

APPLICATION OF PULSE CLOSING TECHNOLOGY FOR AUTOMATIC LOOP RESTORATION

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ABSTRACT

This paper aims to quantitatively evaluate and compare the reliability impact of employing an automatic loop restoration scheme in a typical distribution system, with and without pulse closing technology. Sustained interruptions, momentary interruptions and voltage sags are the three major attributes of the service reliability that are taken into account in the reliability case studies.

INTRODUCTION

There are a large number of solutions available to electric utilities for distribution system reliability improvements. These solutions have various impacts on the reliability of the electric power delivered to the customers. Sustained interruptions, momentary interruptions and voltage sags are three major attributes of the service reliability. A sustained interruption refers to the situation where the electric service is interrupted for a long period of time, normally for a time greater than 1 minute [1]. A momentary interruption is a brief disruption in the electric service, usually lasting no longer than a few minutes. The maximum duration of a momentary interruption varies from utility to utility, but is typically between one and five minutes [2]. A voltage sag is defined as the decrease in the RMS voltage between 10 to 90 percent of the nominal voltage for durations from 0.5 cycles to 1 minute [1]. Voltage sags that can cause problems for sensitive equipment usually originate from faults within the transmission and distribution systems [3]. The occurrence of voltage sags is far greater than the number of interruptions. Hence, for specific customers, the financial losses caused by voltage sags may be significant.

Automatic loop restoration schemes (ALRS) are employed in electric power distribution systems to perform fault detection, isolation, and service restoration activities sequentially and automatically, so as to improve the service reliability. There are several approaches available to electric utilities for developing an ALRS. Generally, the midpoint switching devices in each feeder and the normally open switching devices connecting neighboring feeders are retrofitted to establish an ALRS. Following a fault scenario in the distribution network, the

local information is gathered and analyzed by the smart switching devices and appropriate open/close commands are issued in order to isolate the faulted section and restore the service to as many as possible of the affected customers. Normally the operating logic of conventional ALRS involves a fault re-ignition process in order to test for faults. This creates thermal and mechanical stress on all the distribution system equipment that carries the fault currents. It also produces voltage sags affecting sensitive customers [4].

There are two basic strategies to overcome the fault re-ignition issue involved in the operating logic of conventional ALRS. The first solution is to provide a communication link between the smart switching devices. In this situation, the status of smart switching devices and their local information are made available to the related automation units via a communication link and hence the blind switching operations are prevented. However, this solution may not be viable in some circumstances, due to costs associated with the communication link and also possible operational failure affecting the operating logic of the implemented ALRS [5]. The second solution is to use smart switching devices based on the pulse closing technology. This solution is mostly suitable for cases where employing a communication link is not justifiable or is technically problematic. Pulse closing injects a low energy current pulse into the circuit to determine if the fault has been cleared. By not closing into an existing fault, short circuit current surges that stress the circuit and components are greatly reduced [6].

This paper aims to quantitatively evaluate and compare the effects on the major attributes of service reliability when employing an ALRS in a typical distribution system, with and without pulse closing technology.

OPERATING PRINCIPLES OF ALRS

A power distribution network is schematically shown in Figure 1. Each feeder consists of a set of sections with load-breaking switches, normally in the Ring Main Unit (RMU) arrangement. Each feeder is connected to one or more feeders through normally-open RMUs. Any fault on a section causes the feeder circuit breaker to operate. After the fault has been located, the faulted section can be isolated from the healthy part of the feeder using the

relevant sectionalizing switches. The circuit breaker and/or the normally-open switching device(s) are then reclosed. This procedure allows the restoration of as many disconnected load points as possible to the main supply or to another feeder through normally-open RMUs.

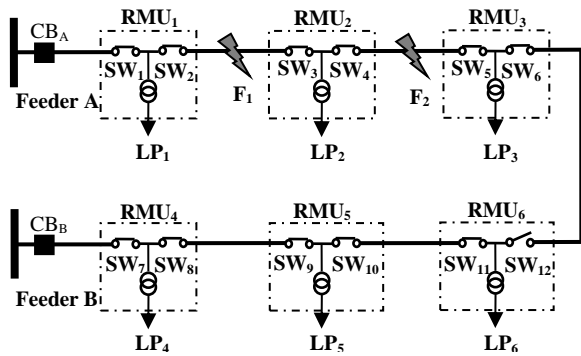


Figure 1: Typical configuration of a power distribution network.

