Effects of Distribution Automation on Distribution System Reliability

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***Abstract*-Distribution automation (DA) has great effect on improving distribution system reliability when the reliability of power supply reaches a certain high level. The application of DA schemes in distribution system is mainly aimed at fast and precise detecting and handling of fault, to narrow fault coverage and shorten fault outage time,thereby enhancing the quality and reliability of customers. The effects of four kinds of DA schemes on distribution system reliability are compared and presented in this paper. The contribution of this paper is to provide quantitative measures of the reliability impacts of DA schemes, comparative case studies are conducted on a typical wiring method in real systems.**

***Keywords*-Distribution automation schemes, power distribution system, reliability.**

I. Introduction

In the condition of electric market, reliability plays an important role upon competitiveness of electric utilities. These may result in that utilities have to provide good quality of power to attract the customers and that can be realized by the distribution automation (DA). Analysis of the customer failure statistics has shown that distribution system makes the greatest contribution to the unavailability of power supply to customers[1], due to radial configuration of feeders and high failure rates in equipments and feeder sections.When the reliability of power supply reaches a certain level, DA is necessary and can greatly help improve the distribution system indices, including System Average Interruption Frequency Index(SAIFI),System Average Interruption Duration Index (SAIDI) and Average Service Availability Index（ASAI), etc.

DA has attracted significant attention from both industry and research facility. Much effort has been devoted to investigate this problem from many different aspects. Ref. [2] investigated that when fault indicators were applied to distribution systems, how it can improve distribution reliability. It was early in the lower level of distribution automation. In 1980s, the advanced feeder automation system [3] based on intelligent equipment such as auto-reclosers and sectionalizers were developed. For its advantages, it has already been implemented broadly in China [4][5]. After that, with the development of communication, a new feeder automation system based on FTUs (Feeder Terminal Units) and communication network was presented in recent years. Ref. [6] presented a feeder automation system based on substation automation platform that had be applied to electrical distribution systems in Viet Nam. Improved reliability was evaluated when applied it with high economic-technical efficiency. Ref. [7] proposed a distribution feeder automation control method based on smart distribution feeder terminal units and more details can be found in Ref. [8]. Ref. [9] studied a fault diagnosis schemes based on the combination of two different DA programs, which were the centralized control method of fault management and the smart distribution feeder terminal unit control method of fault management.

Although many methods and works have been presented in the articles for developing the DA to improve reliability of power supply, but always there has been a lack of well materials associate with the reliability impacts of these automation schemes. Considering this phenomena, this paper provides a comparison about the efforts of different DA schemes on the distribution system reliability. In this paper, we gather information about typical DA systems, as well as real-world reliability parameters and capital costs of equipments. Therefore it can get realistic results of cost and reliability analysis.

This paper is organized as followings: the reliability evaluation procedure is introduced in Section II. Then the results of comparative case studies which have been conducted on a typical wiring method are presented in Section III. Conclusions are given in Section IV.

II. Reliability Evaluation Procedure

A. Reliability evaluation algorithm

In the program we adopt the Failure Mode Effect Analysis (FMEA) method as introduced in [1], which is a very useful and effective reliability evaluation method in distribution system. It is an inductive method to identify and analyze all possible modes of each component, including simple failure modes, faulty operation modes, the influence of system, the surrounding components and customers. Considering the actual situation of distribution network, FMEA ignores the constraint of power flow and voltage,mainly focus on connectivity in distribution system reliability evaluation. These assumptions mainly aim to reduce computation overhead from power flow analysis and consider other

TABLE I
BASIC DATA FOR DISTRIBUTION SYSTEM

Feeder Number	Length (km)	Number of Customer
1	2	250
2	3	100
3	1	50
4	2	250
5	3	100
6	1	50

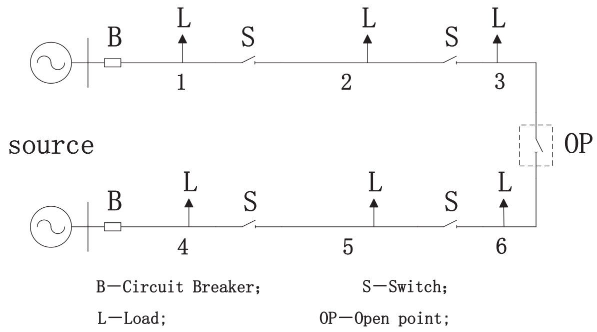

Fig. 1. DA schemes mode 1

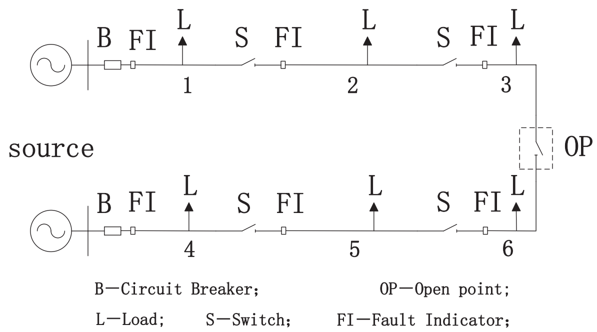

Fig. 2. DA schemes mode 2

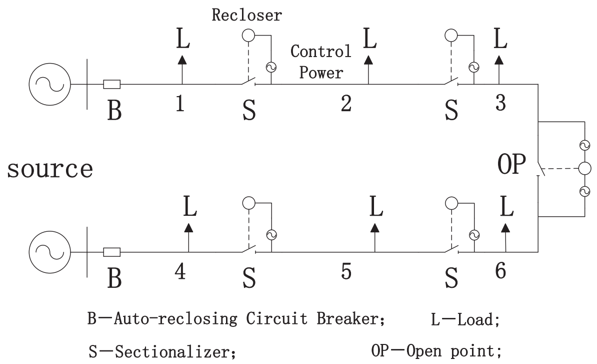

Fig. 3. DA schemes mode 3

random factors such as weather, operation condition and so on.

B. Typical DA schemes for distribution system.

In this paper, we use the “hand in hand” wiring method, which is common in actual projects, to assess the impact on system reliability of different DA programs. Fig. 1 shows the single-line topology of the test system.

In order to assess the reliability performance of the test system when different levels of DA are employed, the following cases are considered in the analyses:

1. Case 1: No automation schemes

The elementary case which proposes to show the reliability performance of the test system that there is no automation applied for the network. In this situation, when a component failed, customers affected by the failure called for repairment. Then repair crews went to the fault area. They began patrol from tripping circuit breakers along the distribution lines to find the fault sections. After that, through the proper switching actions, the faulted section was isolated and the power service was restored for other healthy sections of the network. By the time these tasks were accomplished, the precise fault location and the repair or replacement activities were carried out. Finally, the network returned to its normal operating status [10].

2. Case 2: The fault location schemes based on fault indicators

This program can be divided into two types depending whether the fault indicators have remote communication function, the case considered in the article is the simple one(Mode 2). When a shortcircuit or an earth fault occured on overhead lines, fault indicators on the fault line would flipped or flashing from substation to the fault point to indicate the failure sections. However, fault indicators on non-fault lines, non-fault branches and the sections downstream the fault point had no change. Then repair crews starting from the substation, along fault lines, to the section between the last

TABLE II
RELIABILITY DATA FOR DISTRIBUTION FEEDER

	Failure Rate 1/(yr•100km)	Repair Time (h)	Maintenance Rate 1/(yr•100km)	Maintenance Duration (h)	Time required for fault notification and location (Seconds)	Time required for switching (Seconds)
Feeder	8.36	3.012	10.75	6.047	--	--
Case 1	--	--	--	--	3600	1800
Case 2	--	--	--	--	1800	1800
Case 3	--	--	--	--	1200	600
Case 4	--	--	--	--	300	60
Case 5	--	--	--	--	24	12

flipped or flashing fault indicator and the first no reaction fault indicator. Obviously, this is the fault section. This method can quickly determine the fault sections, branches and points, help saving a lot of time for power healing.

3. Case 3: The feeder automation schemes based on temporal coordination of switches

The feeder automation system based on temporal coordination of switches consist of mast switches , sectionalizers and auto-reclosers installed on feeders(Mode 3), as shown in Fig.3. When a failure occurred in distribution system, this scheme worked on each feeder. The logical actions were formed by detecting the variation of fault current and voltage. Then the fault records, location and isolation of faulted feeder sections can be realized automatically after the coordination of reclosers and sectionalizers, and finally achieving the non-fault zones' power supply in distribution system through network reorganization. As a result, repair crews can be sent directly to the faulted area and carrying out precise fault location and repair activities. As a result, the network returns to its normal status.

The whole process does not need the participation of communication and master / sub-station systems, at the same time, it realizes faster troubleshooting process.

4. Case 4：The centralized control schemes based on DA master stations

In centralized control systems based on DA master stations, master station is the core of the whole project (Mode 4), as shown in Fig.4. As the control center, which relies on communication, can achieve global network's data acquisition and control through the real-time data provided by Supervisory Control and Data Acquisition (SCADA) systems. When a failure occured, FTUs would send fault information to the master station. Based on the switch status, fault monitoring and network topology analysis, master station would determine the fault sections and issue remote control commands to achieve fault isolation and recover power supply of nonfault zones, this is what people called " three remote control system ".Throughout the troubleshooting process by remote control, switches take only one action for fault isolation and nonfault zone power restoration.

5. case 5：The local control schemes based on smart distribution feeder terminal units

The local control systems based on smart distribution feeder terminal units exchange data by FTUs to realize communication and do not need the participation of DA master stations and sub-stations (Mode 5). The core of this technical scheme is the smart terminal units. Fig.5 shows the mode.

As the management of some little faults could conduct not only depend on a single "smart" center of master stations, even SCADA communication was broken, power failure handling and restore process would not be affected. When this scheme was used for loop network or radial feeders, breakers (reclosers) can be used on the lines. Breakers (Reclosers) can perform automatically through the cooperation of smart distribution features of FTU and without communication network. Due to breakers (reclosers) have the capacity to cut down short circuit current, matched with protection, it will effectively reduce the action number of substation export, which can significantly shorten fault handling time.

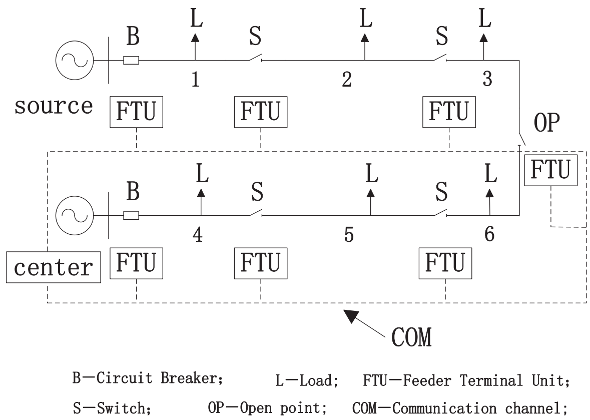

Fig. 4. DA schemes mode 4

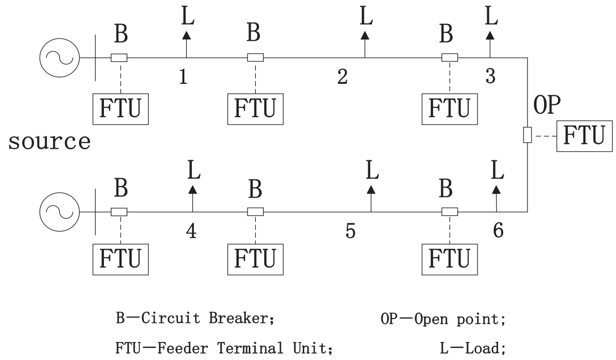

Fig. 5. DA schemes mode 5

III. Study Results

The reliability data can be found in Table I. The basic data required for different DA schemes in the above described are assumed according to Table II. They are from real-world components or engineering judgments by experts, so the results of reliability analysis have a lot of realistic significance.

Reliability studies of the above described DA schemes are mainly on the effects of overhead line faults. Therefore, other components of the test system are considered fully reliable.

Figs. 6–9 respectively show the system reliability indices of the test system for different case studies. As expected, when employing DA schemes, the reliability of the test system is greatly improved. What's more, these improvements are more prominent when applying more sophisticated DA schemes.

