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Radial Electrical Distribution Systems Automation Using Genetic Algorithm

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*Abstract***.** The majority of outage events experienced by customers are due to electrical distribution failures. Increasing network reliability is a necessity in order to reduce interruption events. Distribution network automation can trim down outage events and increase system reliability. Network automation has to be done using optimization approaches. Genetic Algorithm (GA) is a relatively new technique used in power systems optimization problems. Distribution network automation is one of the aspects tackled using GA. However, practical application to distribution network automation in the Kingdom of Saudi Arabia has never been done. In Saudi Arabia, the practice in distribution network automation is based on experience but not on scientific approaches. This paper presents an effective application of the GA optimization technique to determine the optimum location of protective devices in practical radial distribution network in the Kingdom. The effect of different objective functions, constraints and GA parameters on the optimal location of such devices is examined.

1. Introduction

Electric power distribution system reliability is a measurement of how well the electric power distribution system can be expected to provide the customer with an adequate and secure supply of power to meet the customer's requirements. The concept of adequacy is generally considered to be the existence of sufficient facilities within the system to satisfy the customer demand. Security is considered to relate the ability of the system to respond to disturbances arising within the system. The investigation conducted in this paper deals with system adequacy.

There is an increasing interest in optimization approaches for distribution systems planning and expansion. Optimization problems generally take one of two forms, the first is to minimize cost while satisfying all reliability constraints, and the second is to minimize customer interruptions subject to cost constraints [1].

Many Optimization search techniques have been used to optimize the location of protective devices such as simulated annealing [2], binary programming [3], mathematical modeling [4], genetic algorithm [5], goal programming and fuzzy goal programming [6], but for complicated distribution reliability optimization problems of moderate size and larger, genetic algorithms will almost always outperform other optimization methods with gains being reflected in both solution quality and computation time [7].

2. Genetic Algorithm Optimization Technique

Genetic algorithm (GA) has different applications in power systems such as capacitor placement [8], optimal pi controller SVC design [9], on-line switching operations [10], a hydro unit commitment model [11], optimal power flow (OPF) problems [12], maintenance scheduling [13], power transformer optimum design [14] and power system planning [15]. Genetic algorithms have proven to be robust and efficient when applied to difficult optimization problems and their application to distribution planning problems has increased exponentially in recent years [7].

The genetic algorithm outperforms traditional techniques because it searches a population of points in parallel, not a single point. Also, it does not require derivative information or other auxiliary knowledge; only the objective function and corresponding fitness levels influence the directions of search. Genetic algorithm can be used to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly nonlinear [7, 16, 17]. This paper illustrates the utilization of the GA to optimize the location of protective devices in distribution networks.

The basic GA optimization is summarized in the following procedures:

1. The algorithm begins by creating a random population composed of pre-specified number of individuals. Each individual represents all possible locations of the protective device in the network under study. The (1) in the individual denotes that there is a protective device to be considered in this location. The (0) denotes that there is no protective device to be considered in this location.

2. The algorithm then creates a sequence of new generations. At each step, the algorithm uses the individuals in the current generation to create the next generation. To create the new generation, the algorithm performs the following steps:

   a. Assesses each individual by projecting the randomized protective devices locations on the distribution network. Reliability indices are used as fitness functions.

   b. Select parents based on their fitness.

   c. Produce children from the parents. Children are produced either by making random changes to a single parent (mutation) or by combining the vector entries of a pair of parents (crossover). These two genetic operations do not complement each other, both of them should be used in a typical GA. Even though each one of them can be used between the range 0-100%, however, it is the usual practice to give the crossover operation high weights and the mutation operation low weights.

   d. Replace the current population with the children to form the next generation.

3. The algorithm stops when a pre-specified number of generations are reached.

Different reliability indices are used as a fitness function including System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Momentary Average Interruption Event Frequency Index ($MAIFI_E$), Energy Not Supplied (ENS), Expected Customer Interruption Cost (ECOST) and Interrupted Energy Assessment Rate (IEAR) [1, 4, 6, 18, 19, 20] which can be calculated using Equations (1) – (7).

