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Optimal Allocation of SVC for Enhancement of Voltage Stability Using Harmony Search Algorithm

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ABSTRACT: In this paper, a meta-heuristic optimization technique known as Harmony Search Algorithm is used to determine the optimal location and size of static Var compensator (SVC) in a transmission network. The demand for electricity is increasing day-by-day and is giving rise to voltage instabilility problems. voltage stability status in a stressed Power system could be improved with effective reactive power compensation and it can be achieved by significant use of SVC. A multi-objective optimization problem is defined to minimize real power losses, improve the voltage profile and reduce L-index. Here L-index is used to find the critical buses in the system for optimal location of shunt connected FACTS controller known as Static Var Compensator(SVC). Harmony Search Algorithm (HSA) is applied to find the optimal sizes of SVC for solving Multiobjective optimization problem. Simulations are performed on IEEE 14-bus and IEEE 30-bus test systems.The results for base case and 125% overloading cases show that the optimal location and sizing of SVC minimizes real power losses, improves voltage profile and reduces L-index.

KEYWORDS: Meta-heuristic, Voltage stability, SVC, L-index, Harmony search algorithm, Multi-objective optimization.

I. INTRODUCTION

Voltage stability can be defined as the ability of a power system to maintain acceptable voltage levels under normal operating conditions and after occurrence of disturbances [1]-[2].In current days an instability ,usually known as voltage instability which has been observed and been responsible for major network collapses in many countries. The voltage instability is mainly related with reactive power imbalance. The loading of a bus in the power system depends on the reactive power support that the bus can receive from the system. When the system reaches the maximum loading point (MLP) or the voltage collapse point both the real and reactive power losses increases rapidly. Therefore the Reactive power support must be local and adequate [3]-[5].Introducing sources of reactive power that is shunt capacitors and /or Flexible AC Transmission systems(FACTS)controllers at the suitable location is the most effective way for Utilities to enhance the voltage stability of the system. The rapid development of fast-acting and self-commutated power electronics converters, well known as Flexible Alternating Current Transmission system (FACTS)controllers, introduced in 1988 by Hingorani [6],are useful in taking fast control actions to ensure these unity of power systems. The Static VAR compensator (SVC) has been effectively used to provide voltage stabilization at critical buses amongst existing FACTS devices. In [7] the effects of SVC and TCSC on voltage collapse are studied by Canizares and Faur .The Voltage Stability Assessment of system with shunt compensation devices including shunt capacitors, SVC and STATCOM are compared in the IEEE 14 bus system [8]. FACTS devices are expensive and are not economical to place more devices in the system. In the literature there are different indices to find the weak bus for the location of FACTS devices [9]-[10]. Hence optimal placement and sizing of FACTS devices are the important issues. Appropriate placement of FACTS devices at suitable location with proper sizes would lead to maximum loading margin [11]-[13]. In [14] D.Thukaram and Abraham lomi proposed to select a suitable size and location of SVC in EHV network for voltage stability improvement based on L-Index of load bus. Four different objective functions namely, loss minimization, voltage profile improvement, Voltage stability Enhancement and Total cost minimization are proposed by S.Durairaj et al [15].

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In this paper SVC is used for shunt compensation. It is a shunt-connected Static VAR Generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to provide voltage support. It can also reduce power losses in the system when it is installed in a proper location. Here L-index is used to find the weak bus in the system to place the SVC device and it is also for Voltage Stability analysis. L-index gives scalar number to each load bus. This index value ranges from 0 (no load system) to 1(Voltage collapse). The bus with highest L-index value will be the weakest bus in the system and hence this method helps in identifying the weak load bus which need critical reactive power support. Minimization of L-index is also one of the objectives of the optimization problem. A Meta-Heuristic algorithm Known as HSA is proposed to find the optimal sizes of SVC for objective of optimization such as Minimization of Real power loss, and Improvement of Voltage profile.

