Voltage Stability Enhancement of Distribution System Using Network Reconfiguration in the Presence Of DG

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ABSTRACT

Voltage stability improvement is an important issue in power system planning and operation. This article presents the effect of reconfiguration in the presence of distributed generation (DG) in radial distribution system to improve the voltage stability with different load models by using Artificial Bee Colony (ABC) algorithm. The analysis is accomplished using a voltage stability index which can be evaluated at each node of the distribution system. The network reconfiguration involves a mechanism for selection of the best set of branches to be opened, one from each loop, such that the reconfigured radial distribution system possesses desired performance characteristics. The location of DG has the main effect of voltage stability on the system. Simulation study is conducted on 69-bus radial test system to verify the efficacy of the proposed method.

Keywords: feeder reconfiguration, distributed generation, artificial bee colony algorithm, voltage stability index, radial distribution network.

INTRODUCTION

Voltage stability is generally defined as the ability of a system to maintain the voltage at all points of the system, resulting in an increase of load power with an increase of load, and both the voltage and power should be controllable. Voltage stability of a distribution system is one of the keen interests of industry and research sectors around the world. It concerns stable load operation, and acceptable voltage levels all over the distribution system buses. The radial distribution system (RDS) experiences sudden voltage collapse due to the low value of voltage stability index at most of its nodes under critical loading conditions in certain industrial areas. To improve the voltage stability (voltage profile) of the network for a specific loading pattern is to reschedule the load distribution more efficiently. This can be accomplished by network reconfiguration in the presence of DG.

Network reconfiguration is a process of altering the topological structure of the distribution feeders by changing the open/close status of the sectionalizing and tie-switches. During normal operating conditions, networks are reconfigured for loss reduction to reduce system real power losses, and achieve load balancing in order to relieve the network overloads. The voltage stability of the distribution systems can be enhanced, if the loads are rescheduled more efficiently by reconfiguring the network that allows smoothening out peak demands, improving the voltage profile and increase the network reliability.

There have been many studies on the reconfiguration of distribution systems for loss reduction. A switch exchange algorithm [1], approximate power flow technique [2] and linear programming problem [3] were proposed to reconfiguration problem. Genetic algorithm [4], simulated annealing [5], improved Tabu Search [6], ACS algorithm [7], hyper-cube ant colony algorithm [8], discrete particle swarm optimization [9] and comprehensive approach [10] have been proposed for network reconfiguration problem for loss reduction. Voltage stability improvement through reconfiguration is reported in [11-14].

Over the last decade, distribution systems have seen a significant increase in small-scaled generators, which is known as distributed generation (DG). Distributed generators are grid connected or stand-alone electric generation units located within the distribution system at or near the end user. One can further categorize distributed generation technologies as renewable and nonrenewable. Renewable technologies include: solar, photovoltaic or thermal, wind, geothermal and ocean. Nonrenewable technologies include: internal combustion engine, combined cycle, combustion turbine, micro turbines and fuel cell.

DGs are placed at optimal locations to reduce losses. Some researchers presented some power flow algorithms to find the optimal size of DG at each load bus [15, 16]. Analytical approaches for optimal placement of DG in terms of loss reduction [17] and the benefit of reduced line loss in radial distribution feeder with concentrated load [18] have been proposed. Further, many researchers have used evolutionary computational methods for finding the optimal DG placement. GA for placement of DG to reduce the losses [19] and multiobjective evolutionary algorithm for the sizing and placement of DG [20] were proposed. Tabu search algorithm to find optimal placement of distributed generator [21] and genetic algorithm for optimal allocation of DG to reduce system losses [22] have been proposed. The drawback of these methods is voltage stability improvement of the feeder reconfiguration in the presence of DG is not considered.

