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Kai Zou
University of Wollongong, kz965@uow.edu.au

Wickramaarachchi W. Keerthipala
University of Wollongong, wkeerthi@uow.edu.au

Sarath Perera
University of Wollongong, sarath@uow.edu.au

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Abstract

Distribution system reliability assessment is an important part of distribution system operation and planning. This paper presents some approaches taken to minimize the SAIDI (System Average Interruption Duration Index) for a remote distribution feeder in an 11kV distribution system. Resulting from unavailability of alternative backup supplies from the other adjacent feeders, distributed generators (DG) can be used as backup supplies in this case. Coordinating distribution automation (DA) system with DGs, the restoration area can be made larger and the outage time can be shorter, consequently, the distribution system reliability can be improved significantly. In this paper, factors affecting SAIDI are discussed and methods including feeder reconfiguration, recloser installation and replacement and DG installation are applied to minimize SAIDI. Comparative studies are performed and related results are addressed.

Keywords

Saidi, minimization, remote, distribution, feeder

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SAIDI Minimization of a Remote Distribution Feeder

Kai Zou, W. W. L. Keerthipala, and S. Perera

***Abstract*— Distribution system reliability assessment is an important part of distribution system operation and planning. This paper presents some approaches taken to minimize the SAIDI (System Average Interruption Duration Index) for a remote distribution feeder in an 11kV distribution system. Resulting from unavailability of alternative backup supplies from the other adjacent feeders, distributed generators (DG) can be used as backup supplies in this case. Coordinating distribution automation (DA) system with DGs, the restoration area can be made larger and the outage time can be shorter, consequently, the distribution system reliability can be improved significantly. In this paper, factors affecting SAIDI are discussed and methods including feeder reconfiguration, recloser installation and replacement and DG installation are applied to minimize SAIDI. Comparative studies are performed and related results are addressed.**

***Index Terms*—Power distribution reliability, power distribution protection, distributed generator.**

I. INTRODUCTION

DISTRIBUTION reliability is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure [1]. Reliability improvement of electric distribution systems has been an object of research efforts over many years. Reliability indices for distribution systems have been defined by several groups to set benchmarks in power system design. The power system design and maintenance programs performed by utilities should depend on the reliability indices in order to improve system reliability effectively. In rural areas, lack of alternative backup supplies from other adjacent feeders is an obstacle to having highly reliable supply in these areas. Building a new interconnection feeder in remote area is quite time-consuming and cost-ineffective due to complex geographical environment. But with the development of distribution automation (DA) and distributed generation (DG), the distribution systems located in rural area can have higher reliability at relatively lower operation and maintenance costs. DGs are flexible to install and cost-efficient to operate and maintenain. DGs can also be regarded as backup supplies during interruptions. Appropriate coordination of DA and DG has great impact on interruption duration and frequency, which is significantly affect the system reliability.

In this paper, some approaches taken to assess the reliability of a remote distribution system quantitatively are discussed. In Section II, a remote distribution feeder under study is introduced and analysed. Factors affecting SAIDI are discussed and approaches to minimize SAIDI including feeder reconfiguration, recloser replacement and DG installation are presented in Section III. Simulation and related results are in Section IV followed by conclusions in Section V.

II. FEEDER UNER STUDY

The distribution feeder to be analysed is an 11kV feeder located in a remote area. The topology of this feeder is shown in Fig. 1. It is assumed that the length of each section is 2km. The feeder sections from 1 to 14 are the main feeder protected by a breaker at the beginning of this feeder. The feeder sections from 15 to 17 are the branch sections protected by a fuse connected at the beginning of their related branch. The feeder sections from 18 to 31 are the extended branch sections representing increasing number of customers in this area. For simplicity, the components such as feeder sections, manual switches and transformers in each section are combined together as one component by using reliability-network-equivalent method [2] and the load points are lumped together in each section. It is also assumed that customers are uniformly distributed and there are 15 customers in each section. This distribution feeder is supplied by an 11kV busbar and no backup supply is available for any section of this feeder resulting from the geographical location of the entire feeder.

III. FACTORS AFFECTING SAIDI

The objective of this paper is to minimize the distribution system reliability index SAIDI for feeder under study. SAIDI can be calculated by using (1) [3]:

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Kai Zou is with the School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Wollongong, NSW, 2522 Australia (e-mail: kz965@uow.edu.au).

W.W.L.Keerthipala is with the School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Wollongong, NSW, 2522 Australia (e-mail: wkeerthi@uow.edu.au).

S.Perera is with the School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, Wollongong, NSW, 2522 Australia (e-mail: sarath@uow.edu.au).

