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Value-based Distributed Generation Placements for Reliability Criteria Improvement

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Abstract – Restructuring and recent developments in the power system and problems arising from construction and maintenance of large power plants, increasing amount of interest in distributed generation (DG) source. Distributed generation units due to specifications, technology and location network connectivity can improve system and load point reliability indices. In this paper, the allocation and sizing of DG in distribution networks are determined using optimization. The objective function of the proposed method is to improve customer-based reliability indices at lowest cost. The placement and size of DGs are optimized using a Genetic Algorithm (GA). To evaluate the proposed algorithm, 34-bus IEEE test system, is used. The results illustrate efficiency of the proposed method.

Keywords: Distributed generation, Optimization, Reliability improvement, Cost, GA

1. Introduction

Due to competition and restructuring in power systems and changes in management and ownership of electricity industry, the role of distributed generation units expected to be increase dramatically in the future. Also, factors such as environmental pollution, problems establishment of new transmission lines and technology development of DG unit increase the use of these resources. Although, use of DGs can lead to the distribution network to lower loss, higher reliability, etc, it can also apply a high capital cost to the system. This demonstrates the importance of finding the optimal size and placement of DGs. In recent years, several researches have considered methods for locating DGs on distribution power systems. In all papers, improvement of system characteristics is the main objective of DG placement. Almost all papers related to DGs have studied loss minimization and improve voltage profile [2-9] and a few papers have examined DGs for improving the reliability [1, 10].

From the reliability aspect, considering load shedding results in the optimization to be more realistic. As an illustration, in [15] it is assumed that if the total DGs rating in an island are less than the total loads located in that island, it is assumed that no loads can be served and all those loads are shed till the feeder under fault is repaired.

This paper is organized as follow: The Effect of DG on system reliability and reliability assessment introduced in section II. In section III, formulation of problem is introduced and the optimum placement DGs in distribution networks is presented and a composite reliability index is defined. In section IV, the proposed method for optimal DG placement by genetic algorithm is detailed. Simulation results and conclusions are expressed in section V and VI, respectively.

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2. Distribution system reliability assessment

Reliability assessment of distribution power systems and evaluation method has received considerable attention of many researchers and the numerous papers have published in this case. However, evaluation methods in distribution power system need further development [10, 11].

In this paper, the impact to all load points due to each component failure will be considered as well as the average failure rate of the component. Then, the interruption frequency and duration at each load point are calculated to eventually calculate the system reliability indices. The important point should note is that in each error simulation, the effect of network structure, switches, supply ability of loads from the main source of power or other resources, islanding of DGs should be modeling properly. For further explanation, take notice of the exemplifying distribution power system can be supplied by DG units as shown in Fig. 1. For example if fault occurs in first section(AB), with no DG connected to feeder, all load points service must be interrupted during repair operation but with DG connected to second section(BC), some load points loads (due to DG capacity) can be restored via DG source. So DGs can

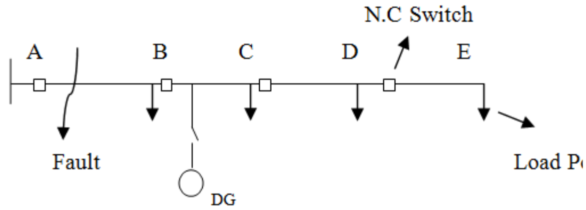

Fig.1. A typical distribution system with one DG

reduce the outage duration and consequently increase the system reliability.

As you've observed DG source has a good effect on distribution power system reliability on utility supply blackouts. [11, 13]

The difference between reliability of distribution system with and without DG, in failure rate and annual outage time index are calculated. The distributed generation is represented by four-state Markov process as shown in Fig. 2 where λ and μ are bus/DG failure and repair rates respectively.

