RELIABILITY IMPROVEMENT OF RADIAL DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION

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Abstract— This paper describes a methodology for reliability enhancement of radial distribution system with Distributed Generation (DG). Assessment of customer power supply reliability is an important part of distribution system operation and planning. Distribution system reliability assessment is able to predict the interruption profile of a distribution system based on system topology and component reliability data. Distributed generation is being adopted in distribution networks with one of the objectives being enhancement of system reliability. Artificial Bee Colony (ABC) algorithm is proposed to obtain the optimal values of repair times and failure rates of each section to improve the reliability.

Key words – distributed generation, artificial bee colony algorithm, reliability indices, failure rate, repair time, radial distribution network.

I. INTRODUCTION

The majority of distribution systems are designed to operate with a radial topology. Radial distribution systems have a set of series components between a substation and a load point, including breakers, lines, cables, transformers, switches, fuses and other equipment. A failure of any component in the series path results in the outage of a load point. Sectionalizing devices provide a means of isolating a faulted section. In some systems there is an alternative supply source for sections that become disconnected from their original source after the failure is isolated.

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipments (except standby) are energized and all customers are energized. Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions. A reliability assessment model quantifies reliability characteristics based on system topology and component reliability data. Areas of inherently good or poor reliability can be identified. The model also identifies over-loaded and undersized equipment that degrades system reliability. Other useful results include the expected number of switch and protective device operations and the sensitivity of results to component reliability parameters.

The reliability of a distribution system may be increased by modifying failure rate and repair time of each section of the network. Such modifications may require additional investments which in the presence of DG may be mitigated. This will result in annual savings. On the other hand cost per unit energy obtained from

DG may be high. Further the traditional reliability indices covered sustained interruption durations. The time necessary to start up the DG should be taken in to account for the reliability evaluation of distribution system. If this time is sufficiently short the customers suffer a momentary interruption, while, if not, they suffer a sustained interruption.

Distributed generation (DG) is expected to play an increasing role in emerging power systems [1]. Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG. Its impact on distribution systems may be either positive or negative depending on the system's operating condition [1-2], DGs characteristics and location. Potential positive impacts include

- improved system reliability;
- loss reduction;
- improved power quality.

Two sets of reliability indices, customer load point indices and system indices have been established to assess the reliability performance of distribution systems. Load point indices measure the expected number of outages and their duration for individual customers. System indices such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) measure the overall reliability of the system [3]. These indices can be used to compare the effects of various design and maintenance strategies on system reliability.

Optimal allocation and sizing of DGs is solved in [4] using an analytical based method to minimize the line loss. The same problem is solved using an ordinal optimization method in [5]. In addition to the line loss, the system reliability is included in the DG planning problem as a constraint in [6] for improving the system reliability, line loss, and voltage profile. In [6], the genetic algorithm (GA) is employed as the required optimization method.

To further improve the system reliability, switches, such as reclosers and cross connections, are incorporated in the DG-based planning problem. An ant colony system algorithm is employed in [7] for finding the optimal placement of reclosers and DGs. This method minimizes an objective function composed of two reliability indices: system average interruption duration index and system average interruption frequency index. A two-step design is presented in this paper. First, the optimal placement of reclosers is identified while the DG locations are fixed. Then, DGs are planned for the reclosers determined in the previous step. A similar problem with the same objective function is solved using GA in [8] and [9]. In [10], an ant colony algorithm based reconfiguration methodology is proposed for solving the optimal switching operation of distribution networks in the presence of DGs.

This paper presents artificial bee colony (ABC) method for optimal failure rate and repair time of each section of a distribution system in the presence of distributed generation. An objective function which reflects cost of modification of failure rates, and repair rate and cost of energy not supplied from DG has been constructed and minimized subject to reliability constraints.

II. PROBLEM FORMULATION

Distributed generation may be used as standby units for reliability enhancement at specific load points. If DG capacity is sufficient to meet the load at a load point in the event of failure of supply from substation then the situation at load point is represent as shown in Fig. 1.

