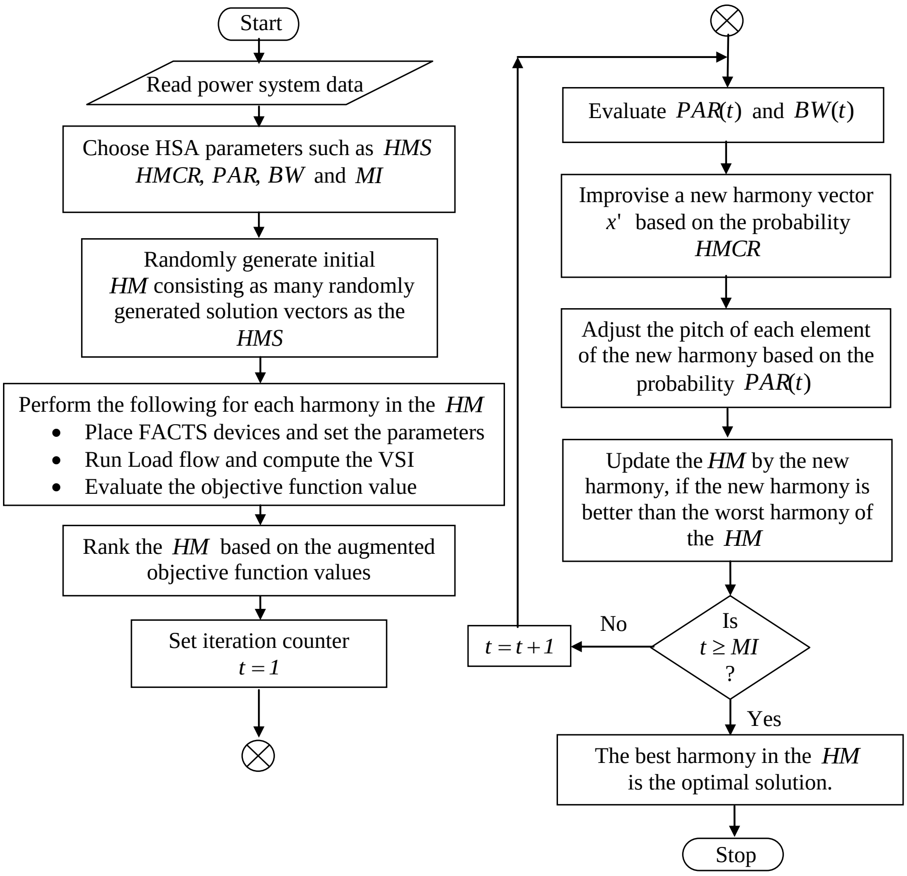

Fig. 1: Flow chart of PM.

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Simulations:

The proposed HSO based strategy is tested on IEEE 30 bus test system. NR technique (Stagg, G.W. and A.H. El-Abiad, 1968) is used to carry out the load flow during the optimization process. The number of FACTS devices is chosen as 5. The results of the PM are obtained and compared with those of SA and GA based approaches in order to demonstrate the effectiveness of the PM.

The locations and their parameters of PM, GA and SA are presented in Table 1. The PM requires three TCSCs and two UPFC at lines 18, 24, 10, 37 and 23, while SA requires one SVC, three TCSCs and one UPFC at lines 35, 26, 19, 31 and 17; and the GA requires one SVC and four TCSC at lines 26, 17, 32, 29 and 33.

The performance in terms of maximum VSI (MVSI) before and after FACTS placement is included in same table. It can be observed from this table that the PM reduces the MVSI from 0.1420 to 0.0843 but the SA and GA are able to reduce the MVSI to 0.1067 and 0.1048 respectively. The %VS enhancement is shown in Fig. 2. The figure indicates that the %VS enhancement of PM is 40.64, while the SA and GA based methods offer a lower %VS enhancement of 24.856 and 26.197 respectively. Besides the computational speed of the PM is found to be fast by Table 2 comparing the execution time of all the methods. It is very clear from the results that the PM enhances the VS and makes it suitable for practical implementations.

Table 1: Comparison of optimal Solutions.

