Auto-reclose Scheme in a Ring Substation Configuration

G. Gutierrez, W. Hernandez

Abstract-- **auto-reclose schemes are of great importance in Power System control requirements in order to improve the reliability of the energy service given to costumers. Implementing automatic controls to reestablish line connections permits reducing time in respect to manual-close operations, which means that in an automatic reclose of a circuit breaker the time spent is less than a minute. In consequence, the reliability starts increasing.**

It is possible to find several configurations of substations; that is why the application of an automatic reclose system requires different specifications according to the topology of the network and substation. For instance, the single busbar arrangement has only one circuit breaker (CB) to reclose while the ring and breaker-and-a-half configurations involve more than one CB. Particularly, ring substations not only require reclosing two circuit breakers, but also it is necessary to consider several conditions of substation topology so as to avoid problems over power equipment in the substation and the power system.

This paper is focused on describing the different conditions that the auto-reclose scheme of a ring arrangement can consider and how it deals with them. A variety of important apparatus such as transformers and capacitive compensators have a direct influence on the reclose scheme definition. Special scenarios have to be taken into consideration, to name a few, the reclose of a circuit breaker when it connects a line to a transformer; a compensation bank in a ring configuration; and circuit breaker switching onto faults.

Because of the electromagnetic impact produced on the substation's components that is appreciable when an auto-reclose is done, it is a requisite to count on a set of criteria to carry out the automatic reclose scheme in a ring configuration. In this case, our operation experience has shown that the auto-reclose should be avoided when the line's circuit breaker is closed and simultaneously it energizes one of the equipment mentioned above. Thus, this know-how becomes critical to design the scheme.

This research shows criteria, conditions and tests of an automatic reclose scheme in a ring substation at 66 kV. Also, several logics forming control system of the reclose scheme will be illustrated.

Furthermore, results of the scheme tests will be analyzed and conclusions and suggestions will be included.

Keywords: **auto-reclose, ring arrangement, substation, transformer, line, capacitor bank, circuit breaker, cut, sotf.**

I. Introduction

THE ring substation concerned in this study encountered some situations that led technical staff to implement an automatic reclose scheme in their lines so as to reduce their reestablishing time after a fault condition. Before applying this scheme of automatic reclose, the mess substation's sub-transmission lines were manually energized after tripping, which used to cause social issues in the community and fees for disconnected lines when times were too long. Accordingly, a renewal of protection and control system, and a special design of the auto-reclosing scheme took place for this substation. The whole actions derived from this work, made possible to implement a scheme taking care transformers and the capacitive bank compensator which share circuit breakers with overhead sub-transmission lines in the ring substation configuration. In this sense, criteria and block logics of reclosing were proposed and applied based on the substation equipment affection originated at the reclosing moment. Numerous tests were made in order to fulfill both the protection equipment and successful auto-reclose operation objectives. The test results will be depicted and analyzed in respect to the logics implemented in auto-reclosing relays.

Additionally, the automatic reclosing usage brings other advantages expected, apart from lowering reconnection times, such as: reducing impacts over line equipment i.e., overvoltages, overloads and even blackouts; and benefits related to the commercial charges and social issues. Consequently, the contributions of this work are significant for power systems with ring arrangement substations; so that it has also been suggested in other places where the ring configuration is operating.

II. Historical Background

The ring substation configuration under study here is located in the northern region of Colombia. It is formed by six overhead sub-transmission lines sharing circuit breakers with power equipment at 66 kV. This equipment includes four transformers and one capacitive compensator. The lines for the auto-reclose study (marked in pink shade) can be appreciated in the Fig. 1.

This work was supported by ISA INTERCOLOMBIA S.A.
Calle 12 sur 18-168, Medellin-Colombia.
G. Gutierrez is Specialist of Protection Systems at ISA INTERCOLOMBIA (gegutierrez@intercolombia.com)
W. Hernandez is an Analyst of Protection systems at ISA INTERCOLOMBIA,
(whernandez@intercolombia.com)
Paper submitted to the 2016 Texas A&M University Relay Conference, USA, Texas April 6th, 2016.

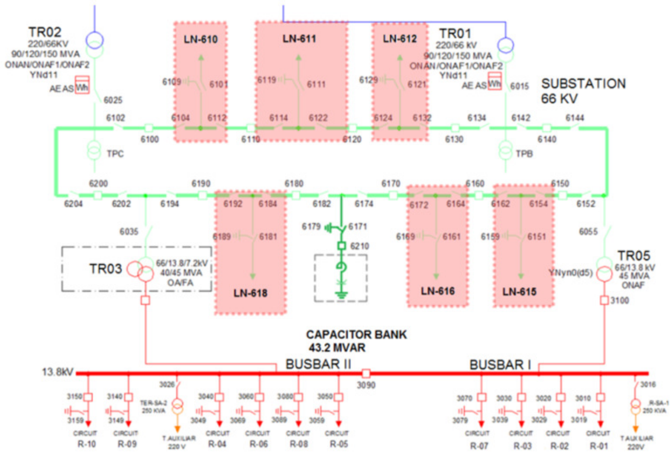


Fig. 1. Ring substation configuration and topology. The squares with pink shade indicate the lines that will be involved in this study.

