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Comparison of Harmony Search Algorithm and Particle Swarm Optimization for Distributed Generation Allocation to Improve Steady State Voltage Stability of Distribution Networks

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Abstract: In this study is tried to optimal distributed generation allocation for stability improvement in radial distribution systems. Voltage instability implies an uncontrolled decrease in voltage triggered by a disturbance, leading to voltage collapse and is primarily caused by dynamics connected with the load. The instability is divided into steady state and transient voltage instability Based on the time spectrum of the incident of the phenomena. The analysis is accomplished using a steady state voltage stability index which can be evaluated at each node of the distribution system. Several optimal capacities and locations are used to check these results. The location of DG has the main effect voltage stability on the system. Effects of location and capacity on incrementing steady state voltage stability in radial distribution systems are examined through Harmony Search Algorithm (HSA) and finally the results are compared to Particle Swarm Optimization (PSO) on the terms of speed, convergence and accuracy.

Keywords: Allocation, distributed generation, harmony search algorithm, particle swarm optimization, voltage stabili

INTRODUCTION

These days various kinds of Distributed Generation (DG) are becoming available and it is expected that is will grow in the future years. DG includes the application of small generators, scattered throughout a power system, to provide the electric power needed by electrical customers.

Such locally distributed generation, has several competence from the view point of environmental restriction and location limitations, as well as voltage stability and transient in the power system (Willis and Scott, 2000; Hadisaid *et al*., 1999; CIGRE, 1998).

The optimal placement and sizing of generation units on the distribution network has been continuously studied in order to achieve different aims. The objective can be the minimization of the active losses of the feeder (Nara *et al*., 2001; Rahman *et al*., 2004); or the minimization of the total network supply costs, which includes generators operation and losses compensation (Celli and Pilo, 2001; El-Khattam *et al*., 2004, 2005; Gandomkar *et al*., 2005); or even the best utilization of the available generation capacity (Keane and O'Malley, 2005). As a contribution to the methodology for DG economic analysis, in this study it is presented an algorithm for the allocation of generators in distribution networks, in order to voltage profile improvement and loss reduction in distribution network. The Harmony Search Algorithm is used as the optimization technique.

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When there is a disturbance in a power system which has a state of voltage instability, an uncontrollable progressive reduction will arise. Voltage stability analysis often requires examination of system state losses and a lot of other related scenarios. Due to this, the established rationale based on steady state analysis is more feasible and it can create an overall forecasting about voltage reaction problems as well. Voltage stability phenomenon is completely known in distribution systems. In radial distribution system resistance to reluctance ratio is high which causes a lot of power loss, hence radial distribution systems are kinds of power systems which are flawed by voltage instability.

The presence of DGs in distribution networks can affect many of the utilizing factors which reduce losses,

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increasing the durability of equipment, improving power quality, total harmony distortion networks and voltage stability by making changes in the path through which power passes. Among these the size and location of DGs are important factors.

In this study the effect of location and capacity on increasing steady state voltage stability in radial distribution systems are examined through Harmony Search Algorithm (HSA) and finally the results arecompared to Particle Swarm Optimization (PSO) on the terms of speed, accuracy and convergence. The analysis is performed using a steady state voltage stability index presented by Charkravorty and Das (2001). This index can be estimated at each node of radial distribution system. The suggested algorithm is applied on the Khoda Bande Loo distribution test feeder in Tehran.

Voltage stability index: An index, which can be evaluated at all nodes in radial distribution systems, was presented by Charkravorty and Das (2001) for identifying the node, which is most sensitive to voltage collapse. One method load flow for radial distribution systems was presented by Das *et al*. (1995) to formulate this index. According to Eq. (1) the steady state voltage stability index for each bus is:

$$SI(m2) = |V(m1)|^4 - 4.0\{P(m2)x(jj) - Q(m2)r(jj)\}^2 - 4.0\{P(m2)r(jj) - Q(m2)x(jj)\}\,|V(m1)|^2 \quad (1)$$

where:

- SI (m2) = Voltage stability index of node m2 (m2 = 2, 3, … , NB).
- NB = The total number of nodes.
- jj = Branch number.
- r(jj), x(jj) = Resistance and reactance of branch jj
- V(m1) = Voltage of node m1.
- V(m2) = Voltage of node m2.
- P(m2) = Total real power load fed through node m2.
- Q(m2) = Total reactive power load fed through nodem2.

Steady state voltage stability index is derived for the two node equivalent system shown in Fig. 1.

