Turkish Journal of Electrical Engineering & Computer Sciences

http://journals.tubitak.gov.tr/elektrik/

Research Article

Turk J Elec Eng & Comp Sci
(2014) 22: 315 – 326

doi:10.3906/elk-1202-86

A novel approach based on reliability sensitivity analysis to allocate protective devices

Hamed HASHEMI DEZAKI[1,*], **Hossein ASKARIAN-ABYANEH**[1], **Mehdi GARMRUDI**[1], **Hossein MAHDINIA**[1], **Kazem MAZLUMI**[2]

[1]Electrical Engineering Department, Amirkabir University of Technology, Tehran, Iran
[2]Electrical Engineering Department, University of Zanjan, Zanjan, Iran

Received: 21.02.2012 • **Accepted:** 05.11.2012 • **Published Online:** 17.01.2014 • **Printed:** 14.02.2014

Abstract: In electrical distribution systems, it is possible to have a reliable system via a well-designed protective scheme. The allocation of protective devices is an important parameter in the design of a protective scheme. Different approaches to optimize the allocation of protective devices have been studied. Because of some uncertainties, it is not the best strategy to select an optimized solution in accordance with certain conditions. The availability of the protective devices seriously affects the reliability of electrical distribution systems. Furthermore, reduction of the investment in some designing processes leads to a decrease in the number of protective devices that will be installed. By considering the insensitivity of malfunctioning or removed protective devices, it is possible to select a flexible scheme having a minimal reliability decrement due to the malfunction or removal of protective devices.

Sensitivity analysis is an appropriate way to determine system robustness against the uncertainties of the model or design parameters. In this article, the reliability sensitivity level is examined according to the allocation of the protective devices. The system average interruption index (SAIFI) variation is selected as the reliability level. In the proposed method, the SAIFI variation is calculated when a protective device malfunctions or is removed. A higher sensitivity level signifies a device having a more proper allocation. Moreover, to prevent any malfunctions, that device must be preserved and revised continuously. Hence, the proposed method can be used to improve the system reliability by adding the protective device to the most appropriate location. To illustrate the efficiency of the introduced method, it is applied to a typical distribution network.

Key words: Sensitivity analysis, malfunction and removal of protective devices, system reliability, protection devices, system average interruption frequency index

1. Introduction

Economically supplying customers with electrical energy with a satisfied reliability level is an important function of power systems [1]. Customer failure statistics demonstrate that electrical distribution systems make the greatest contribution to customer interruptions [2]. The analysis of these statistics emphasizes the system reliability improvement. Some strategies that have been studied in reliability improvement are as follows: finding the best placement of protective and switching devices [3–7], adding protective devices [8], reclosing [9,10], decreasing the components' failure rate [1,11], increasing the speed of the repair process [12], and using distributed generation (DG) [13–15] and system reconfiguration [16].

The reliability indices commonly used in distribution systems are classified as load- and customer-based

*Correspondence: hamed.hashemi@gmail.com

indices [17,18]. Customer-based reliability indices are usually selected to analyze system reliability, such as the system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI) [19]. In load-based reliability indices, the cost of energy not supplied is the most popular [20]. The customer average interruption duration index, customer average interruption frequency index, and average system availability index are some other indices used in specific cases [21].

It is possible to improve system reliability by the proper allocation of protective and switching devices. Different intelligent optimization methods have been used in several reliability improvement problems. The genetic algorithm [5,8,11], ant colony system [7,13], tabu search [6], simulated annealing [4], and other algorithms have been selected to solve optimization problems.

In [18,22], the optimization of device placement was determined on the basis of the SAIFI. In [6,8,23,24], the objective function was defined in accordance with the economic indices. The studies in [5,8,11,18,22], [3,12,16], and [6,7,23,24] focused on the optimization of protective devices, switching devices, and both of them, respectively.

As in any other field, many decision parameters in electrical distribution system asset management are inevitably uncertain [25,26], and in the available research, no solution is considered to examine it.

Sensitivity analysis is a useful method to evaluate the system robustness against the uncertainties of model or design parameters. Sensitivity analysis has been examined in different studies in power engineering, as follows: siting the flexible AC transfer systems [25,27,28], stability impact of DGs [29], transient stability [28,30], etc. However, it has not been attempted to determine more effective strategies to improve the distribution system reliability so far. Determining the value of changes regarding uncertainty is possible through sensitivity analysis.