After several occurrences of events on the lines concerning three pole tripping at both ends, it was necessary to think about reducing reestablishing times since this sort of disturbances generated unconformities for users. For example, social problems came up as a consequence of not restoring electricity after a tripping within expected times. Thus, for the company it was necessary to assess protection system limitations and after that a renovation of the protection system took place. Therefore, auto-reclose relays with capacity for managing two circuit breakers were installed and implemented. All of them were set, configured and tested according to equipment considerations and criteria that will be explained in this work.

III. Equipment Technical Problems Derived from Auto-Reclose

Some issues of equipment that should be controlled are: Radial stress of the windings [1]. This becomes critical when the ratio between inrush current after reclosing and the initial fault current is less than 1. In this case, the risk to destroy windings is increased. This situation should be more critical if a transformer is re-energized under load. Another situation over transformer that should be eluded is the switch onto fault condition by a reclose in failure (sotf) [2]. Mechanical stress reflected on the axial force component becomes accumulative with every reclose in failure which damages the conductor turn insulation. This kind of stress is comparative to square of the fault current. The stress accumulation phenomenon can be lowered if the dead time of reclosing is widened. Shunt capacitor bank compensator is also another equipment exposed to the problems derived from a reclosing condition (success or failure) [3]. If a line reclosing condition is done during a capacitor's de-energizing; its Inrush current could reach twice the normal value. According to IEEE Std. 1036-2010 [4], a capacitor bank should be re-energized after 5 minutes for level above 600 V. In reference [5], transient phenomena during capacitor switching brings two negative effects on the capacitance units: dielectric stress produced by overvoltages; and dynamic, thermal and mechanical stresses because of high inrush current. All of these events affect directly the useful life of this kind of power equipment.

According to this information, some criteria for the auto-reclosing design were formulated in order to protect the power equipment, and some settings for these relays were derived counting on the technical characteristics of the circuit breakers as well. For instance, the ring substation has spring circuit breakers accomplishing the Standard [6] regarding O+300 ms + CO +3 min + CO. Hence, dead times of 60 seconds for reclosing, 180 seconds for reclaim time and one shot were considered in this design.

IV. Criteria to Design of the Auto-Reclose Scheme

There are several standard considerations to design a reclose scheme [7] to achieve a successful reclosing, and be sure that negative impact over equipment and power system will be reduced. Some considerations are: circuit-breaker-ready signal which is supervised by the reclosing relay at the end of the cycle; voltage selection and synchronism check signals, which are monitored by synchronism relays permitting the auto-reclose relay to release the close command. All of these concerns were taken into account beforehand in the present work [8] [9]. Moreover, in respect to the aspects commented on chapter III, other additional conditions required to make the auto-reclose safer will be analyzed to reduce reconnection times and protect equipment of the substation. In this way, some locks will be considered.

To Begin, several specifications and states [10] which are necessary to permit or block an auto-reclose of a line will be depicted.

1) Trips and auto-reclose are held three pole

The ring substation relies on three-pole-command circuit breakers. Thus, only trips and auto-reclose of three phases for any kinds of faults have to be held on auto-reclose relays for this configuration.

2) CUTs considered in a ring substation

The *CUT* term will be employed to define a part of the ring bay. A *CUT* will consist of the three elements in a series connection of their closed position: Disconnector1 AND Circuit Breaker AND Disconnector2. The Fig. 2 shows them.

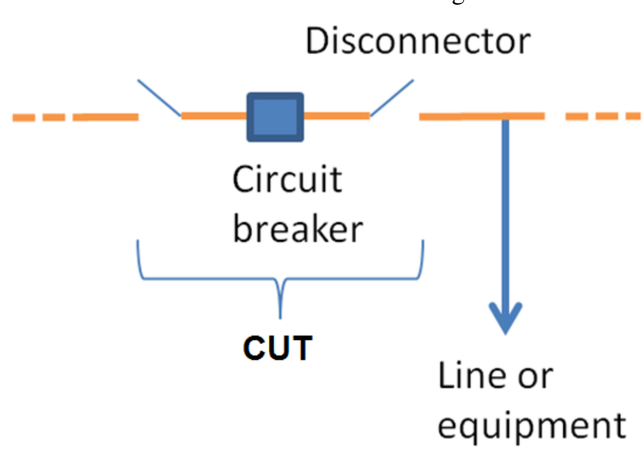


Fig. 2. A *CUT* made up by two disconnectors and one circuit breaker in a ring substation configuration. The series connection of the three equipment positions was also an input to reclosing relays.

As it can be noted, having a disconnector or a circuit breaker opened means that the *CUT* is opened.

3) Automatic reclosing of a circuit breaker (CB) shared between a line and a transformer

This *CB* will not be auto-reclosed before neighbor *CUTs* assure that the transformer has been connected to the ring substation all the time (during pre-fault and fault conditions, and even until dead time for reclosing). In any other case, the successful auto-reclose of a tripped CB will not be possible.

4) Automatic reclosing of a circuit breaker (CB) shared between a line and a capacitor bank

Similar condition to reclose the *CB* described above will be considered here. Previous a fault condition and the whole process to achieve the automatic reclose, the capacitor bank should have been energized at least by the collateral *CUT* in order to allow the auto-reclose of this *CB*. Also, it is possible to accomplish that with an auto-reclose if the compensator's *CB* has already been opened.