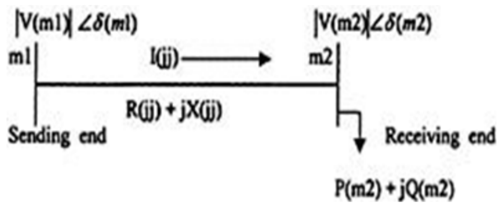

Fig. 1: Steady state voltage stability index is derived for the two node equivalent system

Actually, P(m2) = sum of the real power loads of all the nodes beyond node m2 plus the real power load of node m2itself plus the sum of the real power losses of all thebranches beyond node m2.

Q(m2) = sum of the reactive power loads of all thenodes beyond node m2 plus the reactive power load of node m2 itself plus the sum of the reactive power losses of all the branches beyond node m2.

For all of the network buses, the following Fitness function is defined:

$$\text{Fitness Function} = \sum SI(mi) \text{ , mi = 2, 3,..., NB} \quad (2)$$

In (Khanjanzadeh *et al*., 2011) is presented a method combining optimal power flow and Particle Swarm Optimization algorithm to find the best combination of sites within a distribution network for connecting a predefined number of DG. In this study by Using Harmony Search Algorithm is tried to find the best combination of sites within a distribution network for connecting a predefined number of DG and finally the results are compared to our prior study (Khanjanzadeh *et al*., 2011).

System study: The system which is selected is from one part of Tehran distribution network. The single line diagram of the network is illustrated in Fig. 2. It is a MV feeder with 13 buses. Table 1 and 2 provide the data of lines and buses.

Initially, a load flow was run for the case study without installation of DG. Their results are illustrated in Table 3.

Table 1: Lines data

From	To	Rohm	X ohm
1	2	0.176	0.138
2	3	0.176	0.138
3	4	0.045	0.035
4	5	0.089	0.069
5	6	0.045	0.035
5	7	0.116	0.091
7	8	0.073	0.073
8	9	0.074	0.058
8	10	0.093	0.093
7	11	0.063	0.05
11	12	0.068	0.053
7	13	0.062	0.053

Table 2: Buses data

Bus number	P kw	Q kvar
1	0	0
2	890	468
3	628	470
4	1112	764
5	636	378
6	474	344
7	1342	1078
8	920	292
9	766	498
10	662	480
11	690	186
12	1292	554
13	1124	480

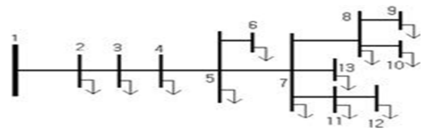

Fig. 2: Single line diagram of feeder

Table 3: Results of power flow without installation

Bus number	stability index
2	0.9811
3	0.9512
4	0.9523
5	0.9435
6	0.9389
7	0.9423
8	0.9287
9	0.9416
10	0.9210
11	0.9139
12	0.9257
13	0.9474

PROPOSED METHODOLOGY

The harmony search algorithm was derived by adopting the idea that the existing meta-heuristic algorithms are found in the paradigm of natural phenomena. The algorithm was recently developed in an analogy with music improvisation process where music players improvise the pitches of their instruments to obtain better harmony (Fesanghary *et al*., 2008).

The HS approach was inspired by the observation that the aim of music is to search for a perfect state of harmony. In music improvisation, each musician plays within possible pitches to make a harmony vector. If all the pitches create good harmony, the musician saved them in memory and increases good or better harmony for next time. Similarly, in the field of engineering optimization, at first each decision variable value is selected within the possible range and formed a solution vector. If all decision variable values lead to a good solution, each variable that has been experienced is saved in memory and it increases the possibility of good or better solutions for next time. Both processes intend to produce the best or optimum (Sirjani *et al*., 2010). Since the procedure of finding the best harmony in metaheurestic algorithms are similar to finding the best harmony in music, Fig. 3 is illustrated to show this similarity.

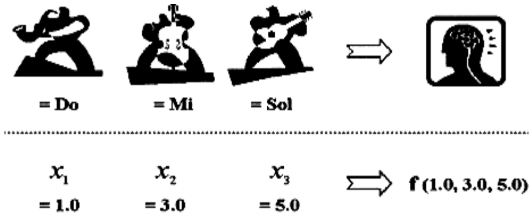

Fig. 3: Comparison between music improvisation and engineering optimizayion

The pitch of each musical instrument determines the aesthetic quality, just as the objective function value is determined by the set of values assigned to each decision variable (Coelho and Mariani,2009). Steps of optimization procedure of HS algorithm are as follows (Geem *et al*., 2001; Fesanghary and Ardehali, 2009; Alinejad-Beromi *et al*., 2007; Geem *et al*., 2005):

Step 1: Initialize the optimization problem and algorithm parameters.
Step 2: Initialize the Harmony Memory (HM).
Step 3: Improvise a new harmony from the HM.
Step 4: Update the HM.
Step 5: Repeat steps 3 and 4 until the termination criterion is satisfied.

