Journal of ELECTRICAL ENGINEERING, VOL. 64, NO. 2, 2013, 76–83

OPTIMIZED PLACEMENT OF CONNECTING THE DISTRIBUTED GENERATIONS WORK STAND ALONE TO IMPROVE THE DISTRIBUTION SYSTEMS RELIABILITY

Hamed Hashemi-Dezaki — Ali Agheli — Behrooz Vahidi — Hossein Askarian-Abyaneh *

The use of distributed generations (DGs) in distribution systems has been common in recent years. Some DGs work stand alone and it is possible to improve the system reliability by connecting these DGs to system. The joint point of DGs is an important parameter in the system designing. In this paper, a novel methodology is proposed to find the optimum solution in order to make a proper decision about DGs connection. In the proposed method, a novel objective function is introduced which includes the cost of connector lines between DGs and network and the cost of energy not supplied (CENS) savings. Furthermore, an analytical approach is used to calculate the CENS decrement. To solve the introduced nonlinear optimization programming, the genetic algorithm (GA) is used. The proposed method is applied to a realistic 183-bus system of Tehran Regional Electrical Company (TREC). The results illustrate the effectiveness of the method to improve the system reliability by connecting the DGs work stand alone in proper placements.

K e y w o r d s: stand alone distributed generations, distribution systems, genetic algorithm (GA), system reliability, energy not-supplied (ENS)

Nomenclatures

T	Total number of customers connected to distribution system
OF	Objective function of the proposed optimization problem
mb	Number of sections located in main branch
λ_{mi}	Failure rate of i-th section located in main branch
$\lambda(s,p)$	Failure rate of p-th section located in s-th lateral branch
N_{mi}	Number of customers supplied through i-th section of main branch
L_{mi}	Amount of customer loads supplied through i-th section of main branch
β	Set of candidate sections to connect a distributed generation (DG)
$flb(i)$	First downstream lateral branch of section i located in main branch
$N(s,p)$	Number of customers supplied through p-th section of s-th lateral branch
$L(s,p)$	Amount of customer loads supplied through p-th section of s-th lateral branch
$ts(s)$	Number of sections located in s-th lateral branch
$blb(i)$	First upstream lateral branch of section i located in main branch
$fdmb(i)$	First downstream main branch of i-th lateral branch
$fumb(i)$	First upstream main branch of i-th lateral branch
X_{si}	Binary variable indicates the existence or not existence of a switching device in section i
M_1	Annual restoration energy by using DGs, in kVA
$M_{2,i}$	Required investment to connect a DG to section i
Y_i	Binary variable indicates section i is a suggested placement to allocate a DG in accordance to the selected scenario
K_1	Accumulative coefficient based on the project life time and other engineering economic parameters
K_2	Cost of interrupted loads per kWh
G	Generation size
I	Algorithm iteration
NPW	Net present value of cash flow
n	Project life time
r	Annual load growth coefficient
p	Profit rate
B_i	Saved cost of year i
S_{DG_i}	Maximum capacity of generation of i-th DG
D_i	Length of section i
L_i	Load of section i
λ_i	Failure rate of section i
P_r	Power capacity of DG r

1 INTRODUCTION

The main objective of the planning and operation of electric power distribution systems is to satisfy the system load and energy requirements as economically as possible with a reasonable assurance of continuity and quality. The two aspects of relatively low cost electrical energy at a high level of reliability are often in direct conflict due to the fact that providing a higher level of reliability

* Electrical Engineering Department, Amirkabir University of Technology, No. 424, Hafez Ave., Tehran, 1591634311 Iran, hamed.hashemi@gmail.com

DOI: 10.2478/jee-2013-0011, ISSN 1335-3632

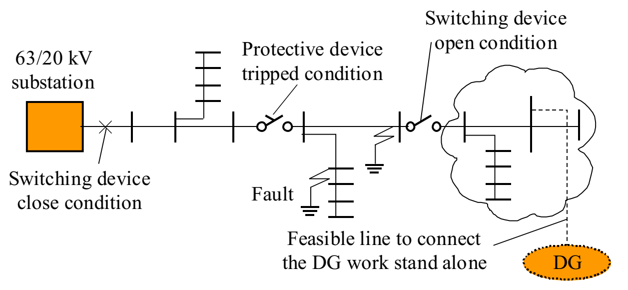

Fig. 1. Energy restoration in a typical distribution system

will cost utilities more in capital and operational expenditures. This has become the justification to emphasize on the optimization of system costs and reliability [1, 2]. To improve the distribution systems reliability, some studies have been reported on finding the best placement of protective and switching devices [2-7], decreasing the failure rates of system components [2, 8], adding protective devices [9], reclosing [10, 11], reconfiguration [12] and using distributed generations (DGs) [13, 14].

Recent years have witnessed a trend towards the development of DGs. The distribution systems have been usually designed to operate with unidirectional power flow. Adding DG to a distribution system imposes a different set of operating condition on the network, such as voltage rise, power loss reduction, stability problems and reliability increasing. The placement of DG connection to system plays a great part on the effects of DG [11–18]. Therefore, researchers tempt to find appropriate methods for optimal placement of DG to improve system characteristics such as reliability increasing and power losses reduction [11, 15]. Most of the studies on DGs sizing and siting have focused on finding the optimized placement based on minimizing the system power losses [19]. Other system parameters such as voltage profile, total harmonic distortion (THD) and reliability have been studied, too [20, 21].