II.BACKGROUND

In the earlier decades several meta heuristic optimization algorithm have been introduced. These algorithms are principally inspired by nature analogy. Due to the applicability in the bulk range of problem, all the algorithms are also called as general purpose approaches. There are several optimization techniques such as Evolution strategies (ES)-1965, Genetic algorithm (GA)-1975,
Simulated annealing (SA)-1983, Ant colony optimization (ACO)-1992, Particle swarm optimization (PSO)-1995, Harmony search algorithm (HSA)-2001, Bee colony optimization (BCO)-2004, Gravitational search algorithm (2009)

Harmony search algorithm

Geem et.al discovered Harmony search algorithm in 2001. Harmony search algorithm is a Meta heuristic technique which is inspired by musical performance process. HS optimization techniques works as a musical appliance which are played to obtain the ideal harmony between the components which are involved in the process for ideal solution. It is based on rules and unpredictability to emulate natural phenomena. Another benefit is that both types of functions discontinuous and continuous can be considered by HS algorithm, because it does neither require differential gradients nor initial value setting for variables. HSA is totally divergence free and also escape local optima.
Sirjani et.al was implemented improved harmony search algorithm to find the optimal location and sizing of SVC with the objective of voltage profile enhancement and reduction in power system losses. The effectiveness of proposed algorithm was checked on IEEE-30 bus test system. The results have been compared with PSO techniques for similar optimal solution then it was found that performance of IHS was better as compared to PSO.

Sanjari et.al implemented HSA to obtain the ideal location of shunt fact devices in the smart grid to improve voltage stability. SVC was considered as the compensation devices. The effectiveness of proposed techniques was checked on IEEE-14 bus test system. Result shows an enhancement of voltage profile and maximization in voltage collapse margin.
Kazemi et.al proposed an algorithm based on harmony search to find the optimal location of FACTS devices with the objective of power system security enhancement. Three types of FACTS-TCSC, SVC and UPFC were considered. Simulation results were checked on IEEE-30 bus test system and it was found that power system security has been improved by optimal placement of FACTS devices. These results were also compared with GA for similar optimal solution but harmony search algorithm has superior performance as compared to GA

III.PROBLEM STATEMENT

The main objective function of this paper is to find the optimal rating of SVC for objective optimization.
This is mathematically stated as [16]-[18]:
Minimize F= [f1, f2, f3] (1)
Where f1 represents the real power losses as

$$f_1 = \sum_{k \in Ni} g_k \left(V_i^2 + V_j^2 - 2 V_i V_j \cos \theta_{ij} \right) = P_{loss} \qquad (2)$$

f2 represents the total voltage Deviation (VD) of all load buses from desired value of 1 p.u.

$$f_2 = VD = \sum_{k=1}^{N_{PQ}} (V_k - Vrefk)^2 \qquad (3)$$

And f3 is the L-index of the jth bus and is given by:

$$f_3 = L_j = \left|1 + \frac{V_{oj}}{V_j}\right| = \frac{s_j^+}{Y_{jj}V_j^2} \qquad (4)$$

The minimization problem is subject to the following equality and inequality Constraints:

i) Load Flow Constraints:

$$P_i - V_i \sum_{j=1}^{Ng} V_j \left(G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}\right) = 0, i = 1,2 \ldots\ldots N_B - 1 \qquad (5)$$

$$Q_i - V_i \sum V_J \left(G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}\right) = 0, i = 1,2 \ldots\ldots\ldots .N_{PQ} - 1 \qquad (6)$$

(ii) Voltage constraints:

$$V_i^{\min} \le V_i \le V_i^{\max}, i \in N_B \qquad (7)$$

(iii) Reactive Power Generation Limit:

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max}, i \in N_g \qquad (8)$$

(iv) Reactive Power Generation

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max}, i \in N_c \qquad (9)$$

(v)Transformer Tap setting limit:

$$t_k^{\min} \le t_k \le t_k^{\max}, k \in N_t \qquad (10)$$

(vi)Transmission line flow limit:

$$S_i \le S_i^{\max}, i \in N_l \qquad (11)$$

IV. SVC IDEAL MODELLING

Static Var Compensator is shunt connected type FACTS device which output is adjusted to exchange capacitive or inductive current and is used to maintain reactive power in network. And SVC contains two main components. Thyristor controlled/switched reactor (TSR) and switched capacitor (TSC). To absorb reactive power TSR is used. And to provide the reactive power TSC is used under serious loading conditions of network. The Static Var Compensator (SVC), constructional details, characteristics and modelling are in [19]-[20]. Fig.1 shows the Equivalent steady-state circuit of svc and fig.2 shows svc connected to an infinite bus. The operating range of SVC is -200Mvar to 200Mvar.