This article emphasizes the implementation of feeder reconfiguration to the distribution system with distributed generator (DG) by an artificial bee colony (ABC) algorithm. A two stage methodology is applied in this article. The first stage is optimal siting of DG by applying the loss sensitivity factor (LSF). The top most nodes are ranked to create a candidate nodes list, and within this list the top ranked index values represented optimal DG location after which optimal sizing was then performed using ABC algorithm is the second stage. The objective of the feeder reconfiguration with DG is to reduce the real power losses and improvement of the voltage profile and voltage stability. The purposed methodology is demonstrated by a 69-bus radial distribution system.

PROBLEM FORMULATION

In the radial distribution system, each radial feeder is divided into load sections with sectionalizing switches and is connected to other feeders via several tie switches. Due to the fact that reducing the real power loss of the distribution feeders is an important purpose in feeder reconfiguration in the presence of DG to minimize the real power loss of the feeders is considered as objective function. The total real power losses of the distribution network can be calculated as follows

$$P_L = min \sum_{k=1}^{n-1} R_k \left|I_k\right|^2 \tag{1}$$

Where

P_L is total system loss,

n is number of nodes in the distribution network,

R_k is resistance of k^{th} line,

$|i_k|$ is absolute of k^{th} line current, subject to the following.

i) Voltage constraint: voltage magnitude of each branch must lie within their permissible ranges to maintain power quality.

ii) Isolation constraint: all of nodes are energized.

iii) Radial network constraint: distribution networks should be composed of radial structure operation.

For placement of distributed generation, the loss sensitive factors at different buses have been evaluated to select appropriate nodes for DG planning by using load flow program. Artificial bee colony algorithm (ABC) is used to obtain the optimal switching combination and DG size that enhances the voltage stability of radial distribution systems suggested in Chakravorty and Das [23].

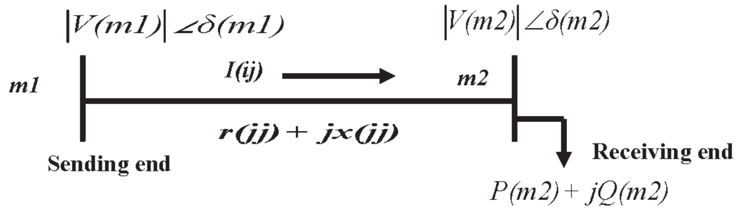


Fig. 1: Simple two node system

Voltage stability index of node *m2* of Fig. 1 can be determined

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

For stable operation of the radial distribution networks, SI (m2) 0.

The node at which the value of the stability index is minimum, is more sensitive to the voltage collapse. The real and reactive power loads of node 'i' is given as:

$$PL(i) = PL_o(i)\left[c1 + c2|V(i)| + c3|V(i)|^2\right] \quad (3)$$

$$QL(i) = QL_o(i)\left[d1 + d2|V(i)| + d3|V(i)|^2\right] \quad (4)$$

Where
$c1=d1=1$, $c2=c3=d2=d3=0$, for constant power load
$c2=d2=1$, $c1=c3=d1=d3=0$, for constant current load
$c3=d3=1$, $c1=c2=d1=d2=0$, for constant impedance load

Composition of 40% constant power, 30% of constant current and 30% of constant impedance loads are considered for composite load.

The computational procedure to find the optimal size and location of DG is described below.

Step 1: Run the load flow for base case.
Step 2: Find the base case loss.
Step 3: Find the optimal location of DG by using loss sensitive index.
Step 4: Find the optimal size of DG by using ABC algorithm.
Step 5: Check constraints violation after the placement of DG.
Step 6: Run the load flow with the optimal size of DG placed at the optimal bus.
Step 7: Calculate the reduction in real power loss after placement of DG.

ARTIFICIAL BEE COLONY ALGORITHM (ABC)

An Artificial bee colony algorithm is an optimization tool that provides a population based search procedure. It was defined by Dervis Karaboga in 2005 and motivated by the intelligent behavior of honeybees. The colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts [24-25]. First half of the colony consists of the employed artificial bees and the second half includes the onlooker's bees. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been abandoned becomes a scout [26].