In distribution systems, a number of utilities and companies use local generation to provide their electrical consumes in both normal and emergency conditions. These DGs work stand alone and by connecting them to the AC network in different conditions, it is possible to decrease energy not supplied (ENS) and increase the system reliability. The joint point of connecting the DG to main network is very important because the placement of connectivity changes the network topology. If the cost of the connecting line and other required devices is venial, the best scenario is the connection of all DGs. This assumption, nevertheless, is not reasonable, since the cost of DG connection to network is considerable. In this way, the connection of all DGs is not economical and the previous choice cannot be the best. To find the optimal solution, a compromise between the cost of ENS (CENS) decrement and that of required connector line is necessary.

According to the above problem statement, the comparison between the cost of DG connection and reliability improvement is necessary. An optimum solution suggests some DGs to connect the main network, not all of them.

The proposed approach tries to find the optimized placement of DG connection to main network. The new method is applicable in both operating and designing conditions. The optimized solution is equal to maximized restoration energy using DGs. Through the application of the proposed method to distribution systems, it is possible to find the optimized energy restoration by DG installation in proper points. If the restorative energy increases, the reliability indices are improved. ENS decrement is directly relevant to the improvement of other indices such as system frequency average interruption index (SAIFI) and system duration average index (SAIDI).

Furthermore, a novel method is proposed to calculate the value of restoration energy that can be achieved by installation of the DG in distribution system. The objective function includes two main terms: CENS decrement by DG connection and the cost investment of connector lines installation.

The objective function is optimized by genetic algorithm (GA). The optimized results determine in which points of distribution system, DG connection is more effective and useful to improve the system reliability. The proposed method is applied to a realistic distribution system of Tehran Regional Electrical Company (TREC). The results illustrate that by connecting the DGs work stand alone to network in appropriate locations, it is possible to improve the system reliability effectively and economically.

2 PROBLEM STATEMENT

ENS would be decreased by connecting the DGs work stand alone. The possibility of connecting some DGs to network increases the restoration energy. In view point of reliability increase by connecting the DG to network, the joint point to connect the DG is very important. Finding the joint point of DGs is useful for operating and designing conditions.

When a fault occurs in the main or lateral sections, the first upstream protective device senses the fault and separates the downstream loads from power supply. Now, if there is the ability to provide the interrupted loads, a proportion of interrupted loads can be restored. This restoration energy occurs through using the switching devices and maneuver strategy. The schematic of energy restoration in a typical distribution system is shown in Fig. 1.

The value of the restoration energy is a function of network topology, protective and switching devices as well as other power supplies that can provide the interrupted loads such as DGs shown in Fig. 1. So the switching and protective devices and position of DGs connection are considered to be important and change the amount of restoration energy.

The problem of finding the solution that demonstrates the proper position of connecting the DG is different in

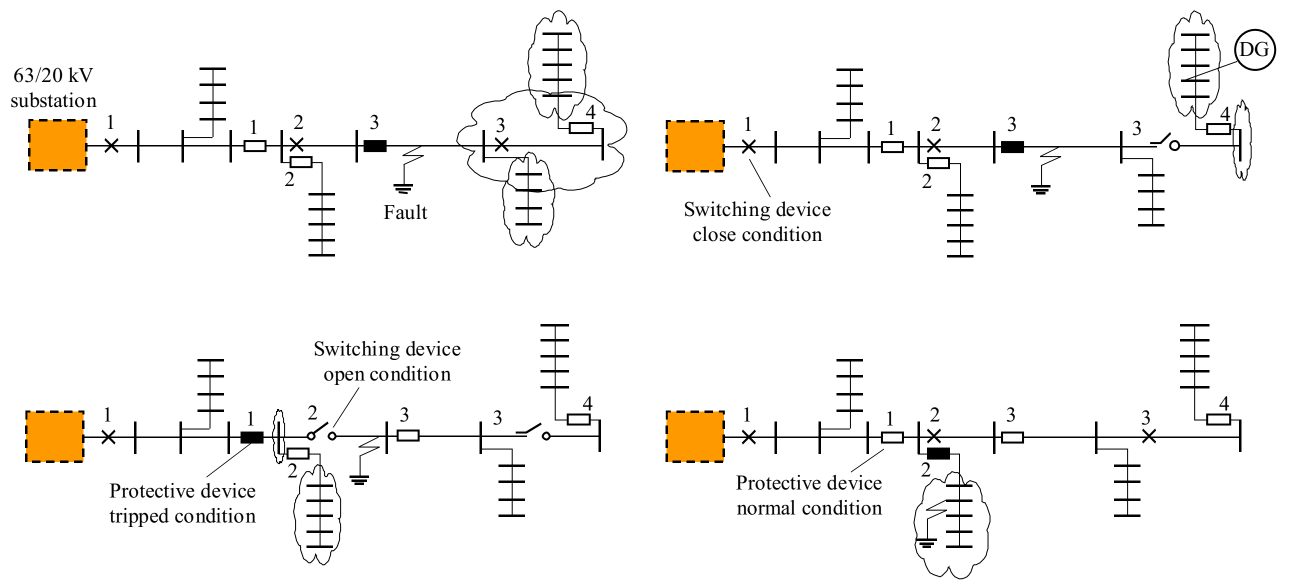

Fig. 2. Typical distribution system: (a) – interrupted area due to a fault occurrence in the main section, (b) – restorable interrupted area due to a fault occurrence in the main section with DGs, (c) – restorable interrupted area due to a fault occurrence in the main section switching and main supply, (d) – limited interruption area in lateral branch due to the fault occurrence in one with a protective device