The removal or damage of any protective device in any protective plan decreases the reliability level [31,32]. However, some devices play a critical role and the removal of these devices results in more intense system reliability variations. It is possible to lessen the likely damages by determining towards which device the system reliability is more sensitive. Determining the system reliability with respect to each device leads to specifying their priority level. Therefore, the monitoring and revising of devices with higher priority periodically helps to increase the system reliability. If there are some devices differing from each other in terms of quality and function, it is recommended to place more reliable devices in more strategic sections. For maintenance and replacement purposes, the system priorities might be assessed on the basis of this analysis.

Finding the best placement to add a protective device according to the maximized reliability is possible by sensitivity analysis. The sensitive location to add the device is the best place to allocate the protective device.

Decision making to select the protective device's allocation is an important factor in the designing process. Moreover, to consider the uncertainties in the optimization of protective schemes in all approaches, a comparison between the best solution and the others is inevitable. The protective scheme having a reasonable reliability level with minimum sensitivity to change the involved parameters would be trustworthy.

In this paper, a novel method based on reliability sensitivity analysis is proposed to determine the proper allocation of protective devices. This method is useful under 3 conditions: a protective device exists in one point of the network, the best placement is considered to add a protective device, and it is necessary to select a protective scheme from a set of them. The proposed method is applied to a typical distribution system.

2. Mathematical fundamentals of the proposed method

The SAIFI is a customer-based index widely used as a reliability criterion [19]. Hence, the SAIFI is appointed as the sensitivity measurement criterion in this paper. The SAIFI definition is demonstrated in Eq. (1):

$$\text{SAIFI}=\frac{\text{Total Number of Interrupted Customers}}{\text{Total Number of Customers Served}}. \tag{1}$$

Calculation of the SAIFI in this paper is based on Eqs. (2)–(5). In the proposed method, faults occurring in the system are classified into 2 groups: those occurring in the main branches and those occurring in the lateral branches. F_1 indicates the number of interrupted customers when a fault occurs in sections of the main branch. Moreover, when a fault occurs in sections of the lateral branches, some customers experience an interruption. F_2 calculates the customer interruption due to the fault occurrence in sections of the lateral branches. An auxiliary function ($A(i,j)$) is defined that helps to simplify the SAIFI calculation [8].

$$A(i,j)=\begin{cases} 1 & \text{exist no protective objects in position } i \text{ to } j \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$SAIFI=\frac{\sum_{i=1}^{2} F_i}{T} \tag{3}$$

$$F_1=\sum_{i=1}^{mb}\lambda_{mi}\left(\begin{array}{l} \sum_{j=i}^{mb} N_{mj}+\sum_{k=1}^{i-1,i\neq 1} N_{mk}\times A(k+1,i) \\ +\sum_{s=1}^{flb(i)}\sum_{p=1}^{ts(s)} N(s,p)\sum_{q=1}^{blb(i)}\sum_{r=1}^{ts(q)} N(q,r)\times A(fdmb(q),i) \end{array}\right) \tag{4}$$

$$F_2=\sum_{s=1}^{flb(i)}\sum_{p=1}^{ts(s)}\lambda(s,p)\times\left(\begin{array}{l} \sum_{j=1}^{mb} N_{mj}\times A(1,p)+\sum_{t=1}^{flb(fdmb(s)}\sum_{p=1}^{ts(t)} N(t,p)\times A(1,w)+ \\ \sum_{v=1}^{blb(fdmb(s)}\sum_{y=1}^{ts(v)} N(v,y)\times A(fdmb(s),fumb(s))\times A(l,w)+ \\ \sum_{l=1}^{fumb(s)-1} N_{ml}\times A(l,p)\times A(l,fdmb(s)) \end{array}\right) \tag{5}$$

2.1. Protective device removal or malfunction

The change in the SAIFI value is determined when device (j) malfunctions or is removed. The SAIFI variation of each protective device is compared with the others. Their minimum value indicates the most important device. The mathematical expression of the reliability variation is shown as follows:

$$\begin{array}{l} X_{available}=[X_{11}\ X_{12}\cdots X_{1n}] \\ X_{1k}=1 \qquad k\in\alpha \\ \Delta SAIFI_k=SAIFI_{new}\Big|_{X_{1k}=1\to 0}-SAIFI_{old} \\ Max\{\Delta SAIFI_1,\Delta SAIFI_2,...,\Delta SAIFI_i,....,\Delta SAIFI_r\}=\Delta SAIFI_j \\ \Rightarrow \text{The section } (j) \text{ is the most sensetive} \\ \quad \text{and should be attended to seriously.} \end{array} \tag{6}$$

In any protective scheme, there are a number of protective devices in specific positions. A binary variable is defined for each section of a distribution system, determining the existence or nonexistence of a protective device in that section. The sensitivity level of the SAIFI indicates the quantity of disparity between various statuses in which, for instance, device (k) exists or not.