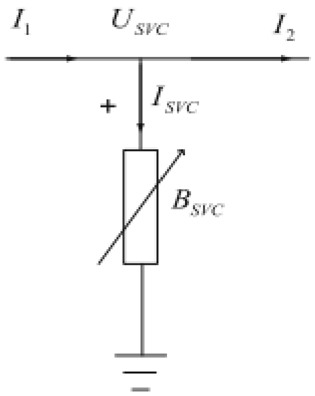

Fig 1: Equivalent steady-state circuit of svc

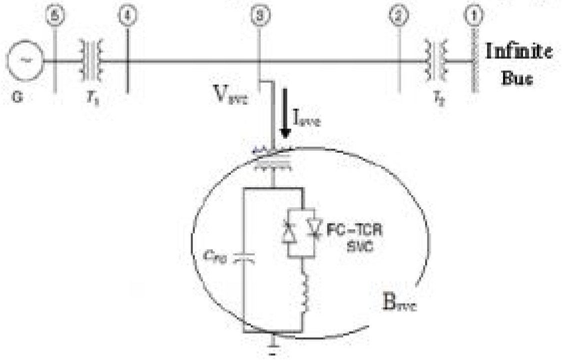

Fig 2: circuit diagram of svc connected to an infinite bus

From Fig.1, the current drawn and reactive power injected
By the SVC can be expressed as:

$$I_{SVC} = jB_{SVC} \times V$$
$$Q_{SVC} = -jB_{SVC} \times V^2$$

The reactive power generated by an SVC is given by

$$Q_{svc}^{\min} \leq Q_{svc} \leq Q_{svc}^{\max} \qquad (12)$$

V. VOLTAGE STABILITY INDEX

In [21], Kessel et al. was developed a voltage stability index based on the solution of the power flow equation. The L-index is a quantitative measure for the estimation of the distance of actual state of the system stability limit. It describes the stability of the complete system. Voltage stability index Lj for any load bus can be defined as given in equation (13)

$$L_j = \left|1 + \frac{V_{oj}}{V_j}\right| = \frac{s_j^{+}}{Y_{jj}V_j^{2}} \qquad (13)$$
$$Where\ V_{0j} = -\sum_{i \in \alpha_G} F_{ji} V_i$$

Where the L-index varies between 0 (no-load) and 1(voltage collapse) and it gives scalar number to each load bus. When the L-index value approaches to 0 the voltage stability is assured.

VI. POWER SYSTEM VOLTAGE STABILITY

At any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency. Present day power systems are being operated closer to their stability limits due to economic and environmental constraints. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. Voltage instability has been given much attention by power system researchers and planners in recent years, and is being regarded as one of the major sources of power system insecurity. Voltage instability phenomena are the ones in which the receiving end voltage decreases well below its normal value and does not come back even after setting restoring mechanisms such as VAR compensators, or continues to oscillate for lack of damping against the disturbances. Voltage collapse is the process by which the voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability . Once associated with weak systems and long lines, voltage problems are now also a source of concern in highly developed networks as a result of heavier loading.

Harmony Search Algorithm

The harmony search algorithm (HSA) is a new meta-heuristic algorithm [22] – [23] inspired by the operation of orchestra music to find the best harmony between components which are involved in the operation process, for optimal solution. It is simple in concept from natural musical performance processes. The musicians starting with some discrete musical notes based on player experience so finally HSA gives optimum value.