view point of design and operating distribution system. If the system is in design process, the problem variables are the number and placement of DG connections. In such conditions, all sections are feasible to connect the DG to network, but if the system is in operating conditions, there are some disconnected DGs. Therefore, the candidate connecting points are the nearest place to the available disconnected DGs. The optimized solutions in this condition are binary variables indicating the connecting or disconnecting the available DGs to network, while the optimized solutions in designing process are integer variables indicating the connecting placement. The summation of the suggested connecting points should be less than the number of the expected DGs. The obtained solutions in design view help determine the supportive strategy to develop the DGs where they are more useful to improve the system reliability.

3 PROBLEM FORMULATION

If the reliability improvement of DGs connection is venial, the best scenario is the connection of all DGs. By considering the required cost of DG connection, the previous strategy cannot be the best. In this situation, the comparison between CENS and cost of required transmission line is not unavoidable. In this paper, using a new objective function to determine the best solution for the finding of the number and placement of the interconnected DGs, a novel approach is introduced.

The proposed objective function includes two main terms: the benefit of energy restoration by DG connection and the cost investment to install of the connector line to connect DG to distribution system. To calculate the value of restoration energy that can be achieved by installation the DG in distribution system, a mathematical method is presented. By using this analytical method, the speed of calculation is increased. The proposed objective function is demonstrated as

$$OF = K_1 \times K_2 \times M_1 - \sum_{i\in\beta}\big(Y_i \times M_{2,i}\big). \tag{1}$$

In this paper, a novel analytical model is proposed to calculate the value of the restoration energy by using DG in distribution systems. An advantage of the proposed analytical model to calculate the different system characteristics is its high speed. Additionally, when the mathematical model is provided to calculate the system characteristics, it is simplified to do the sensitive analyses of different effective parameters. The mathematical model for calculating the restorable energy is expressed in the following equations

$$\begin{aligned} M_1 = {} & \sum_{i=1}^{mb} X_{si} \times \\ & \Big\{\sum_{k=1}^{blb(i)}\sum_{l=1}^{ts(k)} \lambda(k,l)A(1,l)B(1,fumb(k)) + \sum_{w=1}^{i-1}\lambda_w B(1,w)\Big\}\times \\ & \mathrm{Min}\Big\{\Big(\sum_{\substack{z=flb(1)\\-flb(i)+1}}^{flb(i)}\sum_{p=1}^{ts(z)} L(z,p) + \sum_{v=i+1}^{mb} L_{mv}\Big), \sum_{r\in\beta} Y_r P_r\Big\}, \end{aligned} \tag{2}$$

$$A(i,j) = \begin{cases} 1 & \text{if exist none protective object} \\ & \text{in position } i \text{ to } j\,, \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$B(i,j) = \begin{cases} 1 & \text{if exist none switching object} \\ & \text{in position } i \text{ to } j\,, \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

The energy restoration achieved by connecting the DGs to electrical distribution systems is calculated by

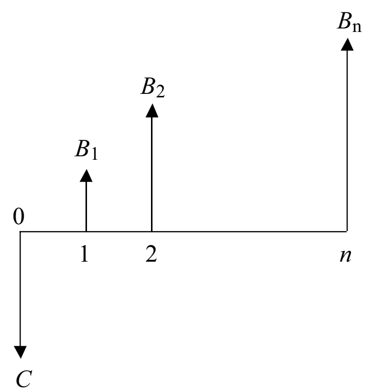

Fig. 3. Typical cash flow of the proposed method

(2) which will be explained on a typical system. In this equation, the value of M1 (the restorable loads by using the DGs) is calculated according to probability of the fault occurrence in the overhead or cable lines, the position of protective or switching devices, the capability of power generation of each DG. In the proposed method, the branches of system are categorized to two groups: main and lateral branches. When a fault occurs in the main sections, by tripping the first upstream protective device, some loads experience an interruption. To clarify this concept, the interrupted area, when a fault has occurred in a main section, is shown in Fig. 2a. As shown in this figure, the protective device 3 isolates the fault location from the system. By tripping of protective device 3, some loads installed to main or lateral sections which are located in downstream of the protective devices experience an interruption. In conventional systems, the interrupted loads cannot be restored until the repair will be completed. An appropriate idea to supply the interrupted loads is using the DGs work stand alone. If there is the DG that is capable to connect the system in necessary times, by using switch 3, it is possible to isolate the fault area and supply the interrupted loads with DG. The restoration process and restored area as described is shown in Fig. 2b. In the restoration process, the minimum value of the capacity of power generation of DGs allocated in interrupted area and the interrupted loads can be supplied by DGs work stand alone.

Furthermore, in some conditions, due to occur a fault in the main branch, some interrupted loads can be restored only by switching and isolating the fault location. In Fig. 2c, the condition which a fault has occurred in a different main section is shown. As it can be seen in this figure, the restorable loads which can be obtained just by switch 2 and 3 have shown.