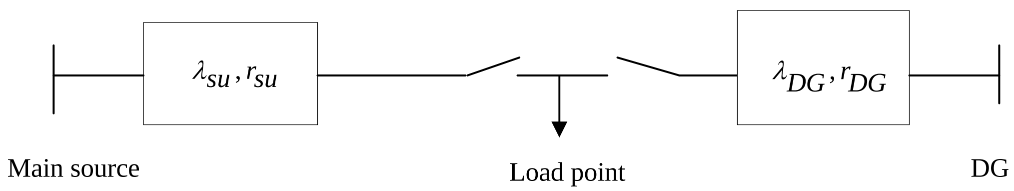

Fig 1. Load point fed from main source and DG as stand by unit

Where,

λ_{su} is the total failure rate up to load point from source,

r_{su} is the average interruption duration from source,

λ_{DG} is the failure rate of DG,

r_{DG} is the average outage duration of DG.

Reliability may be improved for a radial distribution system by modifying failure rate and average repair time of each segment of the system. Addition of distribution generation (DG) may require additional cost per kWh to be paid to the private DG owners. In view of this the objective function is selected as follows

$$F = \sum_{k=1}^{n-1} \frac{\alpha_k}{\lambda_k^2} + \sum_{k=1}^{n-1} \frac{\beta_k}{r_k} + ADCOST\left(EENSO - EENSD\right) \tag{1}$$

Where

λ_k is the failure rate of k^{th} section,

r_k is the average repair time of k^{th} section,

α_k and β_k are the cost coefficients,

EENSO is the expected energy not supplied without DG,

EENSD is the expected energy not supplied with DG.

The objective function constitutes of three parts i.e. first part reflects cost of modifications of failure rates of each section, second part gives cost of modifications in average repair time of each section which is again based on a growth model of repair time and third part represents additional cost to be paid to the owners of DG. This term in fact is the expected energy supplied (EENSO–EENSD) by DG multiplied by additional charge per kWh (ADCOST).

Expected energy not supplied (EENS) is calculated for all load points as follows

$$EENS = \sum_i L_i U_{system,i} \tag{2}$$

Where L_i is average load at i^{th} load point; $U_{System,i}$ is average annual outage duration at i^{th} load point. EENS is calculated without DG is termed as EENSO and that calculated with DG is termed as EENSD.

Calculate $U_{sustem,i}$ accounting without DG to evaluate EENSO as follows

$$U_{system,\,i} = \sum_{k \neq d} \lambda_k r_k$$

'd' is set of distribution segments in series up to k^{th} load point.

Calculate $U_{sustem,i}$ accounting with DG to evaluate EENSD as follows

$$U_{system,\,i} = \lambda_{eq} r_{eq}$$

$$\lambda_{eq} = \lambda_{st}$$

$$r_{eq} = s$$

Where λ_{st} is the failure rate of manual switch

's' is average time to carry out the switching operation.

The objective function is minimized subject to following customer and energy based constraints

1. System average interruption frequency index,

$$SAIFI = \frac{Total\ number\ of\ customers\ interruptions}{Total\ number\ of\ customers\ served} = \frac{\sum \lambda_{system,i} N_i}{\sum N_i} \tag{3}$$

Where N_i is the number of customers at load point 'i

2. System average interruption frequency index,

$$SAIDI = \frac{Sum\ of\ customer\ interruptions\ durations}{Total\ number\ of\ customers\ served} = \frac{\sum U_{system,i} N_i}{\sum N_i} \tag{4}$$

3. Customer average interruption duration index,

$$CAIDI = \frac{Sum\ of\ customer\ interruption\ durations}{Total\ number\ of\ customer\ interruptions} = \frac{\sum U_{system,i} N_i}{\sum N_i \lambda_{system,i}} \tag{5}$$

4. Average service availability index,

$$ASAI = \frac{Customer\ hours\ of\ available\ service}{Customer\ hours\ demanded} = \frac{\sum N_i \times 8760 - \sum N_i U_{system,i}}{\sum N_i \times 8760} \tag{6}$$

5. Average service interruption duration index,

$$ASIDI = \frac{Connected\ kVA\ duration\ interrupted}{Total\ connected\ kVA\ served} = \sum \frac{r_i L_i}{L_T} \tag{7}$$

Where L_i is average load connected to load point *'i'*

6. Average service interruption frequency index,

$$ASIFI = \frac{Connected\ kVA\ interrupted}{Total\ connected\ kVA\ served} = \frac{\sum L_i}{L_T} \tag{8}$$

7. Average customer interruption duration index,

$$ACIDI = \frac{Connected\ kVA\ duration\ interrupted}{Connected\ kVA\ interrupted} = \frac{\sum r_i L_i}{\sum L_i} \tag{9}$$