Thus, ABC system combines local search carried out by employed and onlooker bees, and global search managed by onlookers and scouts, attempting to balance exploration and exploitation process [27].

The ABC algorithm has the following control parameters: 1) the colony size CS, that consists of employed bees E_b plus onlooker bees E_b; 2) the limit value, which is the number of trials for a food-source position (solution) to be abandoned; and 3) the maximum cycle number MCN.

The proposed ABC algorithm is as follows:

Step-1: Read the system data and Initialize the food-source positions x_f (solutions population), where $f = 1,2,\ldots..,E_b$.

Step-2: Calculate the fitness value of the population using

$$fitness = \frac{1}{1 + powerloss} \tag{5}$$

Step-3: Generate new solutions x_{fg} using Equation

$$x_{fg}^{new} = x_{fg}^{old} + u\left(x_{fg}^{old} - x_{mg}\right) \tag{6}$$

and evaluate them as indicated by Step 2.

Where $m \neq 1$ and both are $\in\{1, 2, \ldots, E_b\}$. The multiplier u is a random number between [-1, 1]

x_{fg} is the g^{th} parameter of a solution x_f that was selected to be modified.

Step-4: Apply the greedy selection process.

Step-5: If all onlooker bees are distributed, go to Step 9. Otherwise, go to the next step.

Step-6: Calculate the probability values P_f for the solutions xf using Equation

$$P_f = \frac{fitness}{\sum_{f=1}^{E_b} fitness_f} \tag{7}$$

Step-7: Produce the new solutions for the selected onlooker bee, depending on the value, using Eqs. (6) and evaluate them as Step 2 indicates.

Step-8: Follow Step 4.

Step-9: Determine the abandoned solution for the scout bees, if it exists, and replace it with a completely new solution using Equation 8

$$x_{fg}^{(new)} = min\ (x_{fg}) + u\ [max\ (x_{fg})\ min\ (x_{fg})] \tag{8}$$

and evaluate them as indicated in Step 2.

Step-10: Memorize the best solution attained so far.

Step-11: If cycle = MCN, stop and print result. Otherwise follow Step 3.

RESULTS AND ANALYSIS

To check the effectiveness of the proposed method, 69-bus radial distribution network [29] is considered. It consists of five tie lines and 68 sectionalize switches. The normally open switches are 69 to 73, and the normally closed switches are 1 to 68. The total real and reactive power loads on the system are 3802.19 kW and 2694.06 kVAR and the initial power loss of this system is 225 kW. The lowest bus bar voltage is 0.9092 p.u. which occurs at node 65. Three cases are examined as follows:

Case 1: The system is feeder reconfiguration and without distributed generator

Case 2: The feeder is distributed generation and without reconfiguration

Case 3: The same as case 1 but with distributed generator.

First, load flow [28] is conducted for 69-bus bus test system for base case. The loss sensitivity factors [22] at different buses have been evaluated to select appropriate buses for DG planning and the values are arranged in descending order. Artificial bee colony algorithm (ABC) is proposed to determine the optimal DG-unit size in order to improve the voltage stability in radial distribution system. The Control parameters of ABC method are colony size (Cs) is 30 and MCN is 40. The bus voltage magnitudes are kept within acceptable operating limits ((±5%) throughout the optimization process. Penetration of DG is considered in a range of 10% – 80% of total load.

Table 1: summary of test results

Description		Case 1		Case 2		Case 3
		Existing method [29]	**Proposed method**	**Existing method [29]**	**Proposed method**	**Proposed method**
DG placement	Location	—		61	61	61
	Size (kW)			1773.2	1931.2	1931.2
Open switches		13,18,56, 61,69	14,57,61, 69,70	69,70,71, 72,73	69,70,71, 72,73	12,56,63, 69,70
Min. voltage (p.u.)		0.9428	0.9495	0.9677	0.9688	0.9672
Total real power loss (kW)		99.35	98.58	86.77	78.77	52.79
Loss reduction (%)		55.84	56.18	61.43	64.99	76.53