Facts No		1	2	3	4	5	MVSI
Before Placement		--	--	--	--	--	0.1420
SA	Type of FACTS device	2	3	2	1	2	0.1067
	Line Location	35	26	19	31	17	
	Injected VAR	--	31.462	--	-21.570	--	
	Line Compensation Factor	-0.0532	-0.512	-0.422	--	-0.238	
GA	Type of FACTS device	1	2	2	2	2	0.1048
	Line Location	26	17	32	29	33	
	Injected VAR	-16.132	--	--	--	-	
	Line Compensation Factor	--	0.044	-0.425	-0.630	-0.692	
PM	Type of FACTS device	2	3	3	2	2	0.0843
	Line Location	18	24	10	37	23	
	Injected VAR	--	43.5565	16.601	--	--	
	Line Compensation Factor	-0.512	-0.382	-0.542	-0.542	-0.325	

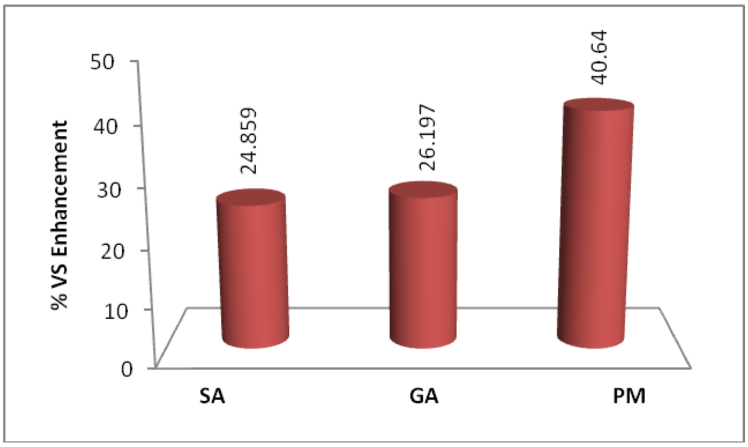

Fig. 2: Comparison of % VS Enhancement.

Table 2: Comparison of Execution Time.

Method	Time (Secs)
SA	23.2
GA	18.7
PM	4.3

Conclusion:

A new methodology involving improved HSO for solving FACTS placement problem has been developed and studied on an IEEE test system. It determines the optimal values for type, location and the parameters. The ability of the PM to produce the global best solution that enhances the VS of the system has been projected. It has been chartered that the new approach fosters the continued use of HSO and will go a long way in serving as a useful tool in load dispatch centre.

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Nomenclature:

BW	bandwidth
FACTS	flexible AC transmission systems
GA	genetic algorithm
g_k	conductance of the transmission line-k
HM	harmony memory
HMCR	harmony memory considering rate
HMS	harmony memory size
HSO	harmony search optimization
MI	maximum number of iterations
nf	number of FACTS devices
$nload$	number of load buses
PAR	pitch adjusting rate
PM	proposed method
P_L	system real power loss
P_{ij} and Q_{ij}	active and reactive power flow from bus-i to j respectively
$P(V,\delta)$	set of real power expressions at PV and PQ buses
P^{sp}	set of specified real powers at PV and PQ buses
$Q(V,\delta)$	set of reactive power expressions at PQ buses
Q_{Gi}	reactive power generation at bus-i
Q^{sp}	set of specified reactive powers at PQ buses
$Q_{Gi}^{\min}$ and $Q_{Gi}^{\max}$	lower and upper limit of reactive power generation at bus-i respectively
$Q_F{}^k$	reactive power support by k^{th} FACTS device in MVAR
Q_{Fi}	reactive power supplied by the FACTS device at bus-i.
SA	simulated annealing
SVC	static VAR compensator
STATCOM	static synchronous compensator
SSSC	static synchronous series compensator
TCPAR	thyristor controlled phase angle regulator
TCSC	thyristor controlled series compensator
UPFC	unified power flow controller
VP	voltage profile
V_i and V_j	voltage magnitude at buses-i and j respectively
η_k	line compensation factor in the range of (-0.8, 0.2) for k^{th} FACTS device

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