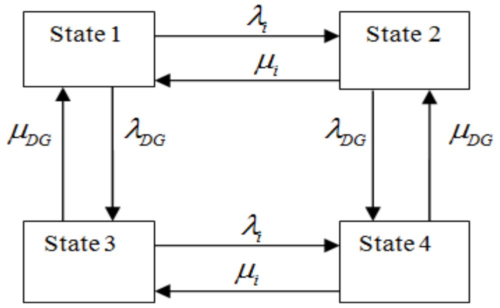

Fig. 2. A typical distribution system with one DG

Direction shown in Fig. 1 shows the transition between different working states of the bus that connected to DG unit.

In first state DG and bus i is in normal condition. In second state, error occurred in the system and bus connection is interrupted. DG interrupted, but the bus is connected yet in third state. In fourth state, DG and distribution has been interrupted and bus is isolated.

When applying matrix techniques to reliability evaluation, we should begin with deducing a matrix that represents the probabilities of making a transition from one state to another state of the Markov Due to four-state model shown in Fig.2, the following chain [16]. Matrix P can represent these transitional probabilities. This matrix is known as the stochastic transitional matrix

$$P = \begin{bmatrix} 1-(\lambda_i+\lambda_{DG}) & \lambda_i & \lambda_{DG} & 0 \\ \mu_i & 1-(\mu_i+\lambda_{DG}) & 0 & \lambda_{DG} \\ \mu_{DG} & 0 & 1-(\lambda_i+\mu_{DG}) & \lambda_i \\ 0 & \mu_{DG} & \mu_i & 1-(\mu_i+\mu_{DG}) \end{bmatrix} \tag{1}$$

Where P_{ij} is the probability of making a transition from state i to state j.

After forming matrix P, we should calculate the limiting probabilities pi corresponding to each state by using matrix multiplication method. If P is the stochastic transitional matrix and α expresses the limiting probability vector, then

$$\alpha \cdot p = \alpha \tag{2}$$

According to this matrix multiplication method the limiting probabilities p_i can be evaluated from (3) and (4).

$$p_i = \begin{bmatrix} \frac{\mu_i\mu_{DG}}{L} & \frac{\lambda_i\mu_{DG}}{L} & \frac{\mu_i\lambda_{DG}}{L} & \frac{\lambda_i\lambda_{DG}}{L} \end{bmatrix} \tag{3}$$

$$L = (\lambda_i + \mu_i)(\lambda_{DG} + \mu_{DG}) \tag{4}$$

After calculating the limiting probabilities, we should compute the frequency of individual states that can be calculated by multiplying the limiting probabilities pi and the rate of departure from state. The frequency of individual states is so obtained using Eq. (5).

$$P_i = f_i \cdot \lambda_i \tag{5}$$

Due to four-state Markov process as shown in Fig. 2, the frequency of individual states and the rate of departure computed as follows.

$$\lambda_d = \begin{bmatrix} \lambda_i+\lambda_{DG} & \mu_i+\lambda_{DG} & \lambda_i+\mu_{DG} & \mu_i+\mu_{DG} \end{bmatrix} \tag{6}$$

$$f = \begin{bmatrix} \frac{\mu_i\mu_{DG}(\lambda_i+\lambda_{DG})}{L} \\ \frac{\lambda_i\mu_{DG}(\mu_i+\lambda_{DG})}{L} \\ \frac{\mu_i\lambda_{DG}(\lambda_i+\mu_{DG})}{L} \\ \frac{\lambda_i\lambda_{DG}(\mu_i+\mu_{DG})}{L} \end{bmatrix} \tag{7}$$

After calculating the frequency of individual states, the frequency of active state of system (first, second and third state) can be calculated by multiplying probability to remain in active state and rate of leaving active state of system

$$f_{123} = p_1 + p_2 + p_3 \cdot \lambda_{total}^{bus} \tag{8}$$

Similarly, the frequency of inactive state of system (only fourth state) can be calculated by Eqs. (9).

$$f_4 = p_4 \cdot \mu_{total}^{bus} \tag{9}$$

Finally, the failure rate and the annual outage time of load point i connected to DG can be evaluated from (10) and (12).