5) Automatic reclosing of a circuit breaker (CB) shared between two lines

The reclose over this *CB* becomes critical when a simultaneous fault condition on the two lines takes place. Then, definitive three pole trips of the three circuit breakers involved are issued. In order to decide if reclosing the common *CB*, other studies should be fulfilled especially if this *CB* will be the first one on reclosing. In fact, to permit automatic reclose on the *CB* 6110 (Fig. 1) after disconnecting both lines LN610 and LN611, it was necessary to analyze for a short period how the power system could support the new line shaped by these circuits. Particularly, some simulations illustrated that if the loop described above occurred, they could cause operational risks related to circuit overloads, under voltages and undesired redistribution of power flow. Thus, the first auto-reclose over common *CB* between two lines should be avoided.

6) Master – Slave auto-reclose scheme could be modified

The auto-reclose scheme stated on this project was Master – Slave. This implies a bay designed by two *CUTs* with two circuit breakers, in which one of them is designated as the leader that is reclosing first (after 60 seconds), and the other one, the follower, that will reclose 200 ms later. So as to contribute to a safe auto-reclose, some modifications to this scheme will be done. For example, when a leader *CB* could not reclose, its follower *CB* could do it, previously assessing the conditions above. Additionally, if the leader made a reclose onto fault, the follower, which is coming to reclose, will be locked dodging a second fault condition throughout the slave *CB*. Fig. 3 illustrates the leader and follower (red circles) circuit breakers in the ring substation.

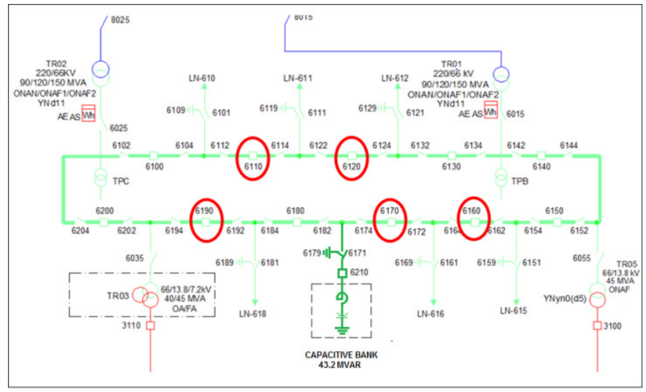


Fig. 3. The follower *CBs* is depicted in red circles for the auto-reclose Master –Slave scheme in the ring substation configuration.

All these criteria lead to develop logics that could involve more than one *CB* and *CUTs* status to decide if it is appropriate to reclose a particular *CB*.

V. Block Conditions of the Auto-Reclose Scheme

Some logics were developed and implemented in the reclosing relays to attain a reliable auto-reclose of a particular *CB*. In this way, negative effects over equipment and power system will be diminished. Therefore, block conditions will be applied to reclose of *CB* open based on the state of the adjacent *CUTs*.

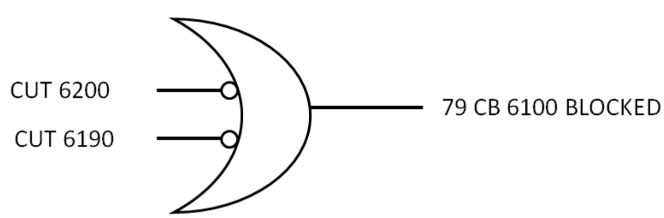
To understand the proposed logics, some conventions are adopted from Fig. 3:

- Every *CUT* undertakes the same name as the *CB* associated.
- *CUT* close state = 1, *CUT* open state = 0
- *CB* auto-reclose blocked = 1, *CB* auto-reclose permitted = 0

According to these conventions, the logic for each CB will be showed next.

A. Block conditions of circuit breaker 6100

This lock concerns any of both *CUTs* 6200 or 6190 closed. Otherwise, *CB* could not be auto-reclosed. This is one of the situations seen above, in which a reenergizing of a transformer (TR02 or TR03) with reclosing of *CB* 6100 should be avoided. The following figure illustrates this scheme.



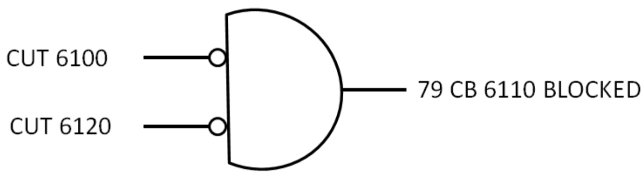
CUT 6200 / 6190	
1	Closed
0	Open

CB 6100	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 4. Block logic for auto-reclose of *CB* 6100. It will be asserted when one of two *CUTs* 6190 or 6200 are open.

B. *Block conditions of circuit breaker 6110*

This is another criterion seen in the chapter IV: a *CB* shared between two lines. It is no adequate to have an auto-reclose of this *CB* before one of the two collateral *CBs* is closed since a new line could be generated for a short period. In this case, severe consequences of overload and under-voltages for the network will be done which were described above. Then, *CUTs* 6100 and 6120 must be closed in order to allow the auto-reclose of *CB* 6110 as it can be seen in the Fig. 5.



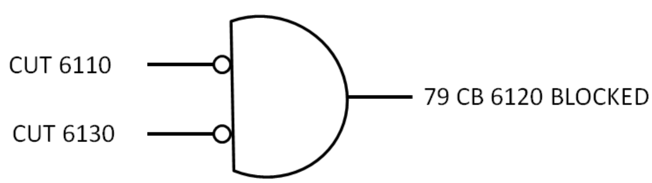
CUT 6100 / 6120	
1	Closed
0	Open

CB 6110	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 5. Block logic for the auto-reclose of *CB* 6110. It will be asserted when both *CUTs* 6100 and 6120 are open.