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \qquad \text{(Int./cust.)} \qquad (1)$$

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \qquad \text{(h/cust.)} \qquad (2)$$

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \qquad \text{(h/int.)} \qquad (3)$$

$$MAIFI_E = \frac{\sum IM_E N_i}{\sum N_i} \qquad \text{(Mom.event/cust.)} \qquad (4)$$

$$ENS = \sum L_a U_i \qquad \text{(kWh/yr)} \qquad (5)$$

$$ECOST = \sum C_i * L_i * \lambda_i \qquad \text{(\$/yr)} \qquad (6)$$

$$IEAR = \sum \frac{ECOST}{ENS} \qquad \text{(\$/kWh)} \qquad (7)$$

Where:

i Load point,

λ_i Average failure rate of load point i,

U_i Average annual outage time of load point i,

N_i Number of customers connected to load point i,

IM_E Number of momentary interruption events,

L_{ai} Average load (kVA) connected to load point i,

L_i Connected KVA load interrupted for each interruption event, and

C_i Cost of interruption.

There are 8760 hours in a regular year and 8784 in a leap year.

3. Case Studies and Results

The proposed technique is illustrated using the practical system shown in Fig. 1. It is a 33 kV overhead radial distribution system supplying 463 customers with a total length of 148.94 km and an average load of 2270 kVA.

The feeder sections' lengths, customer and loading data are shown in Tables 1 and 2 respectively.

Equipment reliability data presented in Ref. [21, 22] are shown in Table 3 and are used for this system.

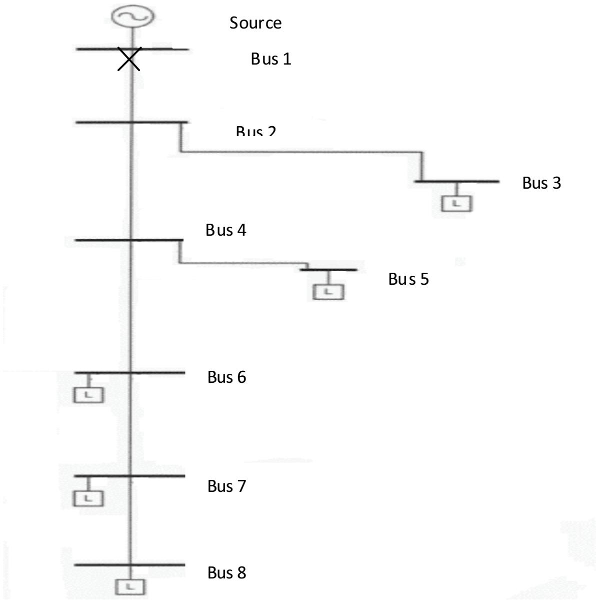

Fig. 1. Practical radial distribution feeder.

Table 1. Feeder sections lengths.

From Bus	To Bus	Section Number	Section Length (km)
1	2	1	5
2	3	2	25.32
2	4	3	50
4	5	4	0.12
4	6	5	33.5
6	7	6	30
7	8	7	5

Table 2. Customer and loading data.

Load Point	Bus No.	Customer Type	Average Load (kVA)	Number of Customers
1	3	Residential	700	151
2	5	Residential	20	4
3	6	Residential	1000	200
4	7	Residential	500	100
5	8	Residential	50	8
Total			2270	463

Table 3. Reliability data.

Equipment	**Failure rate per year**	**Repair/ replacement time (h)**	**Auto-reclosing time (sec)**
Line	0.062 *	4	___
Fuse	0.005	2	___
Sectionalizing Switch	0.05	3	___
Circuit Breaker	0.005	12	1/60
Sectionalizer	0.001	6	10/3600
Auto recloser	0.001	6	5/3600
Power Transformer	0.025	8	___
Distribution Transformer	0.03	4	___

* Per kilometer.