Algorithm to Find Optimal Sizes of Svc Using Harmony Search Algorithm

Step 1: Initialize all the parameters and constants of the Harmony search algorithm. They are QSVCminimum and QSVC maximum, hms, HMCR, PARmin and PARmax.
Step 2: Run the load flow program and find the total real power loss of the original system.
Step 3: Initialize the harmony memory i.e., generates [hms x n] number of initial solutions randomly within the limits, where hms is the harmony memory size and *n* is the number of static var compensators (SVC).
Step 4: obtain the loss reduction (fitness value) using equation (14)Fitness Value = Minimize F= [f1, f2, f3] (14)Repeat the same procedure for all the rows of the harmony vector to find Fitness values and obtain the best fitness value by comparing all the fitness values.
Step 5: Start the improvisation and iteration count is set to one.
Step 6: Improvisation of the New Harmony is generating a new harmony. A New Harmony vector is generated based on the following steps:
(i) Random selection: It is used to select one value randomly for a certain element of the new vector from the possible range (Qsvcmin, Qsvc max) of values.
(ii) Memory consideration: It is used to choose the value for a certain element of the new vector from the specified HM range.
xi=x'i_{x'1,x'2,…x HMS
i } with probability HMCR (15)
x'i_ xi with probability (1-HMCR) (16)
Step 7: Pitch adjustment: It is used to adjust the values of the New Harmony vector obtained in step7. (Between PARmin and PARmax). (bw - band width varies between a higher value and a lower value from first iteration to last iteration)x'i=x'i±rand(0,1)*bw (17)
Step 8: Find the fitness values corresponding to the New Harmony generated and pitch adjusted insteps 6 and 7.
Step 9: Apply Greedy Search between old harmony and New Harmony by comparing fitness values.
Step 10: Update harmony memory, by replacing the worst harmony with the new best Harmony. Obtain the best fitness value by comparing all the fitness values.
Step 11: The improvisation (iteration) count is incremented and if iteration count is not reached maximum then go to step 7.
Step 12: The solution vector corresponding to the best fitness value gives the optimal SVC sizes in n optimal locations.
In the present paper the HAS parameters are hms = 30, HMCR =85%, No of improvisations = 200, PARmin = 0.4 and PARmax = 0.9.

VII. RESULTS AND DISCUSSION

IEEE 14 bus system [24] contains 5 generator buses (bus numbers: 1,2,3,6 and 8), 9 load buses (bus numbers: 4, 5, 7,9,10,11,12,13 and14) and 20 transmission lines including 3 transformers The details of the system data including 3 transformer nominal values are given in [24].The load has been increased from normal load by125% for IEEE 14-bus test system. As the load on the system increases L-index, real power losses at load buses also increases. The results of the corresponding are shown in tables 1- 4.However L-Index is used to find the Weak buses in the system to find the optimal location of Static VAR Compensator (SVC). When the load on the system increases buses 9 and 14 has more L-index and so these buses are the best locations to place the SVC. A Meta-heuristic algorithm known as Harmonic search Algorithm is used to find the optimal size of SVC to achieve objectives. And finally when The SVC devices are placed at the buses 9 and 14 with optimal sizes and the corresponding results such as real power loss, voltage Profile and L-index with different loading Conditions are shown in tables 1-4.

IEEE 30 bus system contains 6 generator buses (bus numbers: 1,2,5,8,11 13), 24 load buses (bus numbers:3, 4, 6, 7, 9,10,12,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30) and 41 transmission lines including 4 transformers. The load has been increased from normal load by125% for IEEE 30-bus test system. As the load on the system increases L-index, real power losses at load buses also increases. The results of the corresponding are shown in tables 5-8.However L-Index is used to find the Weak buses in the system to find the optimal location of Static VAR Compensator (SVC). When the load on the system increases buses 7 and 26 has more L-index and so these buses are the best locations to place the SVC. A Meta-heuristic algorithm known as Harmonic search Algorithm is used to find the optimal size of SVC to achieve objectives. And finally when The SVC devices are placed at the buses 7 and 26 with optimal sizes and the corresponding results such as real power loss, voltage Profile and L-index with different loading Conditions are shown in tables 5-8.