The term $\left(\sum_{w=1}^{i-1}\lambda_w\, B(1,w)\right)$ is calculating the summation of annual failure rate of all main sections while the interrupted loads can be restored with other sources such as DGs work stand alone. This term includes two parts: λ_w and $B(1,w)$ indicate the failure rate of section w and it is possible that restoration operations be conducted due to the fault occurrence in section w. By multiplying the terms $\left(\sum_{w=1}^{i-1}\lambda_w\, B(1,w)\right)$ and minimum value of interrupted loads and capacity of DGs in downstream of the corresponding section,

$$\mathrm{Min}\Big\{\sum_{n=flb(1)-flb(i)+1}^{flb(i)}\ \sum_{p=1}^{ts(n)} L(n,p)+\sum_{v=i+1}^{mb} L_{mv}\ ,\sum_{r\in\beta} Y_r P_r\Big\},$$

the possible ENS decrement can be obtained. The discussed interrupted loads can be restored if and only if connecting the DGs work stand alone is created. This comparison checks the available capability and operational restoration energy.

For the lateral sections and occurrence a fault in them, the similar methodology has been used. The difference between concepts of restoration operations during the failure in lateral and main branches is relevant to performance of protective devices. During all the faults in main sections, the downstream loads experience an interruption that by using DGs and switch located in downstream the fault location can be restored. However, if in any section of a lateral branch which a protective device has been allocated, none downstream loads located in other main or lateral branches experience an interruption. The existence or none-existence of the protective device in the lateral branch is determined by auxiliary function.

It can be seen as described explanation and Fig. 2. d, the position of the protective device affects the extent of the interrupted area. If there is a DG in downstream of the discussed protective device, the restoration of a portion of the interrupted area is possible. The restoration process requires switching devices whose positions change the value of restoration energy.

Since the distribution loads have an annual growth, the value of loads should be considered in (2) by their growth rates. Also, in engineering economical concepts, time value of money is an important subject. By using profit rate, it is possible to determine the net present worth. In Fig. 3, the cash flow of applying the proposed method to a typical system is shown.

The net present worth (NPW) of cash flow shown in Fig. 3 is calculated as (5). The value of B_i is obtained by considering the value of B_1 as (6) and the summation of NPW is simplified to (8). According to (8), the parameter of K_1 is defined.

$$NPW = -C + B_1 + B_2 + \cdots + B_n\,, \tag{5}$$

$$B_i = B_1\left[\frac{1+\frac{r}{100}}{1+\frac{p}{100}}\right]^i, \tag{6}$$

$$g = \frac{1+\frac{r}{100}}{1+\frac{p}{100}}\,, \tag{7}$$

$$NPW = -C + B_1\left(1+\frac{g(g^{n-1}-1)}{g-1}\right), \tag{8}$$

$$K_1 = 1+\frac{g(g^{n-1}-1)}{g-1}\,. \tag{9}$$

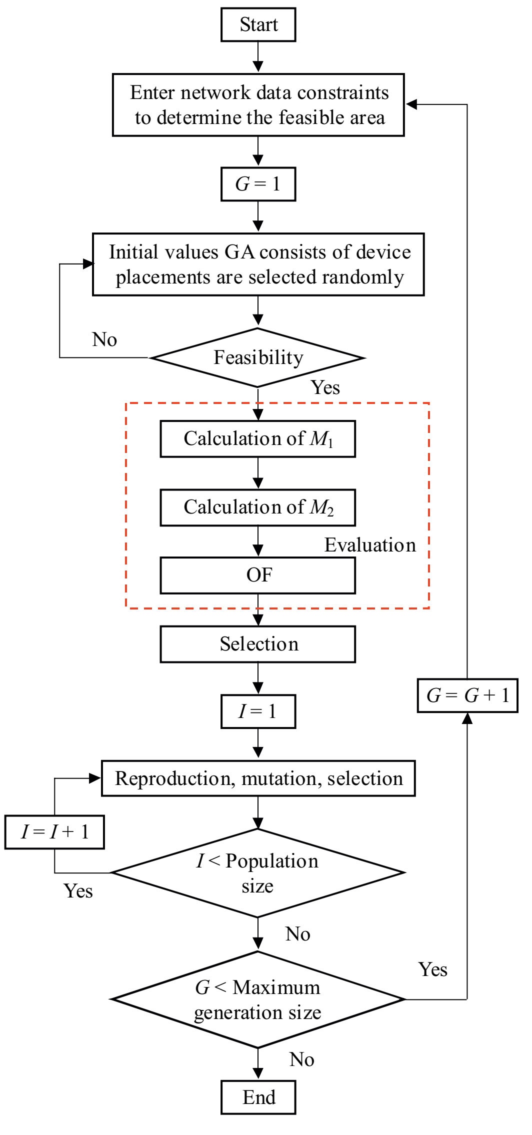

Fig. 4. Flow chart of the optimization by GA

4 OBJECTIVE FUNCTION OPTIMIZATION

Finding the maximum of the objective function is a nonlinear programming. The mathematical expression of the objective function is demonstrated as follows.