$$\lambda_{total}^{bus} = \frac{p_2\lambda_{DG} + p_3\lambda_i}{p_1+p_2+p_3} \tag{10}$$

$$\mu_{total}^{bus} = \frac{1}{\mu_i + \mu_{DG}} \tag{11}$$

$$U_{total}^{bus} = \frac{\lambda_{total}^{bus}}{\mu_{total}^{bus}} = \frac{p_4}{p_1+p_2+p_3} \tag{12}$$

3. Problem formulation

The objective of DGs allocation and sizing in distribution system is to improve reliability criteria under certain limitations at lowest cost. The most commonly customer-based reliability indices, system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) and average energy not supplied per customer index (AENS) are used for objective function. They are defined as follows:

$$SAIFI = \frac{1}{n}\sum_{i=1}^{m}\lambda_i . S_i \tag{13}$$

Where n is total number of customers, λ_i is the failure rate of load point i and S_i is number of customers that would experience an interruption of load point i

$$SAIDI = \frac{1}{n}\sum_{i=1}^{m}\lambda_i . D_i \tag{14}$$

where D_i is the outage time of customers that would experience an interruption of load point i

$$AENS = \frac{1}{n}\sum_{i=1}^{m}L_{ai} . D_i \tag{15}$$

where $L_{a(i)}$ is the average load connected to load point i.

For the purpose of optimization, we define a composite reliability indices and DG cost through weighted aggregation of these indices.

$$OBF = w_{SAIFI}\cdot\frac{SAIFI}{SAIFI_T} + w_{SAIDI}\cdot\frac{SAIDI}{SAIDI_T} + w_{AENS}\cdot\frac{AENS}{AENS_T} + w_{C_{DG}}\cdot\frac{C_{DG}}{C_{DGT}} \tag{16}$$

where the weighting factors are expressing the importance of the aims in objective function and the indices mark by T is the desire value of the reliability indices.

These reliability indices are the most widely used indices to perform the reliability assessment in the distribution network. In this formulation, we incorporate the desired values these reliability indices that are empirically justified. [10]

The DG cost is formulated as:

$$C_{DG} = C_{Install} + \left(\sum_{t=1}^{T_{yr}}\frac{1}{(1+r)^t}\right)C_{O\&M} \tag{17}$$

where C_{INSTAL} is the total installation cost for DGs, $C_{O\&M}$ is the total operation and maintenance cost for DGs, r is the interest rate, and Tyr is the number of years in the study timeframe.

In each possibility answer, due to the arrangement and capacity of distributed generation units, possibility of intentional islands formed by DGs and their ability to supply power for each island can be checked by existing resources in each island. If existing resources in each island could supply power for loads' island, number of customers' island is discounted of number of customer that would experience an interruption. This process is repeated for all lines. It is important to note that the failure rate and outage time index of buses that connected to DG are evaluated from Eqs. (10) and (12).

Calculation steps of objective function:

1. Fault occurs on the system at line i.
2. All areas that are affected by fault is isolated
3. Possibility of intentional islands formed by DGs and their ability to supply power for each island is checked by existing resources in each island
4. Number of customer that would experience an interruption are counted
5. Go to step 2 until simulating fault for all lines is completed
6. The failure rate and outage time of each load point that DG connects to it is calculated by Eqs. (10) and (12)
7. Finally, reliability indices and DGs cost are calculated by Eqs. (13-15) and (17)

4. Implementation of GA

Since the DG placement has a discrete natures, it faces a number of local minima, To consider issue a reliable optimization technique should be employed. The optimization approaches are usually divided into analytical and heuristic approaches. In the smooth functions, the analytical approaches have higher accuracy compared with the heuristic approaches. As the objective function in the discrete optimization problems is non-smooth, it leads to reduce the accuracy of the analytical approach based optimization methods. This lead them to be trapped in the local minima. For non-smooth functions, the heuristic methods can be employed reliably. The heuristic methods are based on the random values and they can find acceptable solution, if only one of these random values is located near to the global minimum [12]. In this paper GA is used to achieve optimal response. GA simulates processes of biology that allows sequential generations in a population to conform their environment. Genetic Algorithm is unlimited optimization techniques, which model the evolutionary conformation in nature. GA generates a new population of answers by suitable genetic operators. The explanation of algorithm implementation is introduced as follows:

Step 1: Coding

Every feasible possible capacities and places for DG allocation needs to be encoded to every population. In this method any bus is encoded by three bits. The first bit indicates the presence or absence of DG units and next two bits represent the capacity of the unit is installed in bus. If the second and third bit is 00, DG type 1 will be selected for placement in desired bus. Likewise, if the second and third bit is 01, 10 and 11, DG Type 2, 3 and 4 will be selected respectively.

The bits of one possible location and their relative information are shown in Fig. 3.

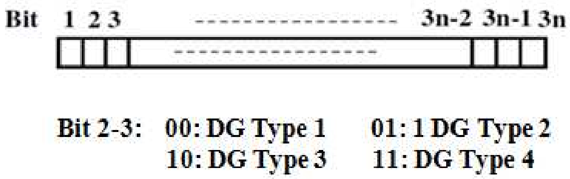

Fig. 3. Bits information for every possible location of DG.

Step 2: Initializing the population

To start algorithm, we need the initial population. To each of the chromosome genes are randomly assigned to zero or one.

Step 3: Calculation of reliability indices and the objective function

In this step constraints are examined. A penalty factor is added to the objective function value, if the constraints are violated.

Step 4: The GA operators

A selection step is to eliminate the least fit population members.

Roulette Wheel Selection: Probabilistic roulette wheel to select individuals based on their fitness value F_i and copy into the new population. The probability Pi for each individual is defined by:

$$P_i = \frac{F_i}{\sum_{i=1}^{\text{Population size}} F_i} \tag{18}$$

Cross Over: Random parent chromosomes are selected by crossover for creating a new generation. Chromosomes of the two parents are divided into two parts. Two parents' chromosomes are slice to similar part. The parts are swapped and integrated to form a new child chromosome.

Mutation: Some genes of the child chromosome are randomly changed to avoid trapped in local minimum during the program.

Step 5: Check convergence criterion

If defined convergence criteria are satisfied or the output of program does not change for a specific number of iterations, the program is stopped and results are printed, else program goes to step 3.

5. Result

To approve the proposed method, the 34-bus IEEE test system, as shown in Fig. 4, is studied. The system is divided into four zones for reduce number of customer that are affected blackouts.

The reliability index weights are chosen as follows:

$W_{SAIFI} = 0.30$, $W_{SAIDI} = 0.30$, $W_{AENS} = 0.33$ and $W_{CDG} = 0.07$. The desire values of the reliability indices are set as follows: $SAIFI_T=10$, $SAIDI_T=100$, $AENS_T=300$ and $C_{DGT}=1000000$. They are empirically justified and indicate the satisfactory level of reliability [10]. The discount rate (r) and the number of years in the study timeframe (Tyr) are chosen 0.0915 and 20 respectively [7].The lines and loads specification of the test system are given in Table 3, 4. [13, 14]

The GA parameters that help to adjust performance of the genetic algorithm for proposed method, as follows:

Population size: 100 individuals
Mutation probability: 0. 1%
Cross-over probability: 90%
Cross-over type: one point cross-over