The above operations can be performed automatically when an ALRS is employed in the distribution network. In a case where employing a communication link is not justifiable or technically problematic, an ALRS can be tuned to operate based on predefined roles and some local information. For illustration purposes, consider the typical distribution network shown in Figure 1. RMU₂ and RMU₆ can be retrofitted to provide an automatic loop restoration strategy for Feeder A. In this case, SW₄ and SW₁₂ are replaced with appropriate switching devices with fault breaking capability. Automation units are installed at RMU₂ and RMU₆ in order to gather the local information and operate the switching devices. When a fault occurs somewhere between feeder circuit breaker CB_A and RMU₂, e.g. F₁, the fault condition is detected by CB_A and hence this switching device operates to interrupt the fault current. As a result, the power service for all the customers supplied by RMU₁, RMU₂ and RMU₃ (i.e., LP₁, LP₂ and LP₃) is interrupted. At the same time, the automation unit of RMU₂ detects the loss of voltage condition on both sides of RMU₂ and the automation unit of RMU₆ detects the loss of voltage condition at one side of RMU₆. After some short time delays, the automation unit of RMU₂ issues an opening command to the switching device SW₄ and the automation unit of RMU₆ issues a closing command to the switching device SW₁₂. The time delays are such adjusted so that SW₄ opens before SW₁₂ goes to the closed position. As a result, the fault is isolated from the rest of feeder and the service is restored for load point LP₃ within a short period of time.

When a fault occurs somewhere between RMU₂ and RMU₆, e.g. F₂, the fault condition is detected by the automation unit of RMU₂ and hence it operates SW₄ to interrupt the fault current. Consequently, the power service is only interrupted for the customers supplied by

RMU₃ (i.e., LP₃). The automation unit of RMU₂ detects the loss of voltage condition on one side of RMU₂ which has been followed by a fault current condition. Therefore, it locks SW₄ in the open position. Similar to the previous case, the automation unit of RMU₆ detects the loss of voltage condition at one side of RMU₆ and accordingly issues a closing command to the switching device SW₁₂. This switching operation re-ignites the fault condition, which is detected by the automation unit of RMU₆. Consequently, an opening command is issued to SW₁₂ and it is locked in the open position. As a result, the fault is isolated from the rest of feeder and the service remains available for the load points LP₁ and LP₂.

The loss-of-voltage closure command by the automation unit of the normally-open RMU could cause the fault to be momentarily placed on the other healthy feeder. This creates thermal and mechanical stress on all the distribution system equipment that carries the fault currents. It also produces voltage sags affecting sensitive customers. This concern can be prevented by employing the pulse closing technology in the normally-open RMU. In this situation, a low energy current pulse is injected into the circuit to determine if the fault has been cleared. Pulse closing is accomplished by a sub-cycle close-open of the switchgear contacts. In fact, the contacts are closed for less than 2 milliseconds. Current flow is established as the contacts close, but the contacts open before the first current zero crossing, at which time the current flow is extinguished [6].

TEST NETWORK AND CASE STUDIES

A typical 20 kV distribution network is used in this paper as a distribution test network for quantitative reliability assessment studies. The single-line diagram of the distribution test network is shown in Figure 2. There are 144 distribution substations (20/0.4 kV) in this network, which are supplied through 6 feeders originating from a sub-transmission substation (110/20 kV). The peak load of the system is about 9.4 MW. More detailed information related to the distribution test network and the typical fault management activities which are carried out following a fault in this network can be found in [7].

In order to compare the impact of the above described ALRSs on the reliability performance of the distribution test network, the following case studies are considered:

- **Case 1:** The distribution test network is operated manually.
- **Case 2:** An ALRS without pulse closing technology is implemented in the distribution test network.
- **Case 3:** An ALRS with pulse closing technology at normally open RMUs is implemented in the distribution test network.