Initialization of the optimization problem and algorithm parameters: In this step the optimization problem is specified as follows:

Minimize f(x)
Subject to $x_i \in X_i$, = 1, 2, ..., N

where f(x) is the objective function; x is a candidate solutions consisting of N decision variables (x_i); X_i is the set of possible range of values for each decision variable, that is, $_L x_i \le X_i \le {}_U x_i$ for continuous decision variables where $_L x_i$ and $_U x_i$ are the lower and upper bounds for each decision variable, respectively; and N is the number of decision variables. In addition, HS algorithm parameters that are required to solve the desired optimization problem are specified in this step. These parameters are the Harmony Memory Size (HMS) or the number of solution vectors, Harmony Memory Considering Rate (HMCR), Pitch Adjusting Rate (PAR) and termination criterion (maximum number of searches). HMCR and PAR are parameters that are used to improve the solution vector; both are defined in step 3.

Initialization of the harmony memory: In this step, the Harmony Memory (HM) matrix), shown in Eq. (3), is filled with as many randomly generated solution vectors as HMS and sorted by the values of the objective function, f(x):

$$HM = \begin{bmatrix} x^1 \\ x^2 \\ . \\ . \\ x^{HMS} \end{bmatrix} \tag{3}$$

Improvising new harmony from the harmony memory: A new harmony vector, $x' = (x'_1, x'_2, ...x'_N)$, is generated from the HM based on memory considerations, pitch adjustments and randomization. For instance, the value of the first decision variable for (x'_1) the new vector can be chosen from any value in the specified HM range x_1^1, x_1^{HMS}. Values of the other decision variables x'_i can be chosen in the same manner. There is a possibility that the new value can be chosen using the HMCR parameter, which varies between 0 and 1 as follows:

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

The HMCR sets the rate of choosing one value from the historic values stored in the HM and (1-HMCR) sets the rate of randomly choosing one feasible value not limited to those stored in the HM. For example, a HMCR of 0.9 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 10% probability. Each component of the new harmony vector, $x' = (x'_1, x'_2, \ldots x'_N)$, is examined to determine whether it should be pitch-adjusted. This procedure uses the PAR parameter that sets the rate of adjustment for the pitch chosen from the HM as follows:

Pitch adjusting decision for

$$x_i^{'} \leftarrow \begin{cases} \textit{with probabilty HMCR} \\ \textit{with probabilty} (1 - \textit{HMCR}) \end{cases}$$

A PARof 0.3 indicates that the algorithm will choose a neighboring value with 30% × HMCR probability. Ifthe pitch adjustment decision for x'_i is Yes, the pitch-adjusted value of x'_i will be $x'_i + \alpha$ where *a* is thevalue of bw × u(-1,1), bw is an arbitrary distance bandwidth for the continuous design variable and u is a uniform distribution between -1 and 1.

Updating the harmony memory: In this stage, if the new harmony vector is better than the worst harmony vector in the HM in terms of the objective function value, the existing worst harmony is replaced by the new harmony. The HM is then sorted by the objective function value.

Termination criterion: The computations are terminated when the termination criterion (maximum number of improvisations) is satisfied. Otherwise, steps 3 (improvising new harmony from the HM) and 4 (updating the HM) are repeated.

Figure 4 shows proposed optimization procedure based on HSA. In this procedure after initializing optimization problem and algorithm parameters, Harmony Memory (HM) is initialized. All transmission lines of the system are considered as a potential location for placement of DG.