By reducing the maintenance and supervision duration for more sensitive devices, the system reliability decrement would be less. While the expected budget to imply the protective designs decreases, by cancellation of the least sensitive device, the reliability decrement will be minimized.

2.2. Selecting a proper protective scheme in the design or optimization of protective device allocation

Decision making in the allocation of protective devices is more difficult when some parameters of the systems are uncertain. In the protective scheme design, this problem is inevitable. In the methods based on optimization, to consider the system uncertainties, a similar problem is made. The proposed method of this paper, based on sensitivity analysis, is useful to make a proper decision.

To determine the proper allocation of protective devices, a new index, named the flexibility index (F.I), is defined. The mathematical expression of the F.I is as follows:

$$\begin{aligned} &F.I_l = \frac{1}{\sum \Delta SAIFI_k} \qquad k \in \alpha_l \\ &Max\left\{F.I_1, F.I_2, ..., F.I_i, ..., F.I_r\right\} = F.I_j \\ &\Rightarrow \text{The scheme } (j) \text{ should be selected.} \end{aligned} \tag{7}$$

The F.I value is determined for each allocation of a protective device. Finding the maximum value of the discussed schemes demonstrates the best scenario. The reliability deficiency of the selected examined scenario according to this analysis will be smaller.

2.3. Adding a protective device to improve the system reliability

Another ability of the proposed method based on reliability sensitivity analysis is determining the best position to allocate an additional protective device. The system sections are categorized into 2 groups: sections equipped with a protective device and those without a device. In this regard, initially, sensitivity analysis is accomplished for the current situation of the protective devices; the device with the minimum level of sensitivity is selected and if it is concluded that the device lacks efficiency, then it must be moved to a better location. As shown in Eq. (8), the positive SAIFI variation of changing the location of the available device recommends that change. Moreover, the negative value of the SAIFI variation, according to Eq. (8), demonstrates that replacing the available protective devices is not recommended.

$$\begin{aligned} &X_{available} = [X_{1j}]\, j = 1:n \\ &X_{1k} = 1 \qquad k \in \alpha \\ &X_{1m} = 0 \qquad m \in \alpha' \\ &\Delta SAIFI_{k \to m} = SAIFI_{new}\Big|_{X_{1k} = 1 \to 0, X_{1m} = 0 \to 1} - SAIFI_{old} \\ &If \qquad \Delta SAIFI_{k \to m} > 0 \\ &\qquad\qquad \forall m \in \alpha' \forall k \in \alpha \\ &Then: \\ &m \in \alpha' \to m \in \alpha, k \in \alpha \to k \in \alpha' \end{aligned} \tag{8}$$

After applying sensitivity analysis based on Eq. (8), subsequent sensitivity analyses are performed for allocating devices in vacant locations. By comparing the calculated sensitivities, the adequate location for the allocation or replacement of a device is determined. The mathematical interpretation of the aforementioned idea is shown in Eq. (9). The location with the maximum SAIFI variation among the vacant locations should be selected to add a protective device.

$$\begin{aligned}
&X_{available} = [X_{1j}] = 1:n \\
&X_{1m} = 0 m \in \alpha' \\
&\Delta SAIFI_m = SAIFI_{new}\Big|_{X_{1m}=0\rightarrow 1} - SAIFI_{old} \\
&Max\left\{\Delta SAIFI_m\right\} = \Delta SAIFI_j \qquad m \in \alpha' \\
&\Rightarrow \text{The } j\text{th section should be selected to add a protective device.}
\end{aligned} \tag{9}$$

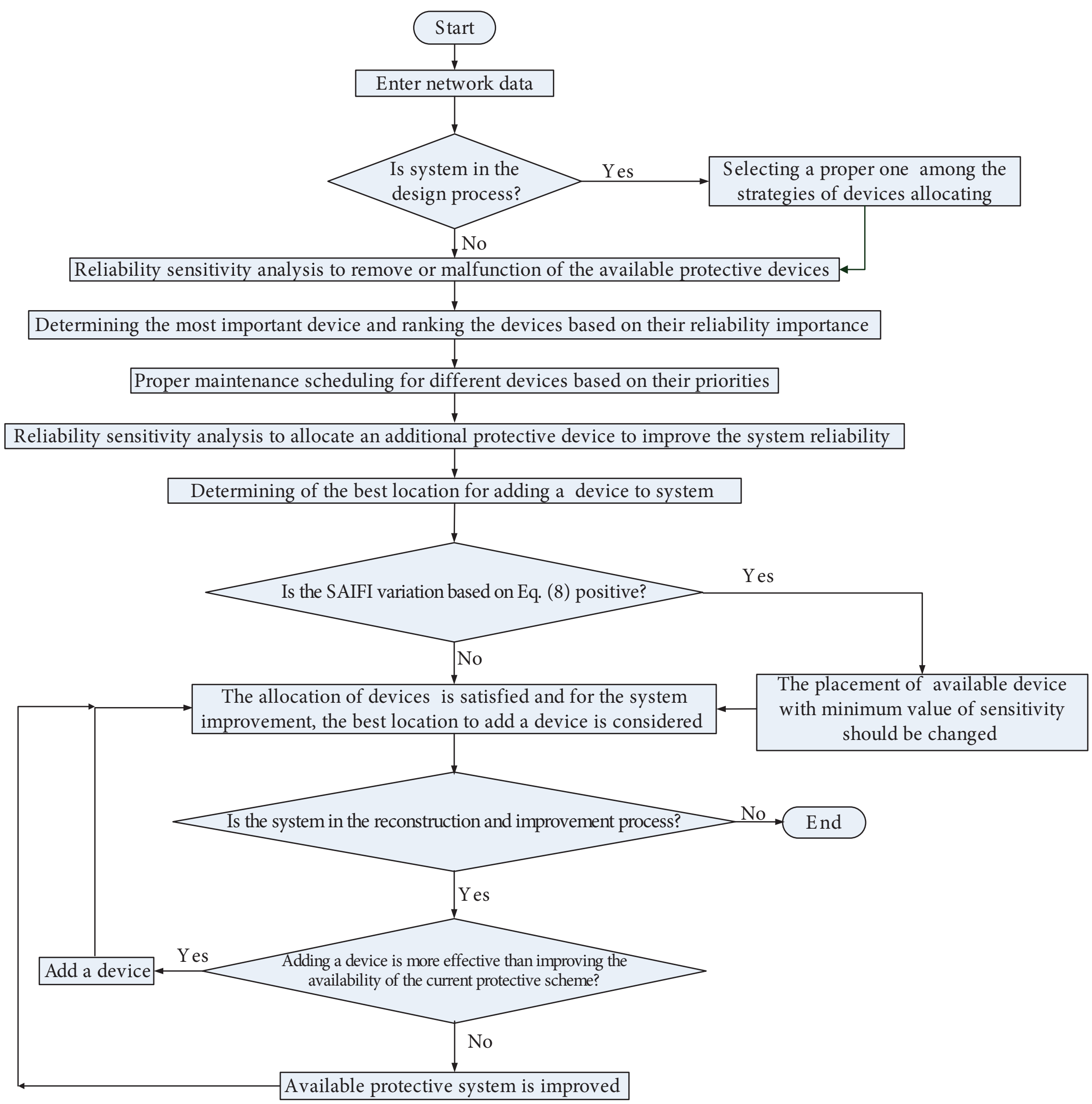

Figure 1. Flow chart of the proposed algorithm.

A flow chart of the proposed algorithm is shown in Figure 1. The sequence of the different steps is elaborately demonstrated in this chart.

3. Test results

To clarify the proposed method's efficiency, it is applied to a typical distribution system, shown in Figure 2. The line parameters, installed load, and failure rate of each section and current location of switching and protective devices are presented in Tables 1 and 2 [8]. The SAIFI variation for the removal of each available protective device is shown in Table 3. These results illustrate the most and least important devices.

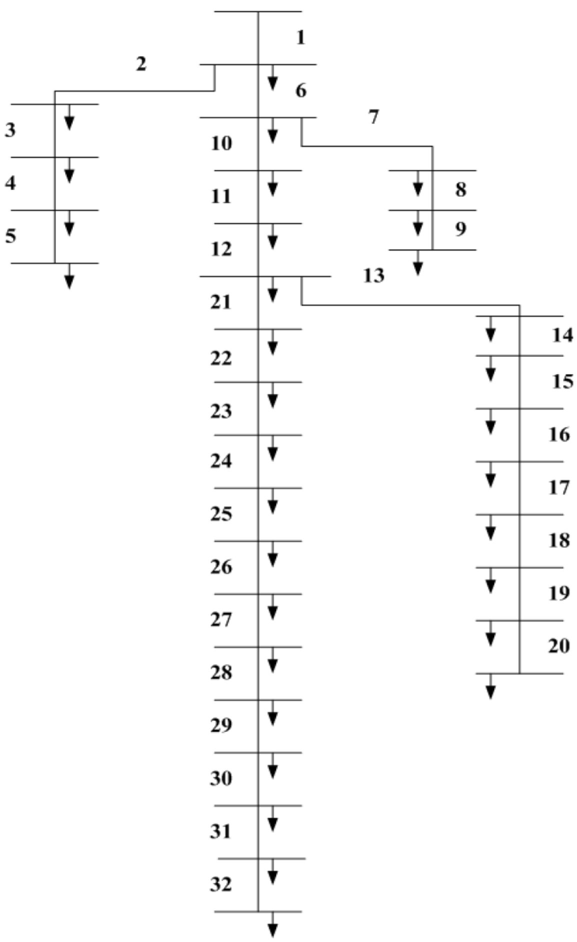

Figure 2. Single diagram of the test system.

Table 1. Protective device placements in the test system.

Device type	Branch No.
Fuse or sectionalizer	2, 7, 10, 13, 21, 27
Recloser	1

The SAIFI value of the current condition of the system is 0.5259. Moreover, the obtained results shown in Table 3 indicate that the most important device is allocated in section 13. This device should be maintained more so than the others. The least important device is one that is allocated in section 10. Its removal or malfunction effect is about 100 times less than that of the most important one.

Table 2. Test system information.

Branch no.	Initial node	End node	N_i	L_i(kVA)	λ_i (fault km^{-1} year^{-1})
1	1	2	5	100	0.00954
2	2	19	6	90	0.0313
3	19	20	4	90	0.27108
4	20	21	8	90	0.09568
5	21	22	5	90	0.18746
6	2	3	4	90	0.05022
7	3	23	2	90	0.06166
8	23	24	21	420	0.14182
9	24	25	15	420	0.14022
10	3	4	7	120	0.03728
11	4	5	1	60	0.03882
12	5	6	4	60	0.1414
13	6	26	2	60	0.02068
14	26	27	3	60	0.02894
15	27	28	5	60	0.18674
16	28	29	8	120	0.14012
17	29	30	12	200	0.0517
18	30	31	12	150	0.1926
19	31	32	5	210	0.07238
20	32	33	4	60	0.10604
21	6	7	7	200	0.12376
22	7	8	8	200	0.24702
23	8	9	2	60	0.148
24	9	10	2	60	0.148
25	10	11	3	45	0.013
26	11	12	1	60	0.02476
27	12	13	4	60	0.231
28	13	14	6	120	0.14258
29	14	15	2	60	0.1052
30	15	16	3	60	0.109
31	16	17	4	60	0.3442
32	17	18	6	90	0.1148

Table 3. Sensitivity level of each protective device removed.

Device placement	SAIFI sensitivity
2	1.3315
7	1.4711
10	0.0541
13	1.7669
21	0.4616
27	1.0759

The placement of devices in accordance with the obtained results can be classified into 2 sets: the main sections (10,21,27) and the beginning of the lateral branches (2,7,13). The value of the SAIFI variation demonstrates that the removal of devices located in the main sections decreases the system reliability less than the removal of devices located in the beginning of the lateral branches. This comparison recommends maintenance at a high level of consideration and the priority of their replacement is higher than that of the others in the system reconstruction.

To complete the sensitivity analysis on the selected distribution network, it is crucial to study the attachment of a protective device to those branches lacking any devices.

Thirteen sections are feasible for allocating an additional protective device to improve the system reliability. The results of the SAIFI variation that are caused by adding a device in these sections are presented in Table 4.

Table 4. Obtained results by adding a device to the current network status according to the sensitivity criterion.

Device placement	SAIFI sensitivity
6	0.0418
11	0.0422
12	0.0407
22	0.0347
23	0.0321
24	0.0371
25	0.0437
26	0.0442
28	0.0368
29	0.0202
30	0.0211
31	0.0221
32	0.0385

From the obtained results shown in Table 4, it is obvious that adding a protective device in feasible sections is not effective to improve the system reliability. The considerable values of the removal of the available protective devices in Table 3 illustrate that this system is satisfied from a view point of reliability. Since the SAIFI variation of the removal or malfunction of any available protective device is considerable, the current position of the protective devices is a good one and any change in the device allocation makes a worse condition. However, it should be considered that the best placement for adding any device is section 26. The candidate location to add a device is selected according to the values presented in Table 4. Moreover, the total SAIFI variation of the protective device scheme and corresponding F.I of this allocation are 6.1521 and 0.1625, respectively.

In addition to the available allocation of protective devices, another 4 proper allocations for protective devices are analyzed according to their flexibility against the malfunction or removal of the devices. In Table 5, the SAIFI variation caused by the removal of each protective device is presented. The SAIFI value, F.I, and total SAIFI variation of alternatives A, B, C, and D are also demonstrated in Table 6.

As can be seen from the results in Table 6, alternatives A, C, and D have greater SAIFI values than the available protective scheme, while the SAIFI value of alternative B is less than the current condition. However, the F.I values of alternatives A,B, C, and D are greater than the available condition. Hence, while the probability of malfunction or removal of protective devices is at a high level, these alternatives can be more effective. Although the SAIFI values of alternatives A, C, and D are not better than the available allocation of protective devices, they can satisfy the system reliability effectively under uncertainties.

Table 5. Results of the sensitivity analysis of the protective device alternatives based on the devices being removed or malfunctioning.

Alternative A		Alternative B		Alternative C		Alternative D	
Device location	SAIFI variation	Device location	SAIFI variation	Device location	SAIFI variation	Device location	SAIFI variation
7	1.2245	2	1.00872	2	1.3400	7	1.3620
10	0.0451	7	1.3427	10	0.0536	10	0.0243
13	1.5204	10	0.0451	13	1.6359	12	0.0567
21	0.4616	13	1.4823	21	0.4702	13	1.6578
27	0.5904	22	0.1373	27	1.0845	21	0.4733
28	1.0850	27	0.4729	—	1.1064	27	0.7513

Table 6. Examination of the results of the criterion of sensitivity to device elimination.

Alternative name	SAIFI	Total SAIFI variation	FI
Alternative A	0.7725	4.9269	0.2030
Alternative B	0.5147	4.48902	0.2227
Alternative C	0.6570	5.6906	0.1757
Alternative D	0.6350	4.3254	0.2311

The comparison among different allocations of protective devices according to the probability of different uncertainties such as the removal or malfunction of protective devices helps select the most flexible scheme. In cases where an alternative exists with the best value of the SAIFI and flexibility level, the selection of a proper one is not complicated. However, selecting a proper alternative is difficult when an alternative has a better SAIFI value and worse flexibility value. In these situations, the probability of uncertainties is the determinant. Since the SAIFI value of alternative B is less than the current condition of the system, while the flexibility level of this alternative is greater than the current condition, alternative B is certainly the best choice among the discussed alternative and current conditions of system.

4. Conclusion

Distribution systems' power quality and reliability have drawn serious attention in recent years. The proper placement of protective devices will increase the system reliability. In this paper, a novel method was proposed to evaluate the proper allocation of protective devices, which is based on the sensitivity analysis. Using the method in this paper, decision making about the system reliability decrement is possible when an available protective device is removed or malfunctions.

Knowing the device's importance in the system reliability facilitates the maintenance and reconstruction priorities. Sensitivity analysis shows the perspective of the system under uncertainties.

Another ability of the discussed method is the determination of the best position to add a protective device. Using sensitivity analysis helps to economically increase the system reliability. By comparing the reliability variations of the removal of the available protective devices and allocating an additional device, the available placement of the devices is appreciable. To illustrate the advantages of the proposed method, it was applied to a typical distribution system. The results obtained by the sensitivity analysis to remove or add a protective device emphasize the effectiveness of the method to satisfy the system reliability under uncertainties.

Nomenclature

T	Total number of customers connected to the system
mb	Number of main sections
λ_{mi}	Failure rate of section (i) of the main branch
$\lambda(s,p)$	Failure rate of section (p) of the sth lateral branch
N_{mi}	Number of customers connected to the ith section of the main branch
$flb(i)$	First downstream lateral branch of section (i) of the main branch
$N(s,p)$	Number of customers connected to section (p) of sth lateral branch
$ts(s)$	Number of sections located in the sth lateral branch
$blb(i)$	First upstream lateral branch of section (i) located in the main branch
$fdmb(i)$	First downstream main branch of the ith lateral branch
$fumb(i)$	First upstream main branch of the ith lateral branch
$X_{available}$	Matrix of placements for the available devices
X_{1j}	Binary variable indicating whether a protective device exists or not in section (j)
α	Set of sections equipped with a protective device
α'	Set of feasible sections to add a protective device
FI_l	Flexibility index of the lth allocation of protective devices
F_1	Number of interrupted customers due to failure of the main sections
F_2	Number of interrupted customers due to failure of the lateral sections
$blb(i)$	First upstream lateral branch of the ith section of main branch
r	Number of feasible allocations for protective devices
n	Total number of system sections
λ_i	Failure rate of section (i)
L_i	Amount of loads installed in section (i)
N_i	Number of customers installed in section (i)

References

[1] A.H. Etemadi, M. Fotuhi-Firuzabad, “Distribution system reliability enhancement using optimal capacitor placement”, IET Generation, Transmission & Distribution, Vol. 2, pp. 621–631, 2008.

[2] R. Billinton, R.N. Allan, Reliability Evaluation of Power Systems, New York, USA, Plenum Press, 1984.

[3] G. Celli, F. Pilo, “Optimal sectionalizing switches allocation in distribution networks”, IEEE Transactions on Power Delivery, Vol. 14, pp. 1167–1172, 1999.

[4] R. Billinton, S. Jonnavithula, “Optimal switching device placement in radial distribution systems”, IEEE Transactions on Power Delivery, Vol. 11, pp. 1646–1651, 1996.

[5] L.G.W. Silva, R.A.F. Pereira, J.R.S. Mantovani, “Allocation of protective device in distribution circuits using nonlinear programming models and genetic algorithms”, Electrical Power System Research, Vol. 69, pp. 77–84, 2004.

[6] L.G. W. Silva, R.A.F. Pereira, J.R. Abbad, J.R.S. Mantovani, “Optimised placement of control and protective devices in electric distribution systems through reactive tabu search algorithm”, Electric Power System Research, Vol. 78, pp. 372–381, 2008.

[7] W. Tippachon, D. Rerkpreedapong, “Multiobjective optimal placement of switches and protective devices in electric power distribution systems using ant colony optimization”, Electric Power System Research, Vol. 79, pp. 1171–1178, 2009.

[8] H. Hashemi Dezaki, H. Askarian Abyaneh, Y. Kabiri Renani, H. Akbar Fakhrabadi, K. Mazlumi, “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.

[9] D.H. Popovic, J.A. Greatbanks, A. Preelj, “Placement of distributed generators and reclosers for distribution network security and reliability”, Electric Power Systems Research, Vol. 27, pp. 398–408, 2005.

[10] A. Pregelj, M. Begovic, A. Rohatgi, “Recloser allocation for improved reliability of DG-enhances distribution networks”, IEEE Transactions on Power Systems, Vol. 21, pp. 1442–1449, 2006.

[11] H. Hashemi Dezaki, H. Askarian Abyaneh, A. Agheli, S.H. Hosseinian, K. Mazlumi, H. Nafisi, "Optimized investment to decrease the failure rate of distribution lines in order to improve SAIFI", The IEEE 4th International Power Engineering and Optimization Conference, 2010.

[12] S. Kazemi, M. Fotuhi-Firuzabad, M. Sanaye-Pasand, M. Lehtonen, "Impacts of automatic control systems of loop restoration scheme on the distribution system reliability", IET Generation, Transmission & Distribution, Vol. 3, pp. 891–902, 2009.

[13] L. Wang, C. Singh, "Reliability-constrained optimum placement of reclosers and distributed generators in distribution networks using an ant colony system algorithm", IEEE Transactions on Systems, Man, and Cybernetics - Part C: Applications and Reviews, Vol. 38, pp. 757–764, 2008.

[14] L. Wang, C. Singh, "Reliability options in distribution planning using distributed generation", IEEE Latin America Transactions, Vol. 8, pp. 557–564, 2010.

[15] S.M. Hashemi, A. Ebrahimi, "A new analytical method for impact evaluation of distributed generation on distribution system reliability", International Review of Electrical Engineering, Vol. 4, pp. 907–913, 2009.

[16] R.E. Brown, A.P. Hanson, "Impact of two-stage service restoration on distribution reliability", IEEE Transactions on Power Delivery, Vol. 16, pp. 624–629, 2001.

[17] F. Soudi, K. Tomsovic, "Optimal distribution protection design: quality of solution and computational analysis", Electric Power and Energy Systems, Vol. 21, pp. 327–335, 1999.

[18] F. Soudi, K. Tomasovic, "Optimized distribution protection using binary programming", IEEE Transactions on Power Delivery, Vol. 13, pp. 218–224, 1998.

[19] R.E. Brown, Electric Power Distribution Reliability, New York, Marcel Dekker, 2002.

[20] K. Alvehag, L. Soder, "A reliability model for distribution systems incorporating seasonal variations in severe weather", IEEE Transactions on Power Delivery, Vol. 26, pp. 910–919, 2011.

[21] A.A. Chowdhury, D.O. Koval, "Current practices and customer value-based distribution system reliability planning", IEEE Transactions on Industrial Applications, Vol. 4, pp. 1174–1182, 2004.

[22] F. Soudi, K. Tomasovic, "Optimal trade-off in distribution protection design", IEEE Transactions on Power Delivery, Vol. 16, pp. 292–296, 2001.

[23] L.G.W. Silva, R.A.F. Pereira, J.R.S. Mantovani, "Optimised allocation of sectionalizing switches and protection devices in distribution networks by using reactive tabu search algorithm", 18th International Conference on Electric Distribution, 2005.

[24] L.G.W. Silva, R.A.F. Pereira, J.R.S. Mantovani, "Optimized allocation of sectionalizing switches and control and protection devices for reliability indices improvement in distribution systems", IEEE/PES Transmission & Distribution Conference & Exposition, 2004.

[25] M. Zangiabadi, R. Fueillet, H. Lesani, M. Kheradmandi, J.T. Kvaloy, A. Helland, "Uncertainty assessment of distribution generation placement in distributed Power", International Review of Electrical Engineering, Vol. 4, pp. 392–398, 2009.

[26] M.D. Catrinu, D.E. Nordgård, "Integrating risk analysis and multi-criteria decision support under uncertainty in electricity distribution system asset management", Reliability Engineering & System Safety, Vol. 96, pp. 663–670, 2011.

[27] X. Fang, J. H. Chow, X. Jiang, B. Fardanesh, E. Uzunovic, A. Edris, "Sensitivity methods in the dispatch and siting of FACTS controllers", IEEE Transactions on Power Systems, Vol. 24, pp. 713–720, 2009.

[28] T.T. Nguyen, V.L. Nguyen, A. Karimishad, "Transient stability-constrained optimal power flow for online dispatch and nodal price evaluation in power systems with flexible AC transmission system devices", IET Generation, Transmission & Distribution, Vol. 5, pp. 332–346, 2011.

[29] T.B. Nguyen, M.A. Pai, "A sensitivity-based approach for studying stability impact of distributed generation", International Journal of Electrical Power & Energy Systems, Vol. 30, pp. 442–446, 2008.

[30] T.B. Nguyen, M.A. Pai, “A sensitivity-based approach for studying stability impact of distributed generation”, International Journal of Electrical Power & Energy Systems, Vol. 30, pp. 442–446, 2008.

[31] J.C. Zapatta, S.D. Kirschen, A.M. Rios, A. Torres, “Modeling of protective system failures to operate for reliability studies at the power system level using stochastic point processes”, International Review of Electrical Engineering, Vol. 5, pp. 311–316, 2010.

[32] J.C. Zapatta, S.D, Kirschen, A.M. Rios, A. Torres, “Reliability assessment of protective schemes considering time varying rates”, International Review of Electrical Engineering, Vol. 4, pp. 1440–1446, 2009.