$$\operatorname{Max} OF = K_1 K_2 M_1 - \sum_{i\in\beta} Y_i M_{2,i} = f(Y_i)$$

$$\text{subject to} \begin{cases} Y_i = 1 \text{ or } 0 \; i \in \textit{Possible Position} \\ \textit{To DG Allocate} \\ \sum_{i\in\beta}(Y_i M_i) \le \textit{Expected Capital.} \end{cases} \tag{10}$$

As this problem is a nonlinear one and being somehow complex, an intelligent optimization method should be used to optimize the suggestive objective function. Genetic algorithm (GA) is selected to solve the optimization problem. GA is one of the intelligent algorithms used to optimize nonlinear programming problems such as [10, 13]. Each possible location for connection a DG is corresponding to a gen in one chromosome. The flowchart of the optimization algorithm using GA is shown in Fig. 4.

5 NUMERICAL RESULTS

In this paper, an electric power distribution system of Tehran Regional Electrical Company (TREC) is selected to apply the proposed methodology of finding the optimum placement for connecting the DGs work stand alone to improve the system reliability.

The single line diagram of the test system is shown in Fig. 5. The system data are listed in Table 1. Also the position of available protective and switching devices are presented in Table 2. The other parameters that have been defined to calculate OF are detailed in Table 3. The coefficients presented in Table 3 are considered in according to experience values of TREC. Furthermore, these values are approximately similar to the considered values of [3, 6, 7].

There are four DGs in nearby the distribution system that work stand alone. The required costs for connector lines to connect any of these DGs have been calculated by help of staffs of TREC. A number of cases for connecting the DGs to some sections are not feasible because different constraints and limitation exist such as geographic and urban barriers. For impossible cases, a great value is considered which is very distinct from other those.

The genetic algorithm to solve the optimization process is implemented using Matlab on a Pentium-IV personal computer. The optimization results are demonstrated in Table 4. The results provide the optimized placement of DGs to connect the system. Sections 27, 103, 171, 181 are four positions that by their connections to DGs, the reliability improvement would be maximized.

The optimization results obviously confirms that location of protective and switching devices directly change the affects of connecting the stand alone DGs. Any fault occurrence in main sections located in the upstream of section 27 results tripping the protective devices installed in the 63/20 kV substation. If any maneuver strategy has been performed, all loads experience an overall interruption. To avoid a long interruption, using the DGs located in downstream is an appropriate choice. Because there is a switching device in section 25, when a fault occurs in sections 1 to 25, the interrupted loads located upstream of section 25can be restored by disconnecting the switching device 25 and connecting the DG to section 27. By comprise the DG connection to other sections such as sections 1 to 25, it is not possible to restore any interrupted loads because the fault area cannot be isolated. Studying the other optimum DGs connections confirm the effects of the location of protective and switching devices on the restoration energy.

The results illustrate the effectiveness of the method in order to improve the cost and reliability of the distribution system. They also confirm by an additional 197540 US $ investment in order to create the connector lines to connect the DGs to system, it is possible to save 8120200

Table 1. Component data for analyzed feeder, columns: 1 – Branch No, 2 – L_i (kVA), 3 – D_i (m), 4 – λ_i (F/Year)

1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	0	80	0.016	38	0	250	0.05	75	0	20	0.004	112	100	15	0.003	149	0	200	0.04
2	0	50	0.01	39	0	50	0.01	76	200	250	0.05	113	100	140	0.028	150	200	240	0.048
3	50	400	0.08	40	0	350	0.07	77	160	240	0.048	114	200	230	0.046	151	0	330	0.066
4	0	500	0.1	41	0	360	0.07	78	0	120	0.024	115	0	10	0.002	152	200	1600	0.32
5	250	50	0.01	42	0	100	0.02	79	100	240	0.048	116	0	50	0.01	153	0	250	0.05
6	0	400	0.08	43	425	140	0.028	80	315	160	0.032	117	100	120	0.024	154	200	150	0.03
7	0	100	0.02	44	0	10	0.002	81	200	120	0.024	118	0	10	0.002	155	315	250	0.05
8	200	200	0.04	45	0	40	0.008	82	0	380	0.076	119	25	350	0.07	156	100	60	0.012
9	315	80	0.016	46	0	40	0.008	83	100	15	0.003	120	0	370	0.074	157	0	180	0.036
10	0	230	0.046	47	0	500	0.1	84	25	70	0.014	121	0	360	0.072	158	50	150	0.03
11	100	210	0.042	48	0	630	0.126	85	200	300	0.06	122	0	40	0.008	159	0	400	0.08
12	25	400	0.08	49	50	10	0.002	86	0	140	0.028	123	0	30	0.006	160	0	500	0.1
13	0	1050	0.21	50	200	600	0.12	87	200	10	0.002	124	0	50	0.01	161	100	10	0.002
14	0	20	0.004	51	200	10	0.002	88	100	330	0.066	125	200	150	0.03	162	0	900	0.18
15	0	20	0.004	52	0	130	0.026	89	0	140	0.028	126	100	310	0.062	163	0	60	0.012
16	50	300	0.06	53	200	15	0.003	90	250	550	0.11	127	0	200	0.04	164	200	850	0.17
17	0	40	0.008	54	500	100	0.02	91	0	5	0.001	128	100	300	0.06	165	0	70	0.014
18	0	370	0.074	55	250	60	0.012	92	200	570	0.114	129	500	150	0.03	166	0	30	0.006
19	50	15	0.003	56	200	450	0.09	93	0	1000	0.2	130	0	120	0.024	167	0	450	0.09
20	200	100	0.02	57	0	190	0.038	94	0	30	0.006	131	0	130	0.026	168	50	450	0.09
21	0	10	0.002	58	250	350	0.07	95	50	500	0.1	132	100	10	0.002	169	0	150	0.03
22	0	30	0.006	59	0	180	0.036	96	0	350	0.07	133	100	400	0.08	170	50	50	0.01
23	0	30	0.006	60	0	180	0.036	97	50	100	0.02	134	160	420	0.084	171	50	200	0.04
24	0	100	0.02	61	500	350	0.07	98	315	50	0.01	135	0	60	0.012	172	0	120	0.024
25	200	50	0.01	62	100	50	0.01	99	315	300	0.06	136	0	150	0.03	173	100	210	0.042
26	100	210	0.042	63	0	160	0.032	100	200	300	0.06	137	0	150	0.03	174	200	260	0.052
27	0	420	0.084	64	0	350	0.07	101	50	630	0.126	138	200	120	0.024	175	50	300	0.06
28	315	80	0.016	65	100	50	0.01	102	0	10	0.002	139	200	120	0.024	176	0	200	0.04
29	0	150	0.03	66	0	15	0.003	103	0	50	0.01	140	0	220	0.044	177	0	30	0.006
30	100	420	0.084	67	100	180	0.036	104	0	60	0.012	141	100	10	0.002	178	100	250	0.05
31	160	450	0.09	68	200	360	0.072	105	0	50	0.01	142	0	220	0.044	179	0	15	0.003
32	100	10	0.002	69	100	420	0.084	106	100	15	0.003	143	0	40	0.008	180	100	8	0.0016
33	400	220	0.044	70	200	240	0.048	107	0	180	0.036	144	0	120	0.024	181	250	120	0.024
34	0	10	0.002	71	160	120	0.024	108	0	40	0.008	145	200	40	0.008	182	0	20	0.004
35	315	150	0.03	72	500	210	0.042	109	250	60	0.012	146	0	60	0.012	183	200	250	0.05
36	315	340	0.068	73	0	70	0.014	110	250	200	0.04	147	50	15	0.003				
37	400	200	0.04	74	100	300	0.06	111	0	15	0.003	148	50	240	0.048				

Table 2. Placement of the protective and switching devices of test system

Device type	Branch No
Fuses	5,16,27,28,58,105,130,131,156,160,79,97,170,171
Isolators	25, 43, 45, 47, 60, 104, 143, 160, 177

Table 3. Objective function parameters

Objective parameter	Value
Permanent failure rate	20 Fault/100 km. year
K_2	1.8 US$/kW
β	All main sections
r	5 %
n	20 years
p	20 %
Interruption duration of fault occurrences	2 hours
Required time for switching	30 minutes
Number of available DGs	4
S_{DG_i}, $i = 1{:}\ 4$	5 MW

US $ by decreasing CENS. Since the obtained solution suggests the connection of all DGs, it is comprehensible that connecting the DGs work stand alone to proper positions improves the system reliability effectively and economically.

5 CONCLUSION

This paper is concerned with the improvement of the distribution systems reliability by connecting the DGs work stand alone to the system. A novel methodology has been introduced to find the optimum solution for the connecting places of DGs. This objective function is defined on the basis of the system cost including the cost of connector lines of the DGs as well as the saving costs resulted from CENS. The mathematical method is introduced to calculate ENS that is an important part of the objective function. In this paper, GA is used to optimize the objective function. The optimization process is applied to a realistic distribution system of TREC. The results illustrate that by connecting the DGs work stand alone to the appropriate places in system, the reliability system will be improved and the system cost decreased. The effec-