C. *Block conditions of circuit breaker 6120*

Similarly to the previous condition, this logic will allow the auto-reclose of *CB* 6120 if both *CUTs* 6110 and 6130 are beforehand closed. So, a loop created by two lines is prevented. The effects over the power system are already known when these conditions were not fulfilled. Therefore, the Fig. 6 shows this logic to block an auto-reclose of *CB* 6120.



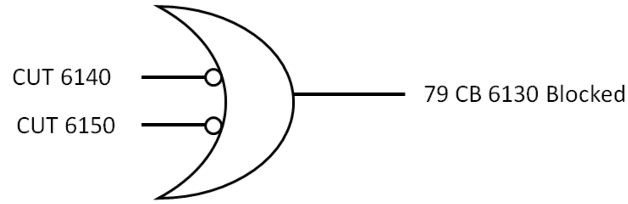
CUT 6110 / 6130	
1	Closed
0	Open

CB 6120	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 6. Block logic for auto-reclose of *CB* 6120. It will be asserted when both *CUTs* 6110 and 6130 are open.

D. *Block conditions of circuit breaker 6130*

This lock involves *CUTs* 6140 and 6150 in order to get reclose of *CB* 6130. The protection criterion is similar to described in condition A, accordingly, reenergizing one or two transformers (TR01 or TR05) should be eluded. Fig. 7 shows this kind of lock over *CB* 6130.



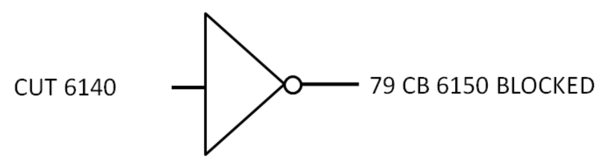
CUT 6140 / 6150	
1	Closed
0	Open

CB 6130	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 7. Block logic for the auto-reclose of *CB* 6130. It will be asserted when one of two *CUTs* 6140 or 6150 are open.

E. *Block conditions of circuit breaker 6150*

An auto-reclose of *CB* 6150 demands that CB 6140 must be closed. On the other hand, the reclose should not be possible because of the transformer reconnection (TR05). Fig. 8 presents this block to avoid an unexpected condition.



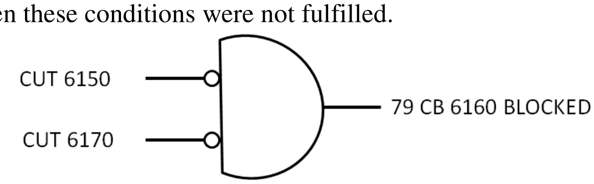
CUT 6140	
1	Closed
0	Open

CB 6150	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 8. Block logic for the auto-reclose of *CB* 6150. It will be asserted when the *CUT* 6140 is open.

F. *Block conditions of circuit breaker 6160*

Similarly to the condition *B*, this logic will allow the auto-reclose of *CB* 6160 if both *CUTs* 6150 and 6170 are beforehand closed (Fig. 9). So, a loop created by two lines is prevented. The effects over power system are already known when these conditions were not fulfilled.



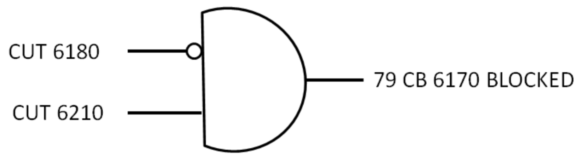
CUT 6150 / 6170	
1	Closed
0	Open

CB 6160	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 9. Block logic for the auto-reclose of *CB* 6160. It will be asserted when both *CUTs* 6150 and 6170 are open.

G. *Block conditions of circuit breaker 6170*

This lock condition involves the positions of *CUTs* 6180 and 6210 in order to prevent a reenergizing of the capacitor bank with the auto-reclose of *CB* 6170. The auto-reclose of the *CB* 6170 will be permitted just with two conditions are accomplished: when *CUT* 6210 is open and when *CUT* 6180 is closed.



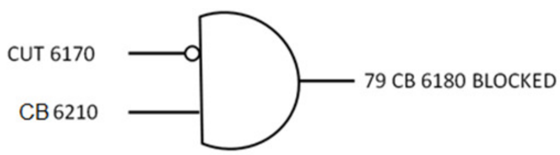
CUT 6180 / 6210	
1	Closed
0	Open

CB 6170	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 10. Block logic for the auto-reclose of CB 6170. It will be asserted when the *CUT* 6180 is open and the *CUT* 6120 is closed.

H. *Block conditions of circuit breaker 6180*

This lock is similar to the previous condition where the main objective is preventing the auto-reclose over the capacitor bank when it is in a de-energizing process (Fig. 11).



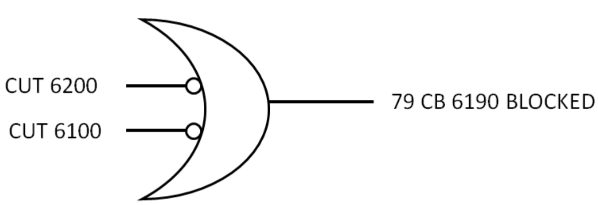
CUT 6170 / 6210	
1	Closed
0	Open

CB 6180	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 11. Block logic for the auto-reclose of CB 6180. It will be asserted when the *CUT* 6170 is open and the *CB* 6120 is closed.