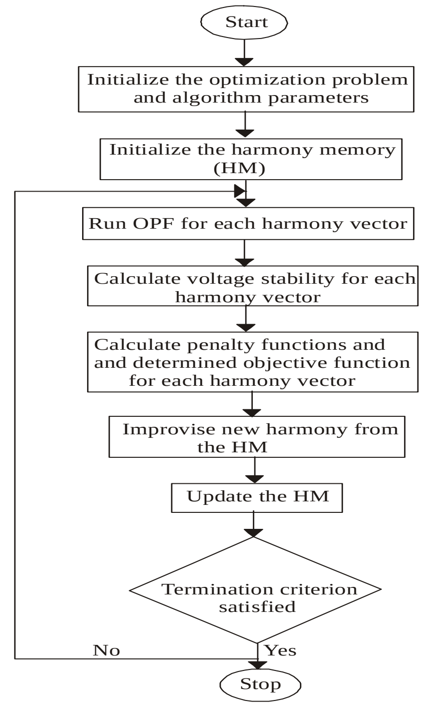

Fig. 4: Proposed optimization method procedure

After initializing HM, OPF is performed for the new system with DGs. Based upon results of OPF, voltage stability of the system is calculated for each harmony vector. Then using the objective function value for each harmony vector that is a potential solution is calculated. Next, a new harmony is improvised from the HM. After these processes, based on the calculated objective function of harmony vectors, HM will be updated. Finally, the termination criterion is checked. Termination criterion is assumed to be the number of iterations in this paper.

SIMULATION RESULTS

Reference (Sedighizadeh and Rezazadeh, 2008) gave us a method synthesizing optimal power flow and Genetic Algorithm (GA) to find the best combination of sites within a distribution network for connecting DGs. Reference (Khanjanzadeh *et al*., 2011) same method by Particle Swarm Optimization (PSO). The results are evaluated for integration of 3 DG into the distribution system. These results are obtained while assuming that all the generators operate at a power factor of 0.95.

The analysis for this system has been done by appraising of value of steady state voltage stability index. A load flow solution for the system using Newton-Raphson load flow method is performed first. Then the results of the load flow are used to appraise the powers P(m2) and Q(m2) at each node. Finally the SI index has been appraised.

Table 4: Optimum capacity and location

Bus number	DG capacity	Fitness function	
By PSO	4	4.0573	0.0834177
	8	4.6701	
	12	2.8894	
By HSA	4	4.1321	0.084259
	8	4.7023	
	6	2.9832	

Table 5: Results of power flow and harmonic power flow without installation

Bus number	Stability index by PSO	Stability index by HSA
2	0.9986	0.9993
3	0.9994	0.9997
4	1.0000	0.9989
5	0.9983	1.0006
6	0.9980	0.9992
7	0.9978	1.0012
8	1.0000	1.0026
9	0.9991	1.0012
10	0.9981	1.0001
11	0.9996	1.0002
12	1.0000	0.9999
13	0.9990	0.9997

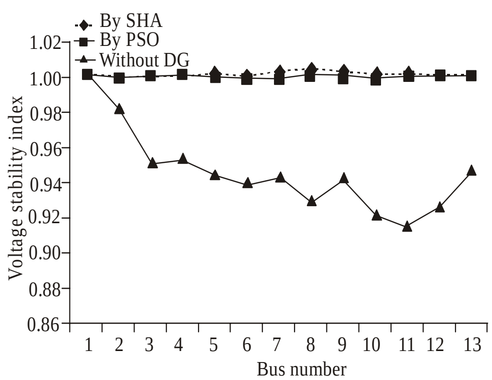

Fig. 5: Voltage instability of the case study network without and with two optimal DGs

In Table 4 the best places for adding DGs with optimal capacities are shown.

The results of optimal capacity and location of DG for case study by HSA and PSO are illustrated in Table 4. The impact of installing three DGs in the case study network with optimal capacity and location is presented in Table 5.

Comparing the results in Table 3 with those of Table 5, we can conclude that with installing three DGs, the voltage instability is improved and the results that assembled by HSA method is more optimum than PSO method. Figure 5 shows voltage instability of the case study network without and with two optimal DGs.

In this study we compare HSA and PSO methods on the terms of speed, accuracy and convergence.

These methods are implemented with MATLAB software and results show that HSA performed in a better form, in terms of both solutions quality and number of iterations than the PSO algorithm.

CONCLUSION

Voltage stability enhancement analysis of distribution networks with the integration of distributed generation is presented in this study. The main conclusions which can be drawn from the results of the analysis are: the location of the DG has a main effect on the voltage stability over its capacity; voltage stability should be taken into account as an objective when dealing with optimum allocation of DG; for the same feeder, distributing an amount of DG power is better than placed it at a certain bus. This is an important conclusion because the locations of the DG can't be controlled and then this may be in some cases helpful for voltage stability enhancement.

In this study the effect of DG capacity and location on voltage stability enhancement of a part of Tehran Network distribution system is analyzed. By comparing the results to PSO results (Khanjanzadeh *et al*., 2011) it can be concluded that using Harmony Search Algorithm is more acceptable.

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