Smart Auto-Reclosing Algorithm in Substations with Breaker-and-a-Half Configuration

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Abstract — ***The number of substations with breaker-and-a-half configuration have significantly increased over the last decades due to their flexibility and high reliability. When the line-breaker is in maintenance, the electricity is supplied through the middle-breaker. When a fault occurs on the line during the previous operating state, the fault is isolated by opening the middle-breaker. However, there is no auto-reclosing algorithm implemented to automatically reclose this middle-breaker, and continue the normal operation of the system. Therefore, this paper introduces an effective, and implementable algorithm for auto-reclosing the middle-breaker in a substation with breaker-and-a-half configuration, when the line-breaker is in maintenance. The control algorithm uses only binary signals from both switches on both the line-breaker and the middle-breaker. These signals can easily be obtained in practical implementation considering IEC 61850 protocol. The implementation of the control logic demonstrates its effectiveness on continue the normal operation of the system.***

Index Terms — ***Key words or phrases in the alphabetical order, separated by commas***

1. INTRODUCTION

TWO essential features in power systems operation are the continuity and the reliability, i.e. the correct operation of the system with all its components operating normally. Recent technological advances have improved the reliability of the electricity network. However, in a few cases, certain elements of the power systems may not be available after large disturbances due to the current operation of the system.

Following a temporal disturbance, the auto-reclose (AR) function (ANSI 79) aims to reestablish the power system continuity as quickly as possible. Auto-reclose function works after every disturbance, typically in high voltage (HV) or extra high voltage (EHV). It auto-recloses the line which has been disconnected due to the trip signal sent by the protection device when a fault occurs.

In general, this function closes the line a few cycles after the circuit breaker was opened [1]. This time is called auto-reclose time and can be adjusted by the user.

It is important to notify that this auto-reclose cycle is successful when the system faces a temporary or unsuccessful fault.

Nowadays, a new bus schemes have been developed and produced a new power system protection schemes. For instance, in a breaker-and-a-half substation, the power system protection scheme changes considerably respecting typical schemes - such as single bus, single breaker and numerous others.

For instance, engineers in numerous parts of the world have had to take into consideration the sum of the currents in breaker-and-a-half substations.

One of the most significant reasons to use this bus scheme is the reliability. According to [1] and [2] only the faulted line is isolated in breaker-and-a-half substations. Then the other lines continue delivering power to the power system. In these, it is noticed the high reliability of the bus scheme because of the high probability to deliver energy to the consumers.

In order to protect the power system and to ensure the integrity of the power system, this paper presents a new and practical methodology for the auto-reclose function. This methodology takes into account possible faults in the line and control signals available in the substation. This methodology is based on the possibility to monitor the breakers and switches using IEC 61850 standard for substations automation.

A typical power system, as shown in Fig. 1, is constituted by two or more electric substations, but are most often constituted by hundreds of them. These substations raise or decrease the voltage in order to reduce losses in the transmission line considering that as high as the voltage is, as small as the losses are.

According to [3], these substations can be built with different types of bus schemes, such as: single bus and single breaker; two buses and one breaker; two buses and two breakers; ring bus; breaker-and-a half; and others. It is obvious that each of these arrangements has different methodology to auto-reclose function and consequently different protection schemes.

In [3], the author notices the significant impact of these schemes in protective relaying, because

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the voltage and the current transformer have to be placed in different positions depending of the bus scheme.

Generally, power systems have been analyzed in steady state. However, power systems are exposed to constant perturbations producing the operation in quasi-steady state (QSS) [3], [4]. Two aspects are considered to define the power system as QSS: firstly, the power system is too large and small changes do not impact on it. Secondly, in case of important perturbations, the power system protections will operate correctly and faster to isolate the fault [3].

A real power system has numerous protection devices to isolate different types of faults when these occur. Other function, such as auto-reclose function (ANSI 79), has the possibility to reconnect the faulted line as soon as the fault is isolated.

In [6], the IEEE defines a relay. This can be defined as an electric device designed to cause a contact operation or similar abrupt change in the associated electric control circuits when an input condition is in a prescribed manner and/or after specified conditions are met in the associated circuit control.

The IEEE in [7] also defines a protection relay as a device whose function aims to detect defective lines or apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action.

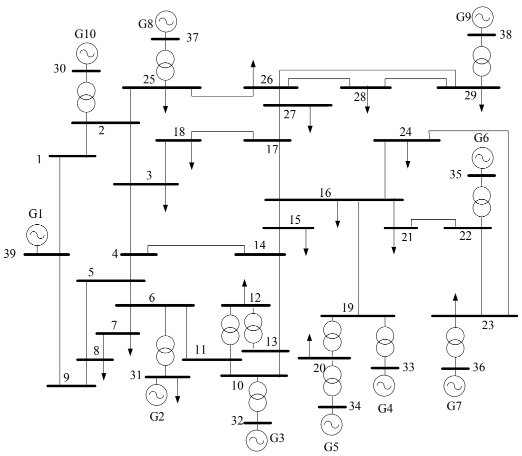

Figure 1. IEEE 39-bus system, an interconnected power system [9]

2. Breaker-and-a-Half Configuration

The breaker-and-a-half scheme is created with a circuit between two other breakers in a three breaker line-up with two buses [1]. There are two buses, but in opposition to other schemes, both buses are energized during normal operation.

This type of scheme is one of the most reliable [1], [2]. In this configuration, only the faulted line is isolated and the other lines continue working.

In Fig. 2, it can be observed the typical arrangement of a breaker-and-a-half scheme. In this figure, it can be noticed a name associated to each element, which will be used later to explain the methodology proposed.

The maintenance is facilitated in this scheme because the entire bus or one breaker can be maintained without transferring or dropping loads.

Relay protection design is a much more complicated and more relays are needed to protect a single circuit. In this scheme, bus and switching devices must all have the same ampacity, since current flow will change depending on the switching device's operating position.

According to [2], this presents more advantages than disadvantages. The most significant disadvantage is the complicated design in protections schemes and the cost of this kind of substations.

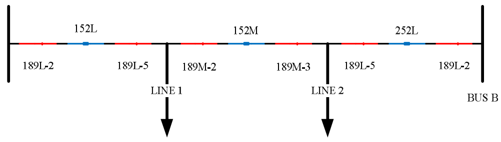

Figure 2. Line diagram for a section of breaker-and-a-half scheme

3. Auto-Reclose Function

Auto-reclose function refers to the ability of the system to close a line as soon as possible when the line was tripped due to a specific disturbance. In other words, this function is used to restore the system to its normal operating configuration. Specifically, the AR function is a property of the protection to restore the line after any momentary disturbance, for example a lightning.

In [3] the authors describe four different types of schemes. The first one scheme considers a high speed reclosing; which means an auto-reclose without delay time. The second takes into account a dead time after the trip signal, frequently cycles or seconds, to dissipate the ionized air and fault arcs. The third considers an auto-reclosing with synchronized measurement. In other words, an auto-reclose with check synchronizing relays to confirm that the two elements of a transmission system are within a given angle and magnitude. The last type of scheme refers to an interlock schemes. This interlock is used when a certain predetermined system conditions or elements are present before reclosing.

4. IEC 61850

IEC61850 is a crucial new international standard to automate substations. It has a significant impact on how electric power systems are now designed and built since this standard was developed. IEC 61850 is a part of the International Electrotechnical Commission's (IEC) Technical Committee 57 (TC57) architecture for electric power systems.

The approach considered by the TC57 standards, including IEC 61850 is innovative and requires a new way of thinking about substation automation. It has resulted in very significant improvements in both costs and performance of electric power systems. This standard is divided in 10 important sections with some subsections [10].

Part 1 and 2 introduce the standard with an overview and a glossary of terms. Chapters from 3 to 5 identify the general and specific requirements for a communication in a substation from a functional point of view. These requirements are then used to identify the services and data models needed.

Section 7 brings the definition of the abstract services and the abstraction of the data objects.

Next sections define the mapping of the abstract data object and services onto the Manufacturing Messaging Specification and onto the Sample Measured Values. Finally a methodology determining the conformance is defined.

5. Proposed Auto-Reclosing Methodology

In this section, a new and practical methodology for the auto-reclose function will be proposed. Nowadays, the current operation of the AR function in the breaker-and-a-half substations consists on auto-reclosing the line breaker (152L in Fig. 3) a few seconds or even milliseconds after the fault and to leave the middle breaker (152M in Fig. 3) open until the manual close is received. In this section, a new and practical methodology will be proposed to solve the issue occurring when the 152L breaker is in maintenance, considering the 152M breaker as a line breaker during line breaker maintenance. We have considered all elements closed to explain the methodology. It has also been considered fiber optic communications in the substation; otherwise this methodology cannot be carried out because other types of communication introduce delays which do not want to be considered in protection issues of the power system.

A. Logic Description

As it can be observed in Fig. 3, the logic proposed is simple and consists on logic gates (AND, OR, inverter and flip flops).

Trip signal is sent from the protection device, possible at a distance protection to open both breakers: 152L and 152M. Moreover, the auto-recloser device (ANSI 79) sends the auto-reclose signal.

As can be noticed, the monitoring of both switches, 189L-2 and 189L-5 for 152L breaker and, 189M-2 and 189M-3 for 152M breaker, is significant. These switches will be monitored using IEC 61850 standard and we will have them available using fiber optic in the entire substation. In general, all switches and breakers are closed. Thus, closed position is checked through an AND logic gate. When all switches are closed, auto-reclose signal is sent to 152L, and when switches 189L-2 and/or 189L-5 are opened, this signal is sent to 152M.

It is evident from Fig. 3 that the auto-reclose signal is sent to both 152L and 152M breakers, however, it is check by an AND gate which also check 189L-2, 189L-5, 189M-2 and 189M-3 position.

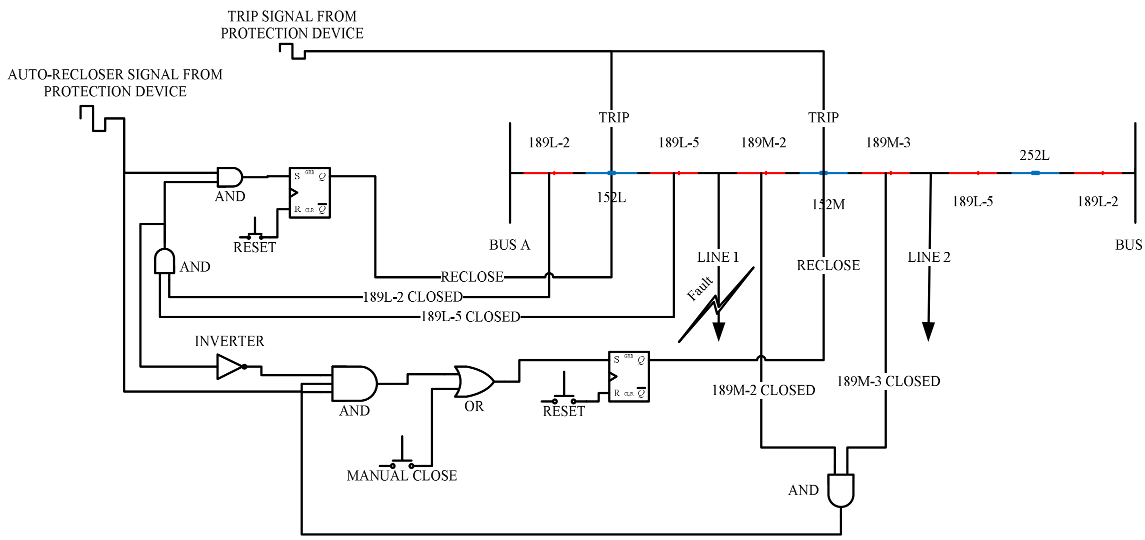

Figure 3. Line diagram for a section of breaker-and-a-half scheme

B. Simulation Description

First of all, it is necessary to notice that the simulations will be made considering a fault in the “Line 1”. When the fault occurs, the trip signal opens both 152L and 152M breakers to isolate it. At this moment, the auto-reclose cycle starts. Milliseconds or seconds later (in our case 400 ms) the breaker (152L or 152M depending on the actual state of the system) is closed due to analog signal sent by the auto-recloser device (ANSI 79).

During a normal operation of entire substation, it is evident that 152M breaker does not auto-reclose after a fault. Then, this breaker has to be manually closed. In this sense, the difficulty starts when the 152L breaker is in maintenance, happening with the power system integrity when the 152L breaker is in maintenance and the 152M breaker must wait to be by manually closed.

According to the text above, it is proposed a new and practical methodology to feed the LINE 1 through the 152M breaker, using this one as a line breaker when the 152L breaker is in maintenance.

According to the methodology proposed, which is feasible to the integrity of the system, to auto-reclose the 152M breaker, it is needed three different signals: (i) auto-reclose signal, (ii) 189M-2 and 189M-3 closed, and (iii) 189L-2 and/or189L-5 opened.

To solve the problem, it is considered that when a breaker will be put in maintenance, the people in charge, who will give maintenance to the breaker, open both switches (in this case, if they operate the 152L, they open 189L-2 and 189L-5). Thus, both contacts will lose the indication of “189L-2 CLOSED” and “189L-5 CLOSED”, and the indication will change to indicate switches opened.

In contrast, 152M will continue operating and the 189M-2 and 189M-3 will be closed. With these combinations, the middle breaker will operate as line breaker.

C. Simulation Results

To prove the validity of the proposed logic, the fault, the auto-reclose and the breakers signals will be shown. Also, the current flows and the voltages will be exposed during the simulations. It is assumed the fault time and the AR time. These simulations have been carried out in Matlab® and Simulink® considering “0’ value as representing inactivated or opened and “1” value represents activated or closed.

C.1 Simulations with 152L Breaker Operating

Figs. 4 and 5 represent the normal operation of the system, i.e. when the 152L breaker is operating. In general, this breaker is closed and the trip signal opens both 152L and 152M breakers. However, the AR signal closes the line breaker and the current flow only through the 152L breaker.

These simulations show that the time duration is 1.5 s and the fault occur at 0.45 s and it is held until the auto-reclose signal is activated at 0.85 s (0.4 s after the trip signal).

Fig. 4(a) represents the trip signal from the protection device, whereas, Fig. 4(b) represents the AR signal sent by the auto-recloser device. It is evident from Fig. 4(c) that the 152L breaker is opened, because of the trip signal, and then it is closed because of the AR-signal. In Fig. 4(d), it can be observed that the 152M breaker is opened because of the trip signal until the manual close is activated (the manual close is not consider in this paper).

From Fig. 4, it can be concluded that the implemented logic works correctly when the system is working without any breaker in maintenance.

Fig. 5 shows the current flows through 152L and 152M and the voltages at BUS A and 152M. According to Fig. 5(a), the current through 152L will be different to zero in the whole case, except when the breaker is opened (from 0.45 s to 0.85 s).

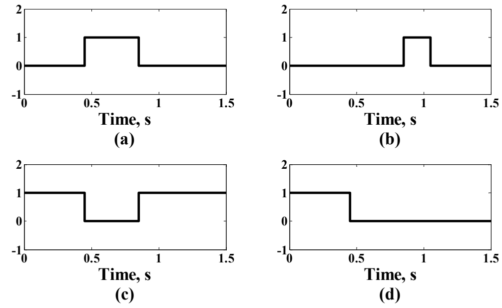

Figure 4. Logic signals when the line breaker is operating. (a) Fault simulated. (b) Auto-reclose signal. (c) 152L breaker position. (d) 152M breaker position.

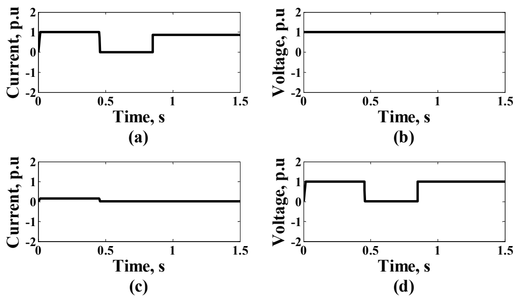

Figure 5. Currents and voltages for the normal operation (a) Current flow through 152L. (b) Voltage at BUS A. (c) Current flow through 152M. (d) Voltage at 152M.

Fig. 5(b) demonstrates that the voltage at the voltage transformer, which is directly connected to the BUS A, is always 1 p.u. It is evident from Fig. 5(a) and Fig. 5(c) that: firstly the line 2 is fed from BUS A and BUS B. After the fault, each circuit is fed by the correspond bus, i.e. BUS A feeds LINE A and BUS B feeds LINE 2. Also from Fig. 5(d) it can be noticed that the voltage at the voltage transformer close to 152M breaker is zero while the line breaker is opened.

C.2 Simulations with 152L Breaker in Maintenance

In these simulations, it is considered that the 152L breaker is opened because it has to be repaired, cleaned or it has low pressure, consequently operator will open both switches 152L-2 and 152L-5. From this assumption, the logic proposed will use the 152M breaker as a line breaker to feed the LINE 1. Fig. 6 shows the logic signal and Fig. 7 the current flows and voltages in the system. From Fig. 6(c) it is evident that the 152L breaker is open because the indication is zero during the simulations. Also, for Fig. 6(d), it is clear that the 152M breaker is working as a line breaker and it receives the auto-reclose signal. In this figure, the middle breaker is open for 0.4 s (time in which the trip signal is active).

Also from Fig. 7(a) and 7(c), it can see that the current flow only flows through the middle breaker.

From these simulations, it is concluded that the proposed logic is working correctly and both configurations will work in order to satisfy the power system integrity.

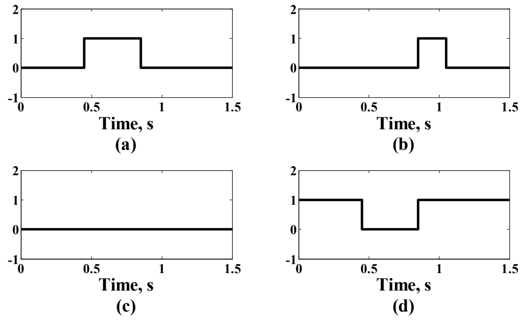

Figure 6. Logic signals when the line breaker is in maintenance. (a) Fault simulated. (b) Auto-reclose signal. (c) Line breaker position. (d) Middle breaker position

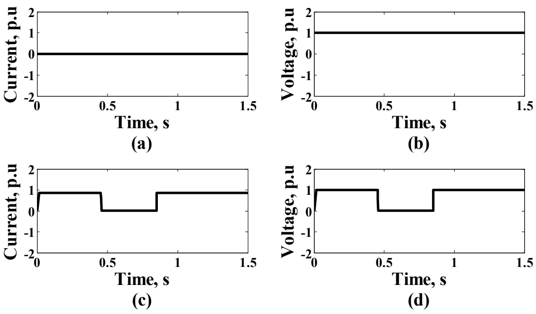

Figure 7. Currents and voltages when the line breaker is in maintenance (a) Current flow through 152L. (b) Voltage at Bus A. (c) Current flow through 152M. (d) Voltage at 152M.

6. CONCLUSION

A new and practical methodology to use middle breaker (152M) as a line breaker (152L) in breaker-and-a-half substations has been proposed. Using Matlab® and Simulink®, the simulations had been carried out using a section of this type of bus scheme. From the simulations, it is concluded that the methodology can be implemented in those bus schemes.

When the line breaker is operating, the auto-reclose signal will be sent to the line breaker and the middle breaker has to be closed manually. In general, it is the most common operation in the system. When the line breaker is operating the middle breaker has to be manually closed, Bus A and Bus B are not synchronized.

Finally it had been proved that when the line breaker is in maintenance or when it faces an issue (e.g. when it has low pressure), the middle breaker can be used as a line breaker. Auto-reclose signal will be sent to the middle breaker to maintain the power system integrity. The only indication needed to use this methodology is the opened condition of the switches (189L-2, 189L-5, 189M-2 and 189M-3). With these parameters, the methodology proposes will use the auto-reclose signal and it will send the signal to the middle breaker. From this condition, the line 1 has to be fed from Bus B because the line breaker is opened and the Bus A is isolate from line 1.

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