I. *Block conditions of circuit breaker 6190*

The lock condition prevents the reenergizing of one or two transformers (TR02 or TR03) with reclosing of *CB* 6190. To allow the auto-reclose of CB 6190 it is necessary to have both *CUTs* 6200 and 6100 closed (Fig. 12).



CUT 6200 / 6100	
1	Closed
0	Open

CB 6190	
1	Auto-reclose blocked
0	Auto-reclose available

Fig. 12. Block logic for the auto-reclose of CB 6190. It will be asserted when one of two *CUTs* 6100 or 6200 are open.

VI. Tests and Results of the Auto Reclose Scheme

In order to verify the correct operation of the auto-reclose scheme and its block conditions, some tests were made by using injection COMTRADE files to test the lines' auto-reclose and protective relays of the ring substation.

The following test results show several conditions analyzed above related to the block of an auto-reclose stage associated to a *CB* when simultaneously one of these events happens: a loop between two lines comes up, and a transformer or a capacitor bank becomes energized. Also, a switch onto fault condition by unsuccessful reclosing test will be shown.

A. *Test of the bay LN-611*

In this test, both a single fault condition and the auto-reclose scheme will be shown. Auto-reclose of *CB* 6120 will be blocked according to the logic of Fig. 6. Fig. 13a illustrates the relay signals during the fault condition.

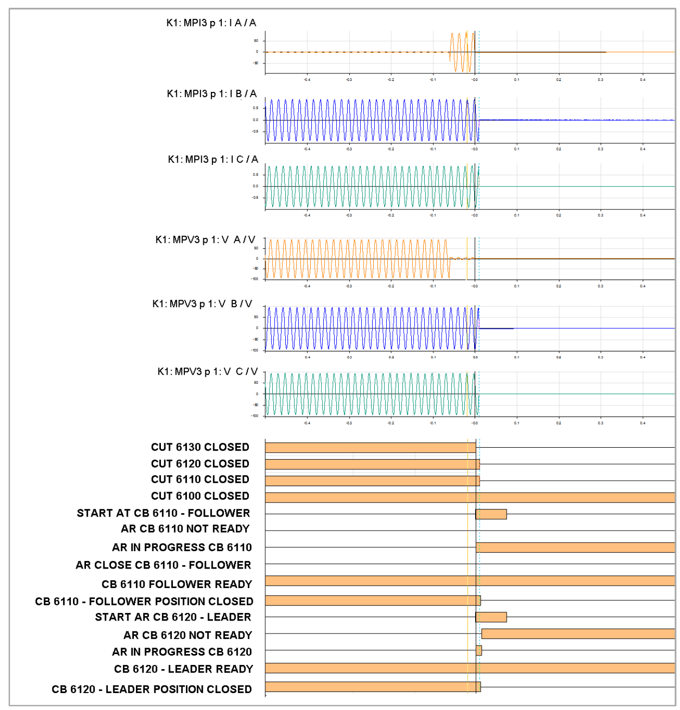


Fig. 13a. Fault condition test result of the bay LN–611. Both auto-recloses *CB* 6110 and *CB* 6120 start cycle as a consequence of external tripping. Conversely, reclosing in progress of *CB* 6120 became unlatched quickly.

In this fault condition, *CUT* 6130 was tripped at the same time of *CUTs* 6110 and 6100. This was made intentionally to represent a simultaneous fault in the line LN-612 in which the *CB* 6130 should have also tripped. As it can be seen from digital signals, the auto-reclose in progress associated to *CB* 6120 was disabled after 8 ms of starting. This behavior fulfills the logic applied in the Fig. 6, blocking the auto-reclose of *CB* 6120. The following figure shows the final state of the auto-reclose associated to this circuit breaker.

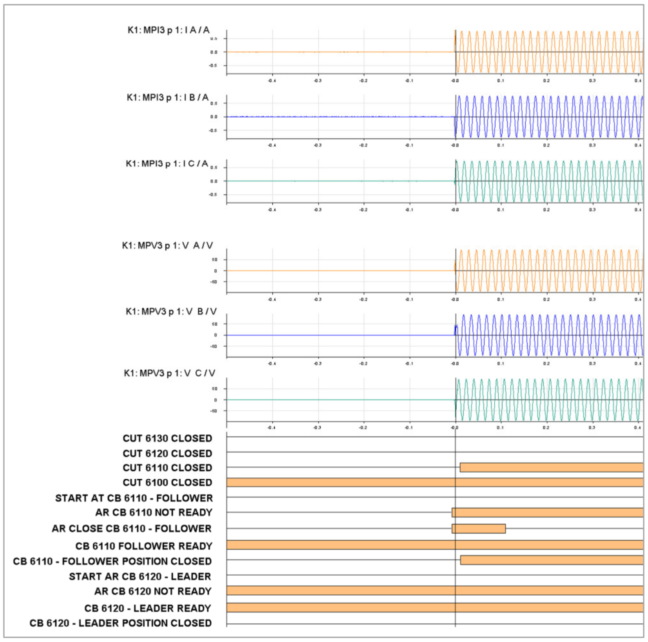


Fig. 13b. Auto-reclose scheme test result of the bay LN–611 handling *CB* 6110. The *CB* 6120 did not reclose.