Several case studies are illustrated using different objective functions and constraints to identify the optimum location of the selected protective device. It is assumed that the protective device can be installed at the beginning (upstream end) of a section. (*i.e.,* optimum location 3 means that the beginning of Section 3). Two protective devices are considered namely, the auto recloser and sectionalizer. Usually, the optimum location of these devices is obtained based on experience. However, the resulting solution could be one of the visible solutions but may not be the optimum solution. The studies presented here are based on scientific techniques using genetic algorithm to obtain the optimum solution.

Genetic algorithm parameters used in these case studies are shown in Table 4.

Table 4. Genetic algorithm parameters.

Population size	10
Number of generations	20
Percentage crossover	80
Percentage mutation	15

Case (1). Auto Recloser Optimum Location Subject to Different Objective Functions

The feeder is protected by a circuit breaker on section number (1). The possible locations to install the auto recloser are Locations, 2, 3, 4, 5, 6 and 7. System reliability was evaluated with the auto recloser installed in these locations. Table 5 shows the reliability indices for the system for all of the possible solutions.

Table 5. System reliability indices considering different locations for the auto recloser.

	Location					
	2	3	4	5	6	7
SAIFI	1.2318	<u>1.031</u>	1.389	1.1775	1.1408	1.3445
SAIDI	7.412	<u>5.8506</u>	8.1456	6.261	6.1512	7.782
CAIDI	6.0173	5.6744	5.8642	<u>5.317</u>	5.392	5.7882
MAIFIE	6.95	<u>5.8104</u>	7.8429	6.6406	6.4349	7.5902
ENS	17030	<u>13625</u>	18787	14535	14232	17955
ECOST	27714	21547	30042	21613	<u>21271</u>	28409
IEAR	1.6273	1.5814	1.5991	<u>1.4869</u>	1.4945	1.5822

Table 5 shows all possible locations for the auto recloser and the corresponding reliability indices. The lowest value of a reliability index corresponds to the optimum location for a certain index.

The proposed genetic algorithm optimization technique was applied to the system shown in Fig. 1. This technique identified the optimum location of the auto recloser for different objective functions. Table 6 shows the auto recloser optimum locations subject to different objective functions obtained using the GA optimization technique. The result shown in Table 5 can be used to verify the result of the proposed technique shown in Table 6. The resulting optimum locations using GA in the other cases can be verified in a similar manner.

Table 6 shows that auto recloser optimum location changed as objective function changed and could be location number 3, 5 or 6. However, Location 3 was identified as the optimum location with most of the objective functions

Table 6. Auto recloser optimum location.

Case	Objective function	Optimum Location
1	SAIFI	3
2	SAIDI	3
3	CAIDI	5
4	$MAIFI_E$	3
5	ENS	3
6	ECOST	6
7	IEAR	5

The optimum location of the auto recloser is sensitive to the objective function. The set of indices shown in Table 6 measure system reliability from different perspectives. SAIFI and $MAIFI_E$ reflect the frequency of outage events. SAIDI and CAIDI reveal the duration of interruptions. ENS is an energy oriented index. ECOST and IEAR return the cost of interruption. System planner is required to select the most significant objective function that fits its requirements.

Case (2). Sectionalizer Optimum Location Subject to Objective Function (SAIDI) with Different Constraints

If the system planner is interested in utilizing more than one reliability index, an index can be used as the objective function and another index can be incorporated as a constraint. The values of these constraints were selected to be within the upper and lower limits of the reliability indices for all possible cases as shown in Table 5. Table 7 illustrates the effect of using SAIDI as an objective function with different constraints. It can be seen that a constrained objective function results in different locations for a sectionalizer to be installed in the network.

Table 7. Sectionalizer optimum location.

Case	Constraint	Optimum Location
1	SAIFI < 1.1	3
2	CAIDI < 5.35	5
3	$MAIFI_E < 7.88$	4
4	ENS < 14000	3
5	ECOST < 21500	6
6	IEAR < 1.48	5

Case (3). Protective Device Optimum Location Using a Minimum Composite Index

Another approach can be used to incorporate more than one reliability index in the automation process. A composite objective can be used in which different indices are used and weighed according to the importance of these indices. A target value needs to be prespecified [5].