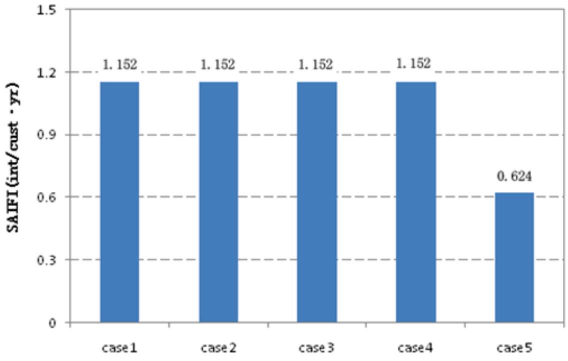

Fig. 6. Variation of SAIFI in different cases

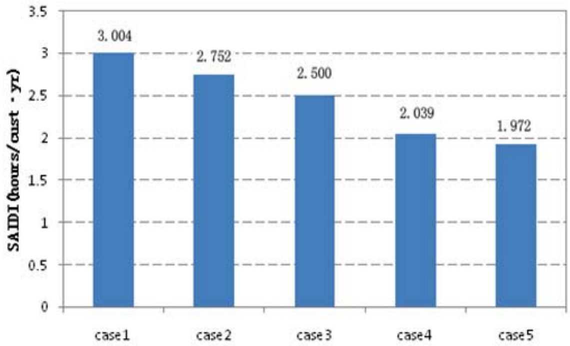

Fig. 7. Variation of SAIDI in different cases

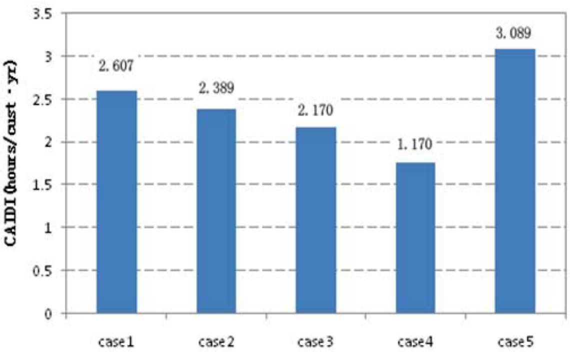

Fig. 8. Variation of CAIDI in different cases

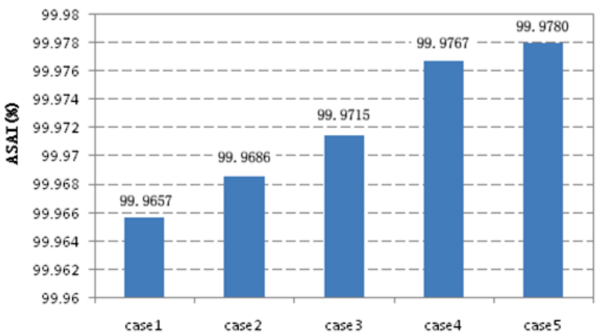

Fig. 9. Variation of ASAI in different cases

Fig 6 clearly shows that when employed the first three schemes, it has no effect on SAIFI. However, case 5 has a significant impact on reducing system interruption frequency. As in the first four schemes, fault on any section will result in power outage of the whole line, in case 5, fault isolation and recovery can be completed without the entire line outage when a fault occurs on the section behind.

Fig 8 reflects the average interruption duration of customers. As it is described, DA schemes all improve this index in case 2-4, but when applied case 5, the value increase a lot, even higher than the base case. It is an interesting phenomenon. The reason of this phenomenon is that case 5 can significantly help reduce system outage frequency; however, the corresponding outage time is not reduced proportionally, so it results in the increase of CAIDI.

IV. CONCLUSION

This paper present four typical DA schemes applied in distribution systems, as well as a comparison of their effects on reliability of the electric power distribution systems.

The results of case studies show that employing either DA schemes can improve the reliability of the test system .The indices of SAIFI and ASAI are gradually enhanced with the improvement of DA level.At the same time,compared with the first three DA schemes, case 5 scheme is proved more effective. It can reduce both frequency and duration of customers. However,when employing case 5,CAIDI gets very terrible ,it has relationship with the structure of network , the type of load and so on. These discoveries may offer a better understanding about these DA schemes' contribution to distribution system reliability and have a certain significance for projects in the future.

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