Case-1: The feeder is reconfiguration without distributed generation

For this case the summary of test results of existing and proposed method are tabulated in Table 1. From this table, it is observed that the optimal configuration obtained by the proposed method is 14, 57, 61, 69 and 70, which has a real power loss of 98.58 kW is less than the existing method [29]. This amounts to a reduction of 56.18% in total power loss. Before reconfiguration, the minimum bus voltage is 0.9092 p.u. and the minimum bus voltage and average voltage of the system is improved to 0.9495 p.u and 0.9870 p.u after reconfiguration.

Case-2: The feeder is distributed generation and without reconfiguration

The optimum size of DG at bus 61 is 1931.2 kW. The improvement of minimum bus voltage of system after optimally placing the DG by proposed method is 0.9688 p.u. The average voltage of the system is 0.9878 p.u after installing DG. Similarly the losses have reduced to 78.77 kW. This amounts to a reduction of 64.99% in total power loss.

Case-3: The feeder is distributed generation with reconfiguration

The same as case 2 except that there is feeder reconfiguration, the optimum size of DG at bus 61 is 1931.2 kW. The optimal configuration in this case is 12, 56, 63, 69 and 70, which has a real power loss of 52.79 kW. This amounts to a reduction of 76.53% in total power loss. The minimum bus voltage of the system is 0.9672 p.u and the average voltage of the system is 0.9901 p.u.

For enhancement of voltage stability in radial distribution system, the load at each node is increased gradually, the minimum value of voltage stability index occurring at minimum voltage node. Critical loading condition for different types of load, different values of substation voltage and different case results are given in Table 2-5.

A DG is connected at appropriate node, it increased and supported the voltage and stability in the system. The connection point of DG influenced the voltage stability in the system. DG strongly supported the voltage at nearby nodes and has less impact on distant nodes. Being the most sensitive node, bus 61 is selected for best candidate location for DG placement in case-2. The same node has also been selected as the most suited location in case-3. Fig 2. Show the plots of variation of Vmin and SImin w.r.t. total real and reactive power load for constant power load for case-3. It is observed that the shape of the plots is the stability index of a node varies almost linearly with the real and reactive power loading.

From Table 2-5, it is observed that the critical loading for composite load is the maximum and that for constant power load is minimum for three cases. The critical loading for constant current load lied between these composite load and constant power load. The stability index and consequently the voltage are minimum for composite load in all cases. The critical loading points or collapse points are indicated beyond which a small increment of load causes the voltage instability.

Table 2: Critical loading condition for base case

Load type	Substation voltage (p.u)	Critical loading condition			
		TPL (MW)	TQL (MVAr)	SI_{min}	V_{min}(p.u)
Constant Power (CP)	1.000	12.183	8.621	0.0510	0.4717
	1.025	12.799	9.058	0.0566	0.4844
	1.050	13.431	9.505	0.0621	0.4954
Constant Current (CI)	1.000	15.128	10.569	0.1086	0.5104
	1.025	15.824	11.237	0.1183	0.5798
	1.050	16.604	11.748	0.1276	0.5958
Constant Impedance (CZ)	1.000	14.104	9.969	0.2203	0.6748
	1.025	14.798	10.513	0.2398	0.7010
	1.050	15.523	11.029	0.2539	0.6974
Composite load	1.000	14.824	10.416	0.0698	0.5128
	1.025	15.493	10.978	0.0809	0.5269
	1.050	16.314	11.631	0.0898	0.5498