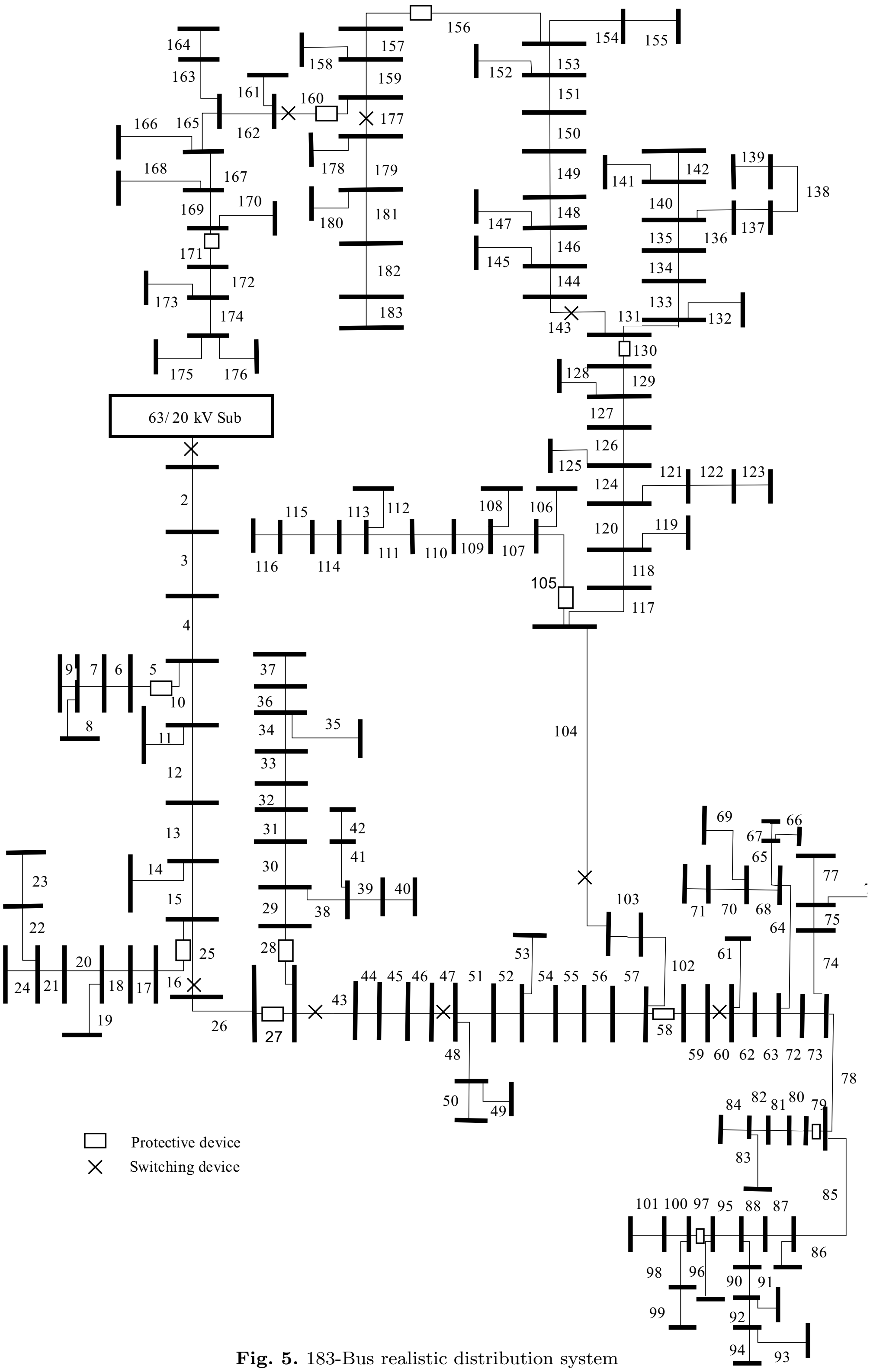

Fig. 5. 183-Bus realistic distribution system

Table 4. Test results

Desired characteristics	Optimum parameters
Appropriate places for DG allocation	27, 103, 117, 181
Optimized value of the objective function	8120200
Capital cost to install the maneuver lines for connecting the DGs ($)	197540
Annual restoration energy using DG connection (kW/year)	270673

tiveness of the introduced method becomes obvious from the test results.

References

[1] BILLINTON, R.—ALLAN, R. N.: Reliability Evaluation of Power System, Plenum Press, New York, 1984.

[2] TIPPACHON, W.—RERKPREEDAPONG, D.: Multiobjective Optimal Placement of Switches and Protective Devices in Electric Power Distribution Systems Using Ant Colony Optimization, Electric Power System Research **79** (Mar 2009), 1171–1178.

[3] ETEMADI, A. H.—FOTUHI-FIRUZABAD, M.: Distribution System Reliability Enhancement using Optimal Capacitor Placement, IET Gener. Transm. Distrib. **2** No. 5 (2008), 621–631.

[4] CELLI, G.—PILO, F.: Optimal Sectionalizing Switches Allocation in Distribution Networks, IEEE Trans. on Power Delivery **14** No. 3 (July 1999), 1167–1172.

[5] BILLINTON, R.—JONNAVITHULA, S.: Optimal Switching Device Placement in Radial Distribution Systems, IEEE Trans. on Power Delivery **11** No. 3 (July 1996), 1646–1651.

[6] SILVA, L. G. W.—PEREIRA, R. A. F.—MANTOVANI, J. R. S.: Allocation of Protective Device in Distribution Circuits Using Nonlinear Programming Models and Genetic Algorithms, Electrical Power System Research **69** No. 1 (July 2004), 77–84.

[7] SILVA, L. G. W.—PEREIRA, R. A. F.—ABBAD, J. R.—MANTOVANI, J. R. S.: Optimized Placement of Control and Protective Devices in Electric Distribution Systems through Reactive Tabu Search Algorithm, Electric Power System Research, **78** No. 1 (Apr 2008), 372–381.

[8] CHANDRAMOHAN, S. *et al*: Operating Cost Minimization of a Radial Distribution System in a Deregulated Electricity Market through Reconfiguration Using NSGA Method, International Journal of Electrical Power & Energy Systems **32** (2010), 126–132.

[9] TENG, J.—LU, C. N.: Feeder- Switch Relocation for Customer Interruption Cost Minimization, IEEE Trans. on Power Delivery **17** No. 1 (Jan 2002), 254–259.