8. Average energy not supplied indices,

$$AENS = \frac{Total\ energy\ not\ supplied}{Total\ number\ of\ customers\ served} = \frac{\sum L_i U_i}{\sum N_i} \tag{10}$$

III. ARTIFICIAL BEE COLONY ALGORITHM (ABC)

Artificial Bee Colony (ABC) is one of the most recently defined algorithms by Dervis Karaboga in 2005, motivated by the intelligent behavior of honeybees. ABC as an optimization tool provides a population based search procedure in which individuals called food positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar. In this algorithm [11, 12], the colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. 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 [13].

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 [14].

The ABC algorithm creates a randomly distributed initial population of solutions ($f = 1,2,\ldots..,E_b$), where 'f' signifies the size of population and 'E_b' is the number of employed bees. Each solution x_f is a D-dimensional vector, where D is the number of parameters to be optimized. The position of a food-source, in the ABC algorithm, represents a possible solution to the optimization problem, and the nectar amount of a food source corresponds to the quality (fitness value) of the associated solution. After initialization, the population of the positions (solutions) is subjected to repeated cycles of the search processes for the employed, onlooker, and scout bees (cycle = 1, 2, …, *MCN*), where *MCN* is the maximum cycle number of the search process. Then, an employed bee modifies the position (solution) in her memory depending on the local information (visual information) and tests the nectar amount (fitness value) of the new position (modified solution). If the nectar amount of the new one is higher than that of the previous one, the bee memorizes the new position and forgets the old one. Otherwise, she keeps the position of the previous one in her memory. After all employed bees have completed the search process, they share the nectar information of the food sources and their position information with the onlooker bees waiting in the dance area. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. The same procedure of position modification and selection criterion used by the employed bees is applied to onlooker bees. The greedy-selection process is suitable for unconstrained optimization problems. The probability of selecting a food-source p_f by onlooker bees is calculated as follows:

$$P_f = \frac{fitness}{\sum_{f=1}^{E_b} fitness_f} \tag{11}$$

Where $fitness_f$ is the fitness value of a solution f, and E_b is the total number of food-source positions (solutions) or, in other words, half of the colony size. Clearly, resulting from using (11), a good food source (solution) will attract more onlooker bees than a bad one. Subsequent to onlookers selecting their preferred food-source, they produce a neighbor food-source position $f+1$ to the selected one f, and compare the nectar amount (fitness value) of that neighbor $f+1$ position with the old position. The same selection criterion used by the employed bees is applied to onlooker bees as well. This sequence is repeated until all onlookers are distributed. Furthermore, if a solution f does not improve for a specified number of times (limit), the employed bee associated with this solution abandons it, and she becomes a scout and searches for a new random food-source position. Once the new position is determined, another ABC algorithm (*MCN*) cycle starts. The same procedures are repeated until the stopping criteria are met.

In order to determine a neighboring food-source position (solution) to the old one in memory, the ABC algorithm alters one randomly chosen parameter and keeps the remaining parameters unchanged. In other words, by adding to the current chosen parameter value the product of the uniform variant [-1, 1] and the difference between the chosen parameter value and other "random" solution parameter value, the neighbor food-source position is created. The following expression verifies that:

$$x_{fg}^{new} = x_{fg}^{old} + u\left(x_{fg}^{old} - x_{mg}\right) \tag{12}$$

Where $m \neq f$ and both are $\in \left\{1,2,...,E_b\right\}$. The multiplier u is a random number between [-1, 1] and $g \in \left\{1,2,...,D\right\}$. In other words, x_{fg} is the g^{th} parameter of a solution x_f that was selected to be modified. When the food-source position has been abandoned, the employed bee associated with it becomes a scout. The scout produces a completely new food source position as follows:

$$x_{fg}^{(new)} = min\left(x_{fg}\right) + u\left[max\left(x_{fg}\right) - min\left(x_{fg}\right)\right] \tag{13}$$

Where (13) applies to all g parameters and u is a random number between [-1, 1]. If a parameter value produced using (12) and/or (13) exceeds its predetermined limit, the parameter can be set to an acceptable value. In this paper, the value of the parameter exceeding its limit is forced to the nearest (discrete) boundary limit value associated with it. Furthermore, the random multiplier number u is set to be between [0, 1] instead of [-1, 1].