Table: 1 Results Of The IEEE 14 Bus Test Systems

LOADING CONDITION	REAL POWER LOSS WITHOUT SVC	SVC OPTIMAL LOCATION	HSA	
			RATING OF SVC	REAL POWER LOSS WITH SVC
NORMAL LOADING	13.3934	9 14	24.5573 6.9526	13.3336
125% LOADING	22.7259	9 14	36.1120 8.9587	22.1941
150% LOADING	35.5578	9 14	61.9958 15.2668	34.3739
175% LOADING	51.61	9 14	106.7474 15.6894	49.6396
200% LO ADING	70.8595	9 14	134.3521 19.2670	68.9691

Table: 2 L-Index and Voltage Profiles At Basecase And 125% Loading

BUS NO	BASE CASE LOADING				125% LOADING			
	WITHOUT SVC		WITH SVC		WITHOUT SVC		WITH SVC	
	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE
1	0.0000	1.0600	0.0000	1.0600	0.0000	1.0600	0.0000	1.0600
2	0.0000	1.0450	0.0000	1.0450	0.0000	1.0250	0.0000	1.0350
3	0.0000	1.0100	0.0000	1.0100	0.0000	0.9800	0.0000	1.0000
4	0.0116	1.0183	0.0115	1.0198	0.0123	0.9883	0.0118	1.0079
5	0.0020	1.0200	0.0020	1.0211	0.0021	0.9926	0.0021	1.0097
6	0.0000	1.0700	0.0000	1.0700	0.0000	1.0400	0.0000	1.0700

7	0.0000	1.0608	0.0000	1.0659	0.0000	1.0302	0.0000	1.0623
8	0.0000	1.0900	0.0000	1.0900	0.0000	1.0700	0.0000	1.0900
9	0.0123	1.0541	0.0120	1.0642	0.231	1.0176	0.1920	1.0635
10	0.0061	1.0495	0.0060	1.0579	0.0066	1.0119	0.0061	1.0554
11	0.0038	1.0561	0.0038	1.0604	0.0040	1.0213	0.0038	1.0583
12	0.0084	1.0550	0.0084	1.0572	0.0090	1.0204	0.0084	1.0540
13	0.0106	1.0501	0.0105	1.0542	0.0113	1.0139	0.0106	1.0502
14	0.0248	1.0343	0.0240	1.0521	0.369	0.9925	0.241	1.0483

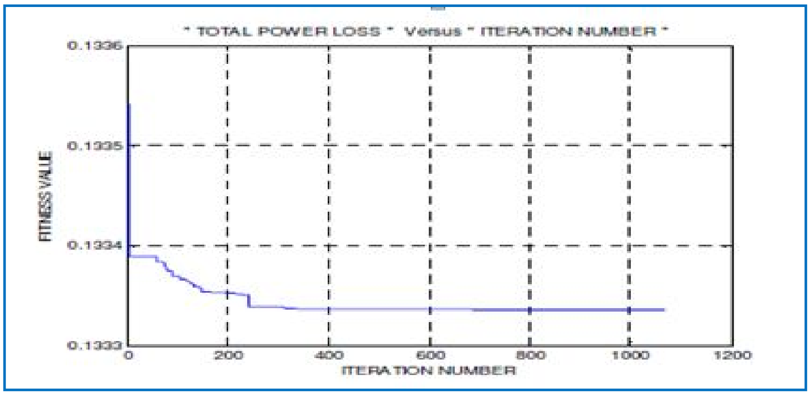

Fig: 3 Performance of HSA algorithm

Table 3: Results of the IEEE 30 bus test system

Loading condition	Real power loss Without SVC	SVC optimal location	HSA	
			Rating of SVC	Real power loss with SVC
Normal Loading	17.5985	7 26	28.3797 4.1207	17.5482
125% Loading	30.3738	7 26	55.0686 5.2598	29.6083
150% Loading	47.2228	7 26	75.3181 6.8942	46.3663
175% Loading	69.3379	7 26	57.2011 11.3811	68.2022
200% Loading	96.5636	7 26	58.3231 10.7663	94.6174

TABLE 4: L-INDEX AND VOLTAGE PROFILES AT BASE CASE AND 125% LOADING

BUS NO	BASE CASE LOADING				125% LOADING			
	WITHOUT SVC		WITH SVC		WITHOUT SVC		WITH SVC	
	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE	L-INDEX	VOLTAGE
1	0	1.0600	0	1.0600	0	1.0600	0	1.0600