Equation (8) shows a composite objective function that utilizes SAIFI, SAIDI and $MAIFI_E$.

An auto recloser is installed on section number (3). Table 8 shows different protective devices optimum locations subject to minimum composite index value.

$$Composite \quad Index = w_1\left(\frac{SAIFI_0}{SAIFI}\right) + w_2\left(\frac{SAIDI_0}{SAIDI}\right) + w_1\left(\frac{MAIFI_{E0}}{MAIFI_E}\right) \tag{8}$$

where:

$SAIFI_0 = 1$, $SAIDI_0 = 2.2$ and $MAIFI_{E0} = 7$

$w_1 = 0.2$, $w_2 = 0.4$ and $w_3 = 0.4$

Based on the results shown in Table 6, it is assumed that the auto recloser was installed in Location 3. Further automation is considered for the feeder shown in Fig. 1. The resulting automation scheme is shown in Table 8.

Table 8 shows that different locations are obtained for the different protective devices. This is due to the distinctive operational function of these devices.

Table 8. Protective device optimum location.

Case	Protective Device	Optimum Location
1	Auto recloser	6
2	Sectionalizer	6
3	Sectionalizing Switch	2
4	Fuse (clearing scheme)	7
5	Fuse (saving scheme)	6

Case (4). Effect of GA Parameters

Sensitivity analysis was carried out to examine the effect of genetic algorithm parameters on determining auto recloser optimum location. These parameters include number of generations, population size, crossover percentage and mutation percentage. One parameter is varied at a time while the other parameters are fixed. SAIFI is used as the objective function in this case. It was found that the GA identified the same optimum location (Location 3) of the auto recloser despite the different GA attributes. This reflects the effectiveness of the GA to locate the optimum location of a protective device regardless of the GA parameters. This feature will assist the system planner to utilize the proposed technique without being concerned about selecting a proper value for the GA parameters. This could support the decision maker to reinforce the network based on scientific methodology to reach an optimum location for the protective devices to achieve the highest system reliability. Unlike the rule of thumb (experience) which may result in a good solution but not the optimum solution.

4. Conclusions

This paper has presented an effective application of the genetic algorithm optimization to practical distribution system automation. Several cases on the practical radial distribution feeder with different objective functions, constraints and genetic algorithm parameters are conducted.

Protective devices' optimum locations depend on the reliability indices, objective functions and constraints.

One location may satisfy an objective function subject to a specific reliability index. However, adding reliability index as a constraint can result in different optimum locations. Multiple reliability indices were combined to form an objective function using the concept of a composite index in which the weights and target values of each index must be determined.

Genetic Algorithm optimization has been shown to be an effective technique to optimize the automation of some electrical distribution systems as has been illustrated.

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التشغيل التلقائي لنظم شبكات التوزيع الكهربائية الإشعاعية باستخدام الخوارزميات الجينية

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المستخلص. رغم أن الخوارزميات الجينية هي أحد الطرق الحديثة التي تستخدم لحل مشاكل التشغيل التلقائي لنظم الطاقة الكهربائية وشبكات التوزيع, إلا أنه لم يسبق أن تم تطبيقها على شبكات التوزيع بالمملكة العربية السعودية، حيث أن هذه العملية عادة ما تتم بالاعتماد على الخبرات السابقة دون الاستعانة بأحد الطرق العلمية، مما يترتب عليه عدم القدرة على تحديد المواقع المثالية لأجهزة الحماية في الشبكات، مما يسبب عدم الوصول إلى الموثوقية المثلى للنظام. يستعرض هذا البحث تطبيق الخوارزميات الجينية لتحديد المواقع المثلى لأجهزة الحماية في شبكة التوزيع في أحد مناطق المملكة. وقد تم اختبار تأثير استخدام دوال أهداف مختلفة ومعاملات الخوارزميات الجينية. وقد بينت نتائج البحث فاعلية تطبيق الخوارزميات الجينية على شبكات التوزيع بالمملكة لتحديد المواقع المثلى لاجهزة الحماية، مما نتج عنه زيادة موثوقية شبكات التوزيع.