From this figure, the follower *CB* 6110 achieved a successful auto-reclose whilst AR CB 6120 NOT READY signal continues latched. The *CB* 6120 did not close since during both states tripping and auto-reclose cycle, *CBs* 6110 and 6130 stayed open as shown in the block logic of Fig. 6.

B. Test of the bay LN-618 reclosing CB 6180

Similarly, a fault condition, the successful auto-reclose of *CB* 6180 and the block of auto-reclose of *CB* 6190 will be shown. The fault situation is shown in the Fig. 14a.

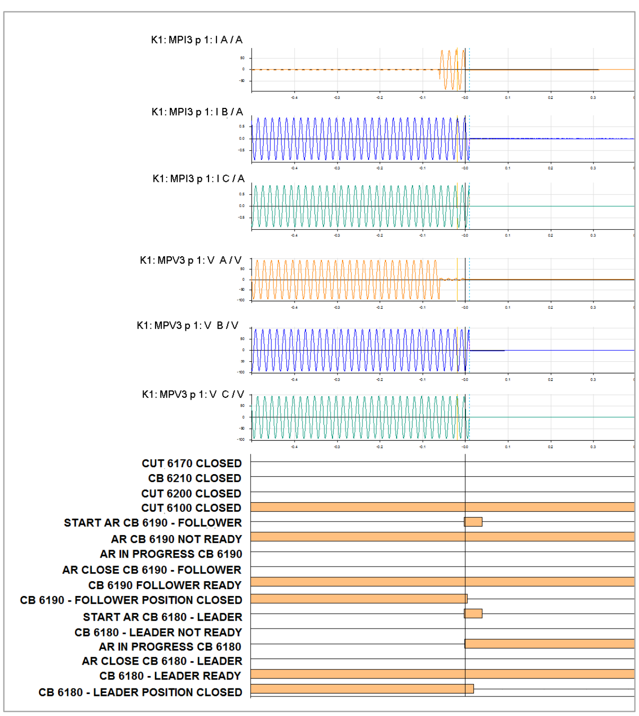


Fig. 14a. Fault condition test result of the bay LN–618 with *CB* 6210, and *CUTs* 6200 and 6170 open. The auto-reclose cycle of *CB* 6190 never started.

Previously to the fault condition, the *CUT* 6200 was opened. Therefore, after tripping of both *CBs* 6180 and 6190 the AR IN PROGRESS CB 6190 signal did not latch as a consequence of the logic implementation depicted in Fig. 12. In this way, the AR CB 6190 NOT READY signal came active from the pre-fault state. The block of its auto-reclose condition is illustrated in the following figure.

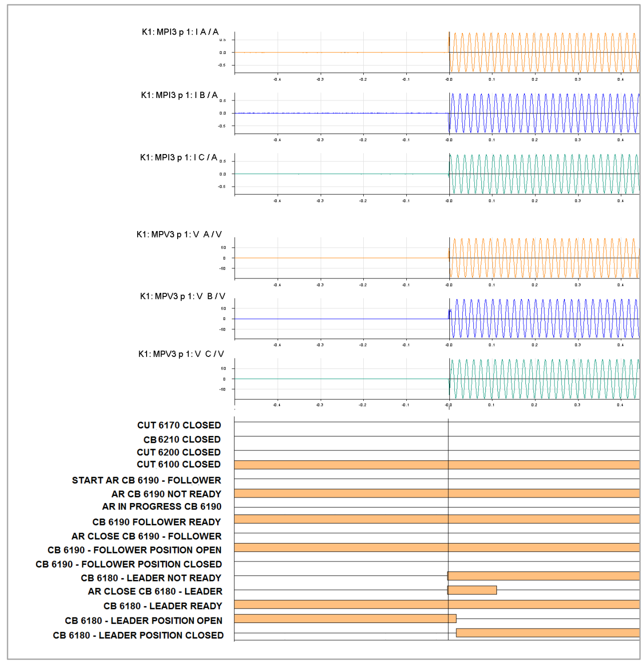


Fig. 14b. Auto-reclose scheme test of the bay LN–618 handling *CB* 6180. . The *CB* 6190 did not reclose.

In this figure, the AR CB 6190 NOT READY signal continued active blocking the auto-reclose of *CB* 6190. It is clearly identified with non-activation of both signals AR CLOSE CB 6190 and CB 6190 – FOLLOWER POSITION CLOSED.

C. Test of the bay LN-618 reclosing CB 6190

By using the same fault condition and the auto-reclose scheme proposed in Fig. 11, line LN-618 was re-energized by only the reclosing of *CB* 6190. Next figure illustrates the fault state and the previous conditions of neighbor *CUTs*.