2	0	1.0430	0	1.0430	0	1.0130	0	1.0330
3	0.0009	1.0215	0.0008	1.0238	0.0009	0.9936	0.0009	1.0126
4	0.0013	1.0129	0.0013	1.0157	0.0014	0.9803	0.0013	1.0033
5	0	1.0100	0	1.0100	0	0.9600	0	1.0100
6	0	1.0121	0	1.0152	0	0.9773	0	1.0058
7	0.0128	1.0034	0.0128	1.0053	0.0140	0.9596	0.0123	1.0234
8	0	1.0100	0	1.0100	0	0.9800	0	1.0000
9	0	1.0510	0	1.0738	0	1.0212	0	1.0429
10	0.0013	1.0444	0.0012	1.0606	0.0014	1.0079	0.0013	1.0317
11	0	1.0820	0	1.0820	0	1.0720	0	1.0820
12	0.0048	1.0574	0.0047	1.0648	0.0050	1.0298	0.0048	1.0483
13	0	1.0710	0	1.0710	0	1.0610	0	1.0710
14	0.0087	1.0424	0.0085	1.0564	0.0093	1.0096	0.0089	1.0296
15	0.0043	1.0378	0.0042	1.0488	0.0046	1.0028	0.0044	1.0239
16	0.0039	1.0447	0.0038	1.0558	0.0041	1.0112	0.0040	1.0321
17	0.0063	1.0391	0.0061	1.0539	0.0067	1.0020	0.0064	1.0251
18	0.0028	1.0279	0.0028	1.0409	0.0031	0.9887	0.0029	1.0112
19	0.0048	1.0253	0.0046	1.0394	0.0052	0.9845	0.0049	1.0076
20	0.0012	1.0293	0.0012	1.0439	0.0013	0.9894	0.0013	1.0126
21	0.0039	1.0321	0.0038	1.0478	0.0042	0.9918	0.0040	1.0168
22	0	1.0327	0	1.0482	0	0.9925	0	1.0178
23	0.0044	1.0272	0.0043	1.0391	0.0047	0.9871	0.0045	1.0119
24	0.0099	1.0216	0.0096	1.0345	0.0108	0.9772	0.0102	1.0066
25	0	1.0189	0	1.0282	0	0.9728	0	1.0143
26	0.0191	1.0012	0.0187	1.0107	0.0212	0.9495	0.0187	1.0120
27	0	1.0257	0	1.0327	0	0.9814	0	1.0192
28	0	1.0107	0	1.0137	0	0.9751	0	1.0029
29	0.0062	1.0059	0.0061	1.0131	0.0069	0.9550	0.0064	0.9939
30	0.0319	0.9945	0.0314	1.0017	0.0357	0.9397	0.0329	0.9793

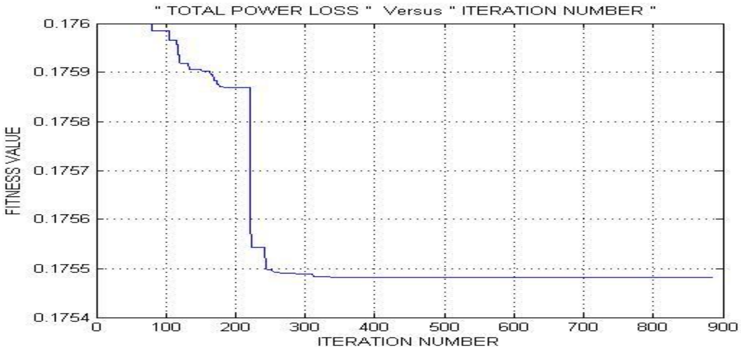

Fig 4: Performance of HSA algorithm for IEEE 30-bus system base case loading

VIII. CONCLUSION

In this present paper HSA optimization algorithm is presented and applied to determine the rating of SVC which satisfies the objectives such as minimization of real power loss, Voltage stability level index (L-Index), and improvement of voltage profile. L-index is used to find the weak buses in the system for optimal placement of SVC. And the final results are presented for IEEE-14 bus and IEEE 30-bus test systems for all loads that is 125%, 150%, 175% and 200% of normal loading and it is observed the proposed algorithm using SVC the objectives are achieved for both IEEE 14-bus system and IEEE30-bus system. Thi shows that the HSA algorithm can be used for practical and large scale applications. Further it is possible to achieve better by using TCSC and UPFC.

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