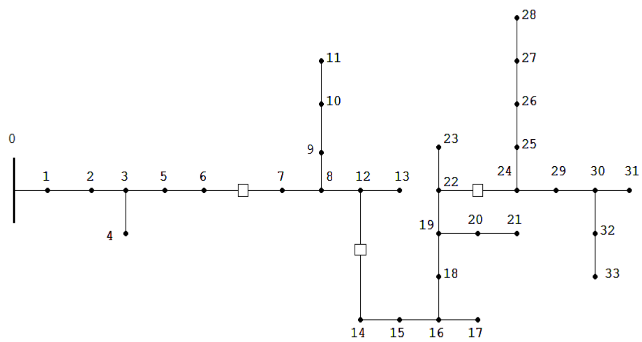

Fig. 4. Test system

The four DG (mini gas turbine) types are used for tests. The relative investment, operating, maintenance cost are shown in Tables 1. The cost of DG unit, construction and protection devices and fuel carriage equipment etc. are included in the investment cost. A maintenance cost consists of annual mechanical and electrical observation and repair cost. The operating cost consists of labor cost, taxes and fuel cost etc. [17, 18].

Table 1. The cost for DG types

Type	*DG Capacity*	*Investment cost ($)*	*Maintenance cost ($/yr)*	*Operating cost ($/yr)*
1	300 kW	182000	11630	78000
2	500 kW	330000	21140	142000
3	700 kW	410000	27310	178000
4	1000kW	550000	32240	237000

Fourth place after the implementation of algorithms for distributed generation units is proposed (The bus 11 and 18 and 19 and 25, respectively, with capacities of 600, 300,

Table 2. Comparison of outputs before and after installation of DGs

	SAIFI	*SAIDI*	*AENS*	C_{DG} *(M$)*	$C_{INTERRUPTION}$ *(M$)*
Without DGs	8.7	92.4	461.4	-------	13.738
With DGs	1.2	5.2	25.9	3.006	0.774

300, 900kW) that network will reach the best reliability.

Table 2 shows the customer-based reliability indices obtained by proposed DG placement method. It can be observed that the system average interruption duration and system average interruption frequency and energy not supply indices improve with DG installation. For a better understanding of how change in reliability indices, Indices changes in Figs. (5-7) are shown.

Last element in Table 2 can be identified with $C_{INTERRUPTION}$ which is the interruption cost. It can be calculated by multiplying the number of customers, the average interruption duration per customer and the imposed because of interruption. The interruption cost is so obtained using Eq. (19). [12]