[10] HASHEMI DEZAKI, H.—ASKARIAN ABYANEH, H.—KABIRI RENANI, Y.—AKBAR FAKHRABADI, H.—MAZLUMI, K.: Optimized Protective Devices Allocation in Electric Power Distribution Systems Based on the Current Conditions of the Devices, IEEE International Conference on Power and Energy 2010, Selangor, Malysia, 2010.

[11] POPOVIC, D. H.—GREATBANKS, J. A.—PREELJ, A.: Placement of Distributed Generators and Reclosers for Distribution Network Security and Reliability, Electric Power Systems Research **27** No. 1 (2005), 398–408.

[12] WANG, L.—SINGH, C.: Reliability-Constrained Optimum Placement of Reclosers and Distributed Generators in Distribution Networks Using an Ant Colony System Algorithm, IEEE Trans. on Systems, Man, and Cybernetics, Part C: Applications and Reviews **38** No. 6 (Nov 2008).

[13] HASHEMI DEZAKI, H.—ASKARIAN ABYANEH, H.—AGHELI, A.—HOSSEINIAN, S. H.—MAZLUMI, K.—NAFISI, H.: Optimized Investment to Decrease the Failure Rate of Distribution Lines in Order to Improve SAIFI, The 4th International Power Engineering and Optimization Conf. (PEOCO2010), IEEE Conference, Shah Alam, Selangor, Malysia, 23–24 June 2010.

[14] KAZEMI, S.—FOTUHI-FIRUZABAD, M.—SANAYE-PASAND, M.—LEHTONEN, M.: Impacts of Automatic Control Systems of Loop Restoration Scheme on the Distribution System Reliability, IET Gener. Transm. Distrib., **3** No. 10 (2009), 891–902.

[15] PREGELJ, A.—BEGOVIC, M.—ROHATGI, A.: Recloser Allocation for Improved Reliability of DG-Enhanced Distribution Networks, IEEE Transactions on Power Systems **21** No. 3 (Aug 2006).

[16] HUNG, D. Q.—MITHULANANTHAN, N.—BANSAL, R. C.: Analytical Expressions for DG Allocation in Primary Distribution Networks, IEEE Trans. on Energy Conversion **25** No. 3 (Sep 2010), 814–820.

[17] ATWA, Y. M.—El-SAADANY, E. F.: Probabilistic Approach for Optimal Allocation of Windbased Distributed Generation in Distribution, IET Renewable Power Generation **5** No. 1 (Oct 2011), 79–88.

[18] KHALESI, N.—REZAEI, N.—HAGHIFAM, M. R.: DG Allocation with Application of Dynamic Programming for Loss Reduction and Reliability Improvement, International Journal of Electrical Power & Energy, **33** No. 2 (Feb 2011), 288–295.

[19] CATRINU, M. D.—NORDGARD, D. E.: Integrating Risk Analysis and Multi-Criteria Decision Support under Uncertainty in Electricity Distribution System Asset Management, Reliability Engineering & System Safety **96** (2011), 663–670.

[20] BROWN, R. E.—HANSON, A. P.: Impact of Two-Stage Service Restoration on Distribution Reliability, IEEE Trans. on Power Delivery **16** No. 4 (Nov 2001).

[21] SOUDI, F.—TOMASOVIC, K.: Optimized Distribution Protection Using Binary Programming, IEEE Trans. on Power Delivery **13** No. 1 (Jan 1998), 218–224.

[22] SILVA, L. G. W.—PEREIRA, R. A. F.—MANTOVANI, J. R. S.: Optimized Investment to Decrease the Failure Rate of Distribution Lines in Order to Improve SAIFI, in 2010 IEEE/PES Optimization Conference & Exposition, Malysia, ShahAlam, 2010.

Received 11 March 2012

Hamed Hashemi Dezaki was born in 1986, Borujen, Iran. He received BS and MS degrees in electrical engineering from Amirkabir University of Technology, Tehran, Iran in 2008 and 2010, respectively. Presently, he is a PhD student at the department of electrical engineering of Amirkabir University of Technology, Tehran, Iran. His main fields of research are protection of power systems, power quality and system reliability.

Ali Agheli Biography not supplied.

Behrooz Vahidi was born in Abadan, Iran, in 1953. He received the BS degree in electrical engineering from Sharif University of Technology, Tehran, Iran, in 1980, the MS degree in electrical engineering from Amirkabir University of Technology, Tehran, in 1989, and the PhD degree in electrical engineering from the University of Manchester Institute of Science and Technology, Manchester, UK, in 1997. From 1980 to 1986, he worked in the field of high voltage in industry as a Chief Engineer. Since 1989, he has been with the Department of Electrical Engineering of Amirkabir University of Technology, where he is now a Professor. Prof. Vahidi is senior member of IEEE His main fields of research are high voltage, electrical insulation, power system transient, lightning protection, and pulse power technology. He has authored and coauthored 250 papers and five books on high voltage engineering and power system.

Hossein Askarian Abyaneh was born in Abyaneh, Isfahan on March 20, 1953. He received the BS and MS degree both in Iran in 1976 and 1982 respectively. He also received another MS degree and PhD from UMIST, Manchester, UK in 1985 and 1988 respectively, all in power system engineering. He published over 140 scientific papers in international journals and conferences. Currently, he is a Professor with the Department of Electrical Engineering and Head of the Electrical Engineering Department, AUT, Iran, working in the area of the relay protection and power quality.