Thus, 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: Initialize the food-source positions x_f (solutions population), where $f = 1,2,\ldots,E_b$. The x_f solution form is as follows.

Step-2: Calculate the nectar amount of the population by means of their fitness values using equation (1)

Step-3: Produce neighbor solutions for the employed bees by using (12) and evaluate them as indicated by Step 2.

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 x_f using (11)

Step-7: Produce neighbor solutions for the selected onlooker bee, depending on the value, using equation (1) 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 (13) 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.

IV. RESULTS AND ANALYSIS

The proposed method is tested on 8-bus distribution system as shown in Fig 2. The system has been modified due to presence of DG at bus-3, bus-6 and bus-8. In the failure of supply from the source at these nodes continuity is maintained with the help of these distributed generations. The data of failure rates, repair time, average load, number of customers and cost coefficients are given in [15]. The ADCOST is selected as Rs.1.5 per kWh in the objective function.

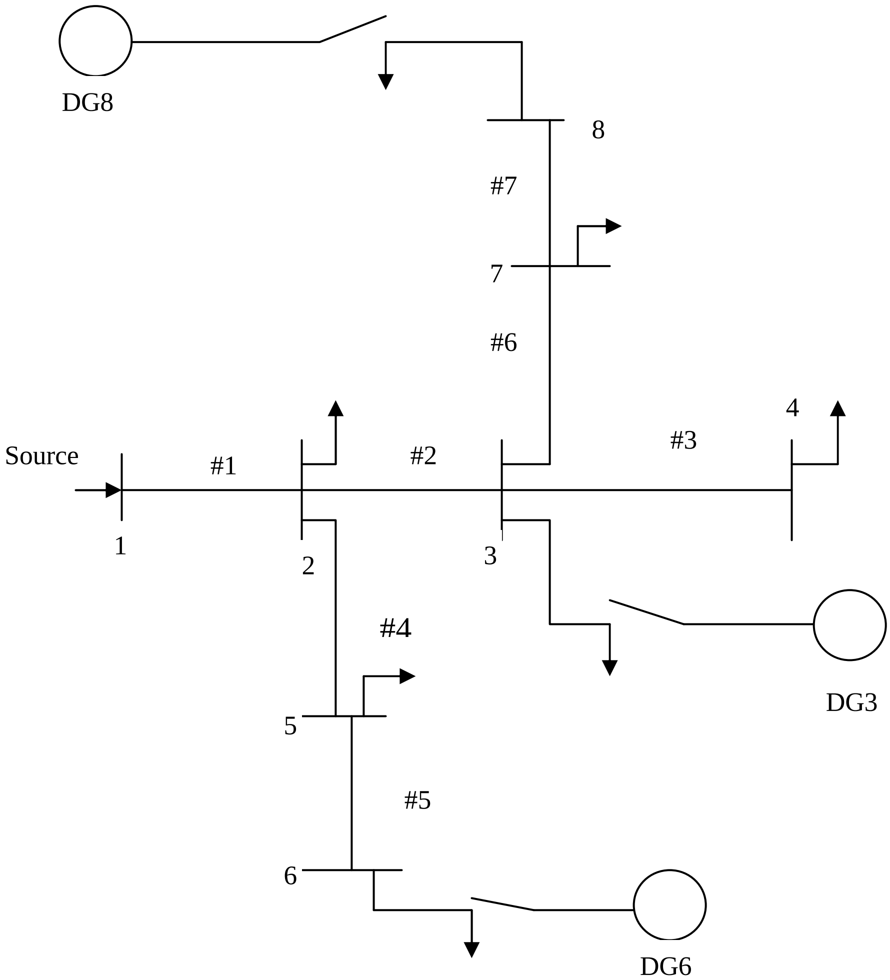

Fig 2. 8- Bus radial distribution system with DG at selected load points

Reliability modeling aspects for load points are calculated as follows

$$\lambda_{system,2} = \lambda_1$$

$$r_{system,2} = r_1$$

$$U_{system,2} = \lambda_1 r_1$$

$$\lambda_{system,4} = \lambda_1 + \lambda_2 + \lambda_3$$

$$U_{system,4} = \lambda_1 r_1 + \lambda_2 r_2 + \lambda_3 r_3$$

$$r_{system,4} = \frac{U_{system,4}}{\lambda_{system,4}}$$

$$\lambda_{system,5} = \lambda_1 + \lambda_4$$

$$U_{system,5} = \lambda_1 r_1 + \lambda_4 r_4$$

$$r_{system,5} = \frac{U_{system,5}}{\lambda_{system,5}}$$

$$\lambda_{system,7} = \lambda_1 + \lambda_2 + \lambda_6$$

$$U_{system,7} = \lambda_1 r_1 + \lambda_2 r_2 + \lambda_6 r_6$$

$$r_{system,7} = \frac{U_{system,7}}{\lambda_{system,7}}$$

The distributed generations are present at buses 3, 6 and 8. The calculation of basic reliability indices will be different as follows

$$\lambda_{system,3} = \lambda_{st3}$$

$$\lambda_{system,3} = \lambda_{st3}$$

Where λ_{st3} is the failure rate of manual switch of DG3

$$r_{system,3} = s_3$$

Where s_3 is average service restoration time of DG3

$$U_{system,3} = \lambda_{st3} s_3$$

Similarly, The basic reliability indices of DG6 and DG8 as follows

$\lambda_{system,6} = \lambda_{st6}$, $r_{system,6} = s_6$, $U_{system,6} = \lambda_{st6} s_6$ and $\lambda_{system,8} = \lambda_{st8}$

$r_{system,8} = s_8$, $U_{system,8} = \lambda_{st8} s_8$