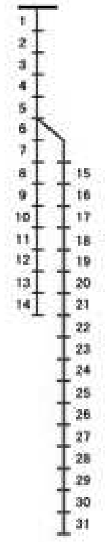

Fig. 1. Topology of the Remote Distribution Feeder

$$SAIDI = \frac{\sum_{i=1}^{T} r_i N_i}{\sum_{i=1}^{T} N_i} \tag{1}$$

where T is the total number of sections, r_i is the outage time for each interruption at i, N_i is the number of interrupted customers for each sustained interruption during the reported period.

To calculate the outage time for each load point in relation to different scenarios during outages, Repair and Isolation Time Matrix (RITM) is used in this paper.

$$RITM = \left[\begin{array}{ccc|ccc} X_{11} & \cdots & X_{1m} & X_{1(m+1)} & \cdots & X_{1(m+n)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mm} & X_{m(m+1)} & \cdots & X_{m(m+n)} \\ \hline X_{(m+1)1} & \cdots & X_{mm} & X_{m(m+1)} & \cdots & X_{m(m+n)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ X_{(m+n)1} & \cdots & X_{(m+n)m} & X_{(m+n)(m+1)} & \cdots & X_{(m+n)(m+n)} \end{array}\right] \tag{2}$$

where X_{ij} is the outage time for section j when there is a fault on section i, m is the total number of main feeder sections and n is the total number of branch sections.

The square RITM can be divided into 4 regions. The top-right region (from X_{11} to X_{mm}) indicates the outage time on main feeder section i for faults on the other main feeder section j. The top-left (from $X_{1(m+1)}$ to $X_{m(m+n)}$) region shows the outage time on healthy main feeder for faults on branches. Similarly, the bottom-left region (from $X_{(m+1)1}$ to $X_{(m+n)m}$) shows the outage time for each branch section when there are faults on main feeder sections and the bottom-right region (from $X_{(m+1)(m+1)}$ to $X_{(m+n)(m+n)}$) indicates the outage time for each branch section when there are faults on the other branch sections. Outage time could be either repair time or isolation time depending on different fault locations, topology and

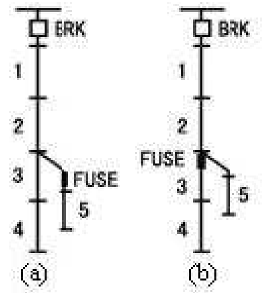

Fig. 2. Topology of a Simple Feeder

TABLE I
RITM FOR THE FEEDER SHOWN IN FIG. 2(A)

Feeder Sections	S1	S2	S3	S4	S5
S1	6	2	2	2	0
S2	6	6	2	2	0
S3	6	6	6	2	0
S4	6	6	6	6	0
S5	6	6	2	2	0

configuration of the feeder and protection scheme [4]. From (1) and (2), SAIDI can be calculated as follows:

$$SAIDI = \frac{\sum_{i=1}^{m+n} (\sum_{j=1}^{m+n} X_{ij} \lambda_i) N_i}{\sum_{i=1}^{m+n} N_i} \tag{3}$$

where λi is the fault rate for section i.

Form (3), it is clear that three parameters (outage time for each section, fault rate for each section and the number of customers) can affect SAIDI directly. Since the total number of customers cannot be changed in this feeder and the inherent characteristics of this feeder makes the fault rate constant over a long-term period [5], therefore, this paper only discusses the factors affecting outage time. Factors affecting outage time are discussed in the following sub-sections:

A. *Feeder Configuration*

The physical feeder topology cannot be changed easily due to high cost and geographical distribution of customers, but different protection schemes can change the configuration of a feeder [6]. For instance, the configuration of the feeder shown in Fig. 2 can be changed by adjusting the breaker setting and removing the fuse installed at the beginning of feeder section 5 to form a new main feeder and a fuse can be installed at the beginning of feeder section 3 to form a new branch. Though feeder configuration can be reconfigured easily, however, the feeder capacity limits and thermal limits should be considered.

It is assumed that the fault rate for each section in Fig. 2 is 0.05 faults per year and there are 10 customers served by each section. The repair time and isolation time is assumed to be 6

TABLE II
RITM FOR THE FEEDER SHOWN IN FIG.2(B)

Feeder Sections	S1	S2	S3	S4	S5
S1	6	2	0	0	2
S2	6	6	0	0	2
S3	6	6	6	2	2
S4	6	6	6	6	2
S5	6	6	0	0	6

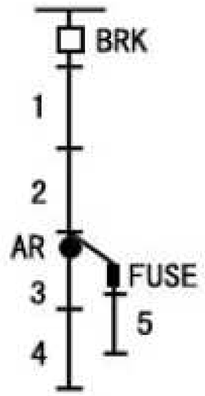

Fig. 3. Topology of a Simple Feeder with AR

hours and 2 hours respectively. The RITMs for Fig. 2(a) and Fig. 2(b) is shown in Table I and Table II respectively. In both tables, the columns are the fault locations and the rows are the related outage time for each section.

The SAIDI for the feeder in Fig. 2(a) is 0.88 hour per year and SAIDI for the feeder in Fig. 2(b) is 0.90 hour per year showing a slight reduction in reliability levels. However, the reconfigured feeder will exhibit improved reliability and hence the SAIDI can be reduced.

B. Protection Scheme

As mentioned above, different protection schemes can change the feeder configuration. Not only that, different protection schemes can also affect the outage time for different feeder sections. A distribution feeder with sufficient DA should be more reliable and the average outage time for a specific period should be shorter. But the cost of implementing DA has a trade-off relationship with the reliability issues. To have relatively higher reliability performance while reducing the capital investment is very important for utilities [7, 8].

An example is illustrated to explain the effect of the protection devices. For the same feeder shown in Fig. 2(a), it is supposed that a new automatic recloser is to be installed at the beginning of feeder section 3 as shown in Fig. 3. In this case, the new RITM is given in Table III and the calculated SAIDI is 0.82 hour per year. The system reliability is improved due to additional automatic recloser. The outage time will be more difficult to determine if large number of automatic reclosers is applied. In Section IV, the effect of different locations and number of automatic reclosers on system reliability will be compared in detail.

TABLE III
RITM FOR THE FEEDER SHOWN IN FIG.3

Feeder Sections	S1	S2	S3	S4	S5
S1	6	2	0	0	0
S2	6	6	0	0	0
S3	6	6	6	2	0
S4	6	6	6	6	0
S5	6	6	0	0	6

TABLE IV
RITM FOR THE FEEDER SHOWN IN FIG. 3

Feeder Sections	S1	S2	S3	S4	S5
S1	6	2	0	0	0
S2	2	6	0	0	0
S3	2	2	6	2	0
S4	2	2	2	6	0
S5	2	2	0	0	6

C. Availability of Backup Supply

In urban area, backup supplies are not considered as a problem due to highly meshed network. But in remote area, where the distribution feeder is far away from the other distribution feeders, the backup supplies from the other feeders become unavailable. To build an interconnection feeder as a backup supply of the existing feeder is expensive and cost-inefficient. In this case, in order to improve system reliability, use of DGs is a good solution. Nowadays, DGs are widely used in load shedding and voltage support in distribution systems. DGs are considered to be reliable backup supplies when part of the distribution system exhibits an outage [7, 8]. Coordinating with DA, the restoration area can be larger and the restoration process can be much faster [10].

Table IV shows the RITM when a DG is installed at the end of feeder section 4 shown in Fig. 3. It is assumed that the capacity of DG is sufficient to supply the whole feeder. Compared with the SAIDI of feeders shown in Fig. 2 and Fig. 3, the value of SAIDI in this case can go further down to 0.5 hour per year, which proves that appropriate installation of DGs can result in better system reliability. More cases about the implementation of DG for the feeder shown in Fig. 1 will be discussed in Section IV and the associated SAIDI values are also calculated in Section IV.

IV. CASE STUDIES

A. Assumptions

To evaluate the reliability benefit of implementing different protection schemes and employing DGs as backup supplies, different comparative studies are conducted. The assumptions behind in various case studies are described as following:

1) Protection Devices: Protection devices including automatic recloser, fuse and circuit breaker are used in case studies. All the protection devices are assumed to be 100% reliable all the time, which means that all the protection devices can trip faults as they are needed. So the fault rate for protection devices is 0 faults per year.

2) Repair Time: Repair time is the time taken to repair or replace the faulted electric components. Repair time can vary depending on several factors such as different faulted electric component, weather condition and fault location. For simplicity, repair time in case studies is assumed to be 6 hours for each faulted section regardless of different conditions.

3) Isolation Time: Isolation time in this paper is defined as the time taken to locate the fault and the time taken to isolate the fault from system. Isolation time also can vary depending on the factors such as travel time, available number of crews, fault location and different types of electric components. In this paper, the isolation time is 2 hours for each section.

4) Fault Rate: Fault rate for each feeder section is assumed to be 0.066 faults per year per km. In this paper, only the fault rate of feeder is considered because only the faults on 11kV feeder sections can affect other healthy sections.

5) Fuse: All fuses are assumed to be installed at the beginning of the branches and they are 100% reliable. It is also assumed that the fuses can only trip the faults located on the branch side and all the fuses have been set and coordinated with other protection devices properly.

6) Automatic Recloser: There are two types of automatic reclosers used in case studies. One is the unidirectional automatic recloser which can only detect the faults located downstream; another is the bidirectional automatic recloser which can detect the faults on both sides. It is assumed that all automatic reclosers can coordinate correctly to isolate the faults as needed.