Table 3: Critical loading condition for different types of load for case-1

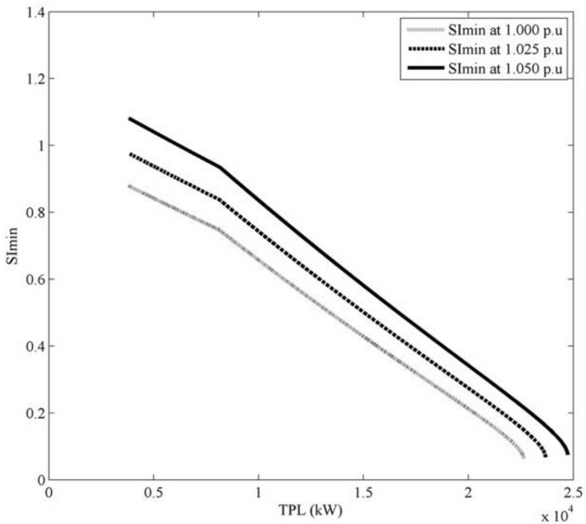
Load type	Substation voltage (p.u)	Critical loading condition			
		TPL (MW)	TQL (MVAr)	SI_{min}	V_{min}(p.u)
Constant Power (CP)	1.000	20.910	14.817	0.07051	0.4814
	1.025	21.967	15.566	0.07943	0.4963
	1.050	23.050	16.334	0.08821	0.5097
Constant Current (CI)	1.000	21.898	15.518	0.07186	0.4841
	1.025	22.419	15.887	0.07969	0.4969
	1.050	22.940	16.256	0.08816	0.5097
Constant Impedance (CZ)	1.000	22.845	16.188	0.07033	0.4813
	1.025	22.845	16.188	0.7753	0.4931
	1.050	22.845	16.188	0.8520	0.5048
Composite Load	1.000	33.065	23.430	0.06592	0.4735
	1.025	34.319	24.319	0.07264	0.4851
	1.050	35.578	25.211	0.07988	0.4968

Table 4: Critical loading condition for different types of load for case-2

Load type	Substation voltage (p.u)	Critical loading condition				DG Size (MW)
		TPL (MW)	TQL (MVAr)	SI_{min}	V_{min}(p.u)	
Constant Power (CP)	1.000	14.319	10.148	0.06403	0.5009	1.9312
	1.025	14.931	10.582	0.06793	0.5083	1.9261
	1.050	15.555	11.024	0.07634	0.5234	1.9212
Constant Current (CI)	1.000	15.331	10.865	0.06223	0.4973	1.7777
	1.025	15.631	11.078	0.06768	0.5079	1.8237
	1.050	15.931	11.290	0.07359	0.5186	1.8696
Constant Impedance (CZ)	1.000	16.262	11.525	0.06024	0.4933	1.6568
	1.025	16.262	11.525	0.06644	0.5056	1.7407
	1.050	16.262	11.525	0.07311	0.5178	1.8267
Composite load	1.000	22.105	15.666	0.05702	0.4866	1.8467
	1.025	22.861	16.202	0.06262	0.4981	1.8923
	1.050	23.614	16.735	0.06853	0.5095	1.9327

Table 5: Critical loading condition for different types of load for case-3

Load type	Substation voltage (p.u)	Critical loading condition				
		TPL (MW)	TQL (MVAr)	SI_{min}	V_{min}(p.u)	DG size (MW)
Constant Power (CP)	1.000	22.644	16.046	0.06247	0.4999	1.9312
	1.025	23.678	16.778	0.06656	0.5079	1.9312
	1.050	24.735	17.527	0.07478	0.5229	1.9312
Constant current (CI)	1.000	23.742	16.824	0.06060	0.4961	1.9312
	1.025	24.191	17.142	0.06625	0.5073	1.9312
	1.050	24.640	17.460	0.07574	0.5246	1.9312
Constant impedance (CZ)	1.000	24.556	17.401	0.06088	0.4967	1.9312
	1.025	24.666	17.479	0.06896	0.5124	1.9312
	1.050	24.788	17.565	0.07560	0.5243	1.9312
Composite load	1.000	35.368	25.063	0.05727	0.4892	1.9312
	1.025	36.543	25.895	0.06278	0.5005	1.9312
	1.050	37.729	26.736	0.06860	0.5117	1.9312