The Control parameters of ABC method are colony size (*Cs)* is 30 and *MCN* is 20.The optimum failure rate and repair time of each section as obtained by proposed ABC method and existing PSO algorithm is given in Table 1.

Table 1: The optimum values of failure rate and repair time

Distribution section	Variables	Existing PSO method	Proposed method	Variables	Existing PSO method	Proposed method
		Failure rates (Year)			Repair times (Hours)	
1	λ_1	0.6	0.6	r_1	15	15
2	λ_2	0.3	0.05	r_2	14	7.5529
3	λ_3	0.1	0.1	r_3	4	4
4	λ_4	0.1	0.1	r_4	8	27.0991
5	λ_5	0.15	0.2213	r_5	22	7
6	λ_6	0.15	0.0583	r_6	6	11.3771
7	λ_7	0.05	0.05	r_7	6	6

Reliability indices for 8-bus radial distribution system are given in Table 2. From the Table 2 the system average interruption duration index (SAIDI) of the system is 10.294 without DG and 7.2395 with DG by ABC method. Note that the decrease of SAIDI indicates an increase of the system reliability. Because of SAIDI depends upon failure rate and repair time of the equipment.

Table 2: Reliability indices for radial distribution system

Index	Existing PSO method		Proposed method	
	Without DG	With DG	Without DG	With DG
SAIDI	12.1650	8.35	10.294	7.2395
CAIDI	14.1043	11.6376	14.6094	11.9252
SAIFI	0.8625	0.7175	0.7046	0.6071
ASAI	0.9986	0.9990	0.9988	0.9992
ASIDI	11.5354	7.0562	10.113	6.0297
ACIDI	14.3640	11.0518	14.6939	11.3007
ASIFI	0.8031	0.6385	0.6882	0.5867
AENS	37.49	22.9325	32.8673	21.5467
Objective function (Rs)	68092		79281	

SAIDI of the system is 8.35 with DG by PSO method and 7.2395 with DG by ABC method. It can be observed the duration related indices improvement with DG installation. Similarly other reliability indices CAIDI, SAIFI, ASIDI, ACIDI, ASIFI and AENS are reduced with DG except ASAI. Average service availability index (ASAI) is improved from 0.9988 to 0.9992 with distributed generations. It can also be seen that the objective function given by the ABC method is 79281 and 68092 by PSO method. It is observed that the objective function obtained by the proposed method is greater than the existing PSO method.

V. CONCLUSION

The reliability improvement is important effect of DGs in emerging active distribution networks. Reliability is measured by reliability indices SAIDI, ASAI, CAIDI, SAIFI, ASIDI, ACIDI, ASIFI and AENS. Electrical power distribution reliability can be improved from different aspects, from planning to operation and maintenance. This paper presents reliability improvement of radial distribution system in the presence of distributed generation. An optimization problem has been formulated which obtains optimum failure rates and repair times of each section. The proposed ABC method is effective as compared to PSO method in terms of objective function improvement.

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