7) Distributed Generator: In case studies, it is assumed that the capacity of distributed generator is sufficient to supply the whole feeder and the distributed generator can run in islanding mode when required. In this paper, all DGs are only started to supply the feeder sections which are in outage subject to an emergency mode. Due to feeder capacity limit, the DG installed in branch sections can only supply related branch, but distributed generator installed in main feeder sections can supply both main feeder and branch sections.

B. *Comparative Case Studies*

Descriptions of these comparative case studies are shown in Table V. An overall brief description of 6 case studies is as follows:

1) Case 1*:* Number of automatic reclosers is placed along the feeder and the recloser placement has been optimized to minimize SAIDI. The feeder configuration is not changed and DGs are not applied in this case.

2) Case 2 and 3: Number of automatic reclosers and their placement are considered. DGs are introduced in these two cases. One DG is placed at the end of main feeder in Case 2 and one DG is placed is placed at the end of the branch in Case 3.

TABLE V
DESCRIPTION OF CASE STUDIES

Case	Feeder reconfigured	Optimize Recloser Location	Number of Reclosers	DG installation	DG Location
1	—	√	0 - 4	—	—
2	—	√	0 - 4	√	S14
3	—	√	0 - 4	√	S31
4	√	√	0 - 4	—	—
5	√	√	0 - 4	√	S14
6	√	√	0 - 4	√	S31

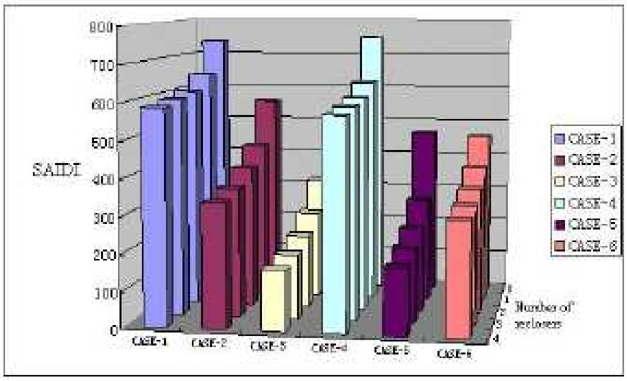

Fig. 4. Results of Case Studies

3) Case 4: The feeder is reconfigured in this case. The fuse at the beginning of feeder section 15 is removed and a new fuse is placed at the beginning of feeder section 6 to form a new branch. Number of automatic reclosers is considered and their placement is optimized.

4) Case 5 and 6: DGs are applied in both two cases for the reconfigured feeder. The difference is that the distributed generator is installed at the end of main feeder in Case 5 while in Case 6 the distributed generator is installed at the end of branch.

C. *Results of Case Studies*

The results of 6 comparative case studies are illustrated in Fig. 4. It is noticed that if the feeder is reconfigured with automatic reclosers or DGs, the system reliability will become worse for this feeder. The value of SAIDI will increase slightly, from 737 minutes in Case 1 to 749 minutes in Case 4, if only feeder reconfiguration is applied. Comparing Case 1 and Case 2 with Case 4 and Case 5, it is obvious that the values of SAIDI are reduced if automatic reclosers are placed properly and the DG is installed at the end of main feeder when the feeder is reconfigured. But in Case 3 and Case 6, when the distributed generator is placed at the end of the branch, the value of SAIDI will increase if the feeder is reconfigured.

It is also obvious from Fig. 4 that the value of SAIDI decreases with the increase of the number of automatic reclosers. But the rate of decrease of SAIDI becomes smaller when the number of automatic reclosers is increased. Consequently, it is suggested that the utilities should consider a tradeoff between capital cost and reliability improvement.

In comparative case studies, it is indicated that Case 3 gives the best results. Even when no automatic recloser is applied, the maximum value of SAIDI in Case 3 can be half of the value in Case 1. If 5 automatic reclosers are installed, the value of SAIDI can reach its lowest value of 164 minutes. Similar values are obtained for Case 5.

V. CONCLUSIONS

This paper presented some approaches for the SAIDI minimization of a remote distribution feeder in an 11kV distribution system. The approaches are based on the reliability-network-equivalent model in which the impacts of feeder configuration, automatic recloser placement and distributed generator application are included in the analysis. The factors affecting system reliability were also indicated in this paper. Comparative case studies are performed to evaluate the system reliability improvement by using different methods. The study results illustrated in this paper indicate that the system reliability is improved by applying a distributed generator as a backup supply. Coordinating automatic recloser with distributed generator, the system reliability can be further improved. In this paper, DG was assumed to be completely defined. However, future research is required in optimizing the location and sitting of different types of distributed generators.

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