In this paper, only faults at 20 kV level of the test system are taken into account. It is also assumed that all the sections have been equipped with local fault passage indicators. When employing an ALRS in the distribution test network, it is assumed that substations 7, 9, 12, 17,

26, 42, 90, 117, and 134 are selected for upgrading. The loop restoration time is assumed to be 40 seconds for both Cases 2 and 3. When employing pulse closing technology in Case 3, it is assumed that the duration of fault re-ignition process is limited to a half-cycle. The overall susceptibility of the customer equipment against voltage sags is represented by the ITIC (CBEMA) voltage tolerance curve.

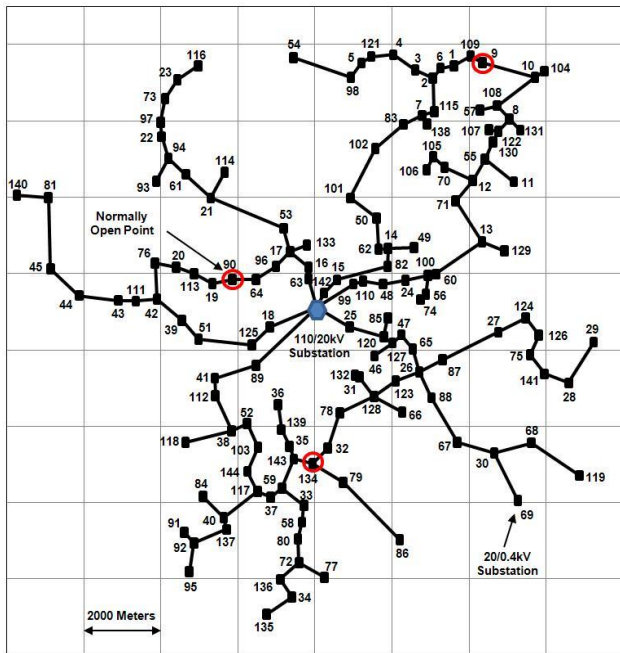


Figure 2: Single-line diagram of a typical 20 kV distribution network which is used as a test network.

STUDY RESULTS

The case studies concerned in this paper have been evaluated using a software package referred to as the “Smart Grid Simulator (SGS)” which has been thoroughly reported in [7]. The system oriented reliability indices of the distribution test network for different case studies are presented in Table 1.

As can be seen from the results presented in Table 1, the service reliability is improved when an ALRS is implemented in the test system compared to the base case study (Case 1). Comparing the results shows that virtually all the reliability indices associated with the sustained interruptions (i.e. SAIFI, SAIDI, ASUI, EENS and ECOST^{SI}) are improved when employing either one of the targeted ALRSs. On the contrary, the reliability indices associated with the momentary interruptions (i.e. MAIFI and ECOST^{MI}) show some deterioration when compared to the base case study without an ALRS. This is mainly due to the operational logic of the implemented automation schemes. When employing either one of the targeted ALRSs, the distribution substations located downstream from the midpoint automatic switching devices see a momentary interruption when a fault occurs

upstream of these switching devices. However, in the base case study, such a fault normally leads to a sustained interruption for these customers. Therefore, when employing an ALRS, the reliability indices associated with the sustained interruptions are improved at the cost of an increase in the momentary interruptions.

The study results indicate that employing ALRS with and without pulse closing technology have almost the same impacts on the reliability indices associated with the sustained and momentary interruptions. However, as shown in Table 1, the reliability indices associated with the severe voltage sag events (i.e. AVSSI and ECOST^{VS}) are improved when employing an ALRS based on the pulse closing technology. This is because of employing a low energy current pulse for the fault checking process involved in the operating logic of the implemented ALRS. As such a short duration injected current cannot lead to a severe voltage sag event for the customers, the AVSSI and ECOST^{VS} indices are improved when employing an ALRS based on the pulse closing technology. It should be noted that the AVSSI and ECOST^{VS} indices only count those voltage sag events which lead to a problem for the customer operations. Actually, when calculating these indices, a voltage sag event observed at the customer site is compared against its voltage tolerance curve. It is counted as a severe voltage sag event only when it occurs in a problematic region of this curve.

Table 1: Test system reliability indices for various case studies

Reliability Index	Case 1	Case 2	Case 3
SAIFI (int/sub-a)	0.2987	0.1669	0.1669
SAIDI (h/sub-a)	0.9140	0.5320	0.5320
MAIFI (eve/sub-a)	0.0065	0.0763	0.0760
AVSSI (eve/sub-a)	0.0950	0.1404	0.1108
ASUI (%)	0.010434	0.006073	0.006073
EENS (kWh/a)	5794	3420	3420
ECOST ^{SI} (€/a)	147725	86056	86056
ECOST ^{MI} (€/a)	111	1383	1376
ECOST ^{VS} (€/a)	1657	2365	1894
Total Cost (€/a)	149494	89804	89326

SAIFI: System Average Interruption Frequency Index
 SAIDI: System Average Interruption Duration Index
 MAIFI: Momentary Average Interruption Frequency Index
 AVSSI: Average Voltage Sag Severity Index
 ASUI: Average System Unavailability Index
 EENS: Expected Energy Not Supplied
 ECOST^{SI}: Total expected cost resulted from sustained interruptions
 ECOST^{MI}: Total expected cost resulted from momentary interruptions
 ECOST^{VS}: Total expected cost resulted from voltage sags
Note: When calculating the reliability indices associated with momentary interruptions and voltage sags, an aggregation window equal to 5 minutes has been applied.

The results of the above comparative case studies clearly show the superior reliability impact of an ALRS with pulse closing technology over a conventional ALRS without such technology. The main origin for this development was the possibility of avoiding fault re-ignition when restoring the loop. When performing the above case studies, it was assumed that the pulse closing based switchgears are fully reliable. This assumption may not be correct. There is always the chance that a device which is required to perform specific tasks in response to an abnormal condition fails to function properly. In order to evaluate the reliability impact of an operational failure in an ALRS with pulse closing technology, an additional study has been conducted for this automation scheme. The results of this study are represented in Table 2. In this study, it has been assumed that, with a certain probability, the pulse closing based switching devices fail to detect the fault condition correctly and hence close into the fault.

As can be seen from the results presented in Table 2, with an increase in the operational failure probability of pulse closing based switchgears, only the reliability indices associated with the voltage sag events deteriorate slightly. All the reliability indices associated with the sustained and momentary interruptions remain almost unchanged. Comparing the results presented in this paper with similar reliability case studies conducted in [5] show that employing the pulse closing technology for developing an ALRS can result in almost similar reliability improvements as those when implementing an ALRS based on the communication link. In addition, this automation scheme is much less sensitive to the operational failure of its advanced technologies. Therefore, an ALRS based on pulse closing technology can be a suitable alternative for cases where employing a communication link is not justifiable or is technically problematic.

Table 2: Test system reliability indices for different operational failure probabilities of the pulse closing based switchgears

Reliability Index	Fully Reliable	5%	10%	15%
SAIFI (int/sub-a)	0.1669	0.1669	0.1669	0.1669
SAIDI (h/sub-a)	0.5320	0.5320	0.5320	0.5320
MAIFI (eve/sub-a)	0.0760	0.0760	0.0760	0.0761
AVSSI (eve/sub-a)	0.1108	0.1123	0.1137	0.1152
ASUI (%)	0.006073	0.006073	0.006073	0.006073
EENS (kWh/a)	3420	3420	3420	3420
ECOST ^{SI} (€/a)	86056	86056	86056	86056
ECOST ^{Mt} (€/a)	1376	1377	1377	1377
ECOST ^{VS} (€/a)	1894	1918	1941	1965
Total Cost (€/a)	89326	89350	89374	89398

CONCLUSION

Employing ALRS for distribution service reliability enhancement has always been an attractive solution for electric utilities. Conventional ALRS improve the reliability indices associated with sustained interruptions at the cost of deterioration in the reliability indices associated with momentary interruptions and voltage sags. Developing an ALRS based on a communication link or pulse closing technology can result in a considerable improvement in reliability performance. In the previous work of the authors, the reliability impacts of employing an ALRS based on the communication link were analyzed. In this paper, the reliability case studies were concentrated on the application of pulse closing technology for developing an ALRS. The results presented indicate the benefits of employing an ALRS based on the pulse closing technology. It can almost result in reliability improvements similar to those when employing an ALRS based on a communication link. Its operating logic is also less sensitive to the operational failure of the implemented pulse closing technology and hence has much less service reliability impact compared to communication failure in the case of an ALRS relying on a communication link.

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