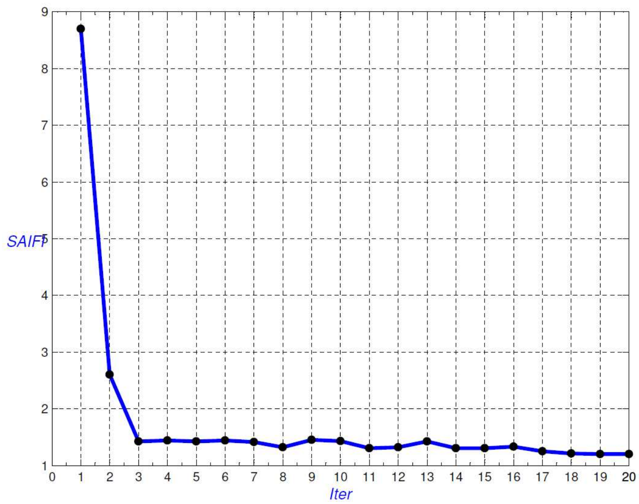

Fig. 5. Variation of SAIFI Index

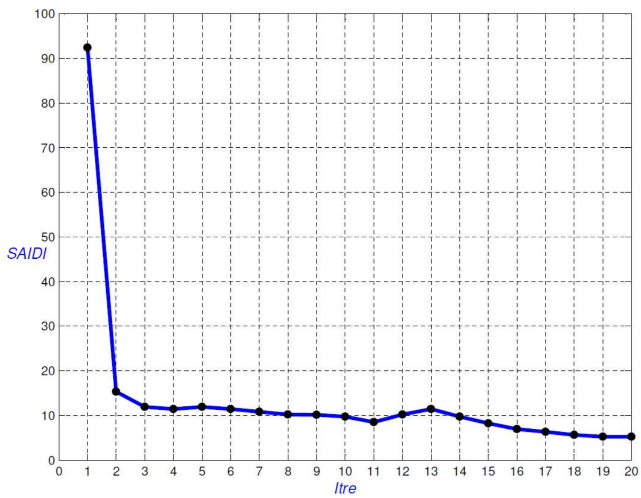

Fig. 6. Variation of SAIDI Index

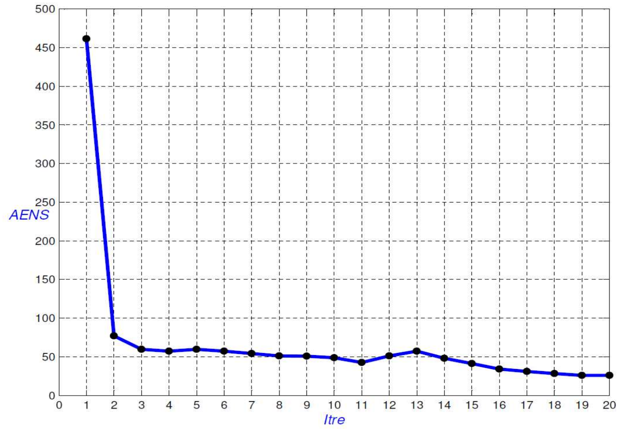

Fig. 7. Variation of AENS Index

$$C_{INTERRUPTION} = NC \times SAIDI \times CI \qquad (19)$$

where NC is the number of customers, CI is the cost of interruption per hour for a customer.

The number of customers is 354 in the test system and the cost per 1 minute interruption is assumed 7$ [19].As observed in Table 2, after installation of DGs, interruption cost decrease. The total cost decreases from M$ 13.738 to M$ 0.774. This difference, M$471.53, is much more than the total cost of DGs, M$3.006.

6. Conclusion

This paper presents a problem formulation and solution for the placement and sizing of DGs optimally. To evaluate the proposed algorithm, the 34-bus IEEE test system, is used. The results are finally compared with the no DG

Table 3. Loads specification of the test system

Bus No.	No. Customers	Q KVAR	P KW	Bus No.	No. Customers	Q KVAR	P KW
1	0	0	0	18	1	2	4
2	0	0	0	19	0	0	0
3	11	29	55	20	0	0	0
4	0	0	0	21	0	0	0
5	3	8	16	22	90	225	450
6	0	0	0	23	3	7	15
7	0	0	0	24	1	1	2
8	0	0	0	25	6	7	23
9	0	0	0	26	0	0	0
10	0	0	0	27	83	20	414
11	7	17	34	28	9	23	45
12	27	70	135	29	17	393	83
13	1	2	5	30	41	121	206
14	8	20	40	31	16	43	82
15	1	2	4	32	13	41	67
16	10	23	52	33	0	0	0
17	0	0	0	34	6	14	28

Table 4. Lines specification of the test system

Line No.	From Bus	To Bus	λ (f/yr)	Line No.	From Bus	To Bus	λ (f/yr)
1	34	1	0.983	18	16	18	14.04
2	1	2	0.65	19	18	19	0.04
3	2	3	12.28	20	19	20	1.98
4	3	4	2.212	21	20	21	4.024
5	3	5	14.29	22	19	22	1.867
6	4	6	11.33	23	22	23	0.617
7	6	7	0.04	24	22	24	2.221
8	7	8	0.118	25	24	25	0.107
9	8	9	0.651	26	25	26	0.512
10	9	10	18.35	27	26	27	1.387
11	10	11	5.236	28	27	28	0.202
12	8	12	3.891	29	24	29	0.77
13	12	13	1.154	30	29	30	1.021
14	12	14	0.32	31	30	31	0.328
15	14	15	7.789	32	30	32	0.106
16	15	16	0.198	33	32	33	1.85
17	16	17	8.891				

condition and it show that reliability indices especially Energy Not Supplying index (ENS) has improved considerably with optimal placement of distributed generation. Test results show that this proposed method is one of the best methods to improve service reliability, reduce the customer outage costs and decrease the power cost.

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