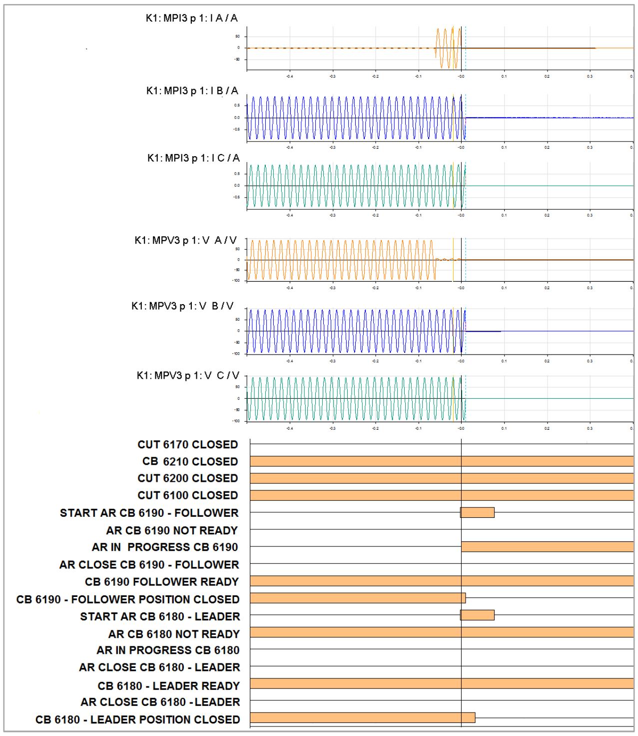


Fig. 15a. Fault condition test result of the bay LN–618 with *CUT* 6170 open and *CB* 6210 closed. After auto-reclosing starting, AR IN PROGRESS CB 6180 signal was never latched.

As it can be seen in the logic of Fig. 11, if *CUT* 6170 is opened and *CB* 6210 is closed, the auto-reclose cycle will not be asserted. Hence, the AR CB 6180 NOT READY signal has been activated all the time leading to the block of auto-reclose of CB 6180. Fig. 15b shows this situation.

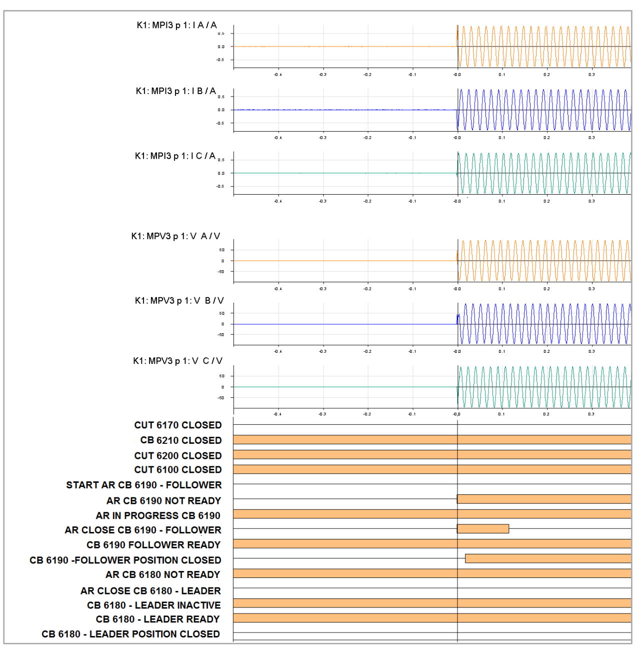


Fig. 15b. Auto-reclose scheme test result of the bay LN–618 handling *CB* 6190. The *CB* 6180 did not reclose.

The AR CB 6180 NOT READY signal continues active as a result of block logic of Fig. 11 in which *CUT* 6170 stayed open.

D. Test of the bay LN-615

This test illustrates a switch onto fault condition by reclosing in failure on this line, which will happen after the activation of the close command signal. Fig. 16a stablishes the fault condition and Fig. 16b shows sotf state.

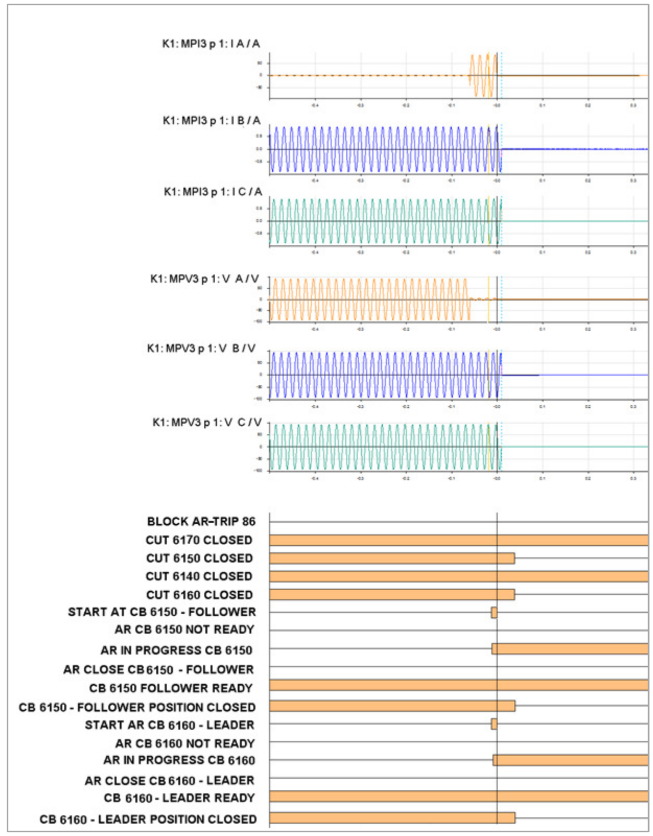


Fig. 16a. Fault condition test result of the bay LN–615. Both auto-recloses *CB* 6150 and *CB* 6160 start cycle as a consequence of external tripping. Additionally, their reclosing in progress signals became latched.