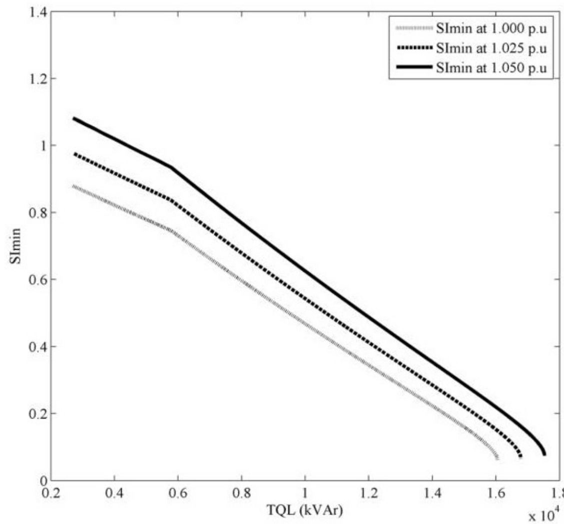


Fig 2. Variation of Vmin and SImin w.r.t. total real and reactive power load for constant power load for case-3. (*Continued*)

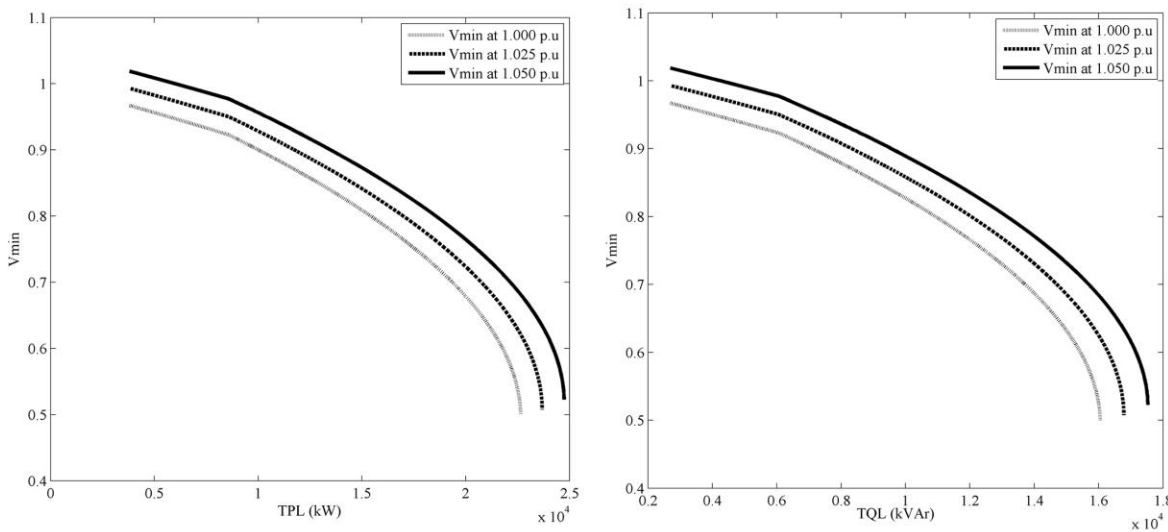


Fig 2. Variation of Vmin and SImin w.r.t. total real and reactive power load for constant power load for case-3.

CONCLUSION

This article presents an artificial bee colony algorithm to improve the voltage stability in radial distribution system. Using voltage stability index, it is possible to compute the voltage stability index at every node and identify the node at which the value of the voltage stability index is minimum and is most sensitive to voltage collapse. Effectiveness of the proposed method has been demonstrated through a 69-bus radial distribution network. Three cases and different load models, i.e., constant power, constant current, constant impedance and composite load modeling are considered for the purpose of voltage stability analysis. It was observed that in case-3 i.e. the distribution system is reconfigured with DG, the critical loading for composite load is maximized and also a great improvement in voltage stability and critical loading conditions for all load models after distribution system is reconfigured with DG.

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