Differently from the other cases analyzed above, both signals AR IN PROGRESS CB 6160 (leader) and AR IN PROGRESS CB 6150 (follower) are latched after the tripping line was made by external protection system. Therefore, a normal reclosing cycle for circuit breakers is fulfilled until reclosing in failure which can be seen in the following figure.

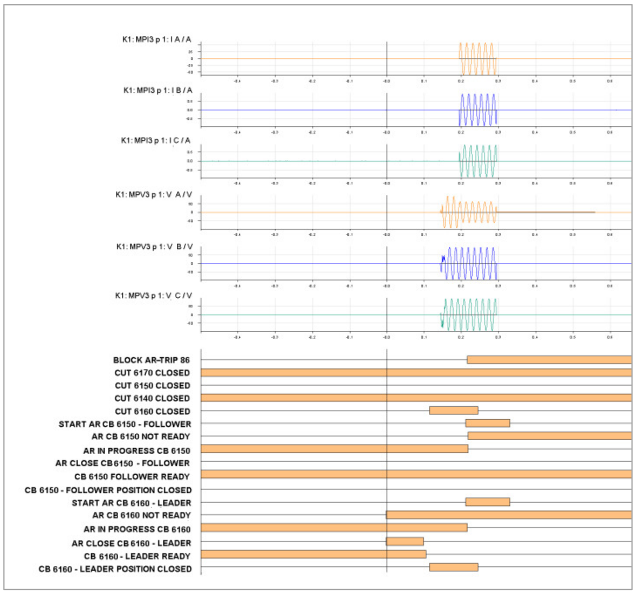


Fig. 16b. Sotf condition test result of the bay LN–615. A reclosing in failure of *CB* 6160 was made.

As it was mentioned before, the new trip after reclosing *CB* 6160 (leader) onto fault stopped the auto-reclose in progress for *CB* 6150 (follower) leading the relay trip 86 (trip and block) triggered. Consequently, AR CB 6150 NOT READY signal was also activated blocking the auto-reclose of this *CB*. In this case, a second sotf condition was avoided. This operation fulfills the initial criteria proposed regarding protecting both equipment and the power system.

VII. Conclusions

An auto-reclose scheme in a ring substation configuration should take into account the presence of different power equipment such as transformers, capacitive and inductive compensation. That equipment determines the different block conditions in the auto-reclose scheme.

The scheme proposed by this document increases the reliability of the energy service given to customers, and also avoids problems related to overvoltages, overloads and blackouts in the power system.

The auto-reclose scheme of a ring arrangement implemented in the substation at 66 kV located in the northern of Colombia was designed considering three important conditions: the automatic reclosing of a circuit breaker shared between a line and a transformer, the automatic reclosing of a circuit breaker shared between a line and a capacitor bank, and the automatic reclosing of a circuit breaker shared between two lines. These conditions led designers to develop some criteria and block logics that were applied to auto-reclose relays which managed two circuit breakers.

The block conditions of the auto-reclose schemes considers not only the circuit breaker ready and synchronism check signals, but also the position of the adjacent *CUTs* and leader and follower *CBs* on pre-fault, fault and auto-reclose cycle steps. With these relay's inputs, relevant modifications were made to the Master – Slave logic of the conventional auto-reclose scheme, making it more reliable for automatic reclose of outage lines. In fact, if one of the two circuit breakers cannot reclose, the other will do it. Another advantage for this adaptation was the control of a second follower trip during leader sotf condition. In this case, if the first *CB* recloses onto fault, the second one, which is on cycle yet, becomes blocked.

During tests, every result proved how logic implementations were accomplished satisfactorily. The scheme makes the general auto-reclose scheme safer for equipment of the ring substation at 66 kV and the power system in general. This methodology and criteria employed in this work should be extended to other levels of ring and breaker-and-half substations with other equipment such as generator, FACTS o motors in order to obtain a successful automatic reclose saving the power equipment from harm.

Finally, this auto-reclose scheme presents an alternative to improve operating power systems and reducing impacts over power equipment.

VIII. References

[1] Y. Li, X. Sun and W. Zhou, "The analysis and computation of transformer winding short-circuit current and strength on permanent fault after reclosing," finished. *Electrical Machines and Systems (ICEMS), 2011 International Conference*, pp. 1 - 5.

[2] J. H. Oh, S. Y. Yun, J. C. Kim, D. Kim and W. Zhou, J. K. Ahn "Evaluation method of transformer damage from auto-reclosing scheme in power distribution system," finished. *Power Engineering Society Summer Meeting, Edmonton, Alta 1999. IEEE (Volume: 2)*, pp. 774 - 779 vol.2.

[3] J. C. Das, "Transients in Electrical Systems: Analysis, Recognition, and Mitigation," US, McGraw-Hill Professional, 2010, pp. 1-6.

[4] IEEE Guide for Application of Shunt Power Capacitors, IEEE Std. 1036-2010.

[5] P. Vukelja, J. Mrvić, M. Senćanić, D. Hrvić, D. Radulović (1999). Transient Phenomena at Energization and Deenergization of Capacitor Banks. Presented at 99IPST025-3.6 International Conference on Power System Transients. [Online]. Available: http://www.ipstconf.org/papers/Proc_IPST1999/99IPST025.pdf

[6] IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers, IEEE Std. C37.04-1999 clause 5.8.

[7] L. A. Davidson, Oklahoma Gas and Electric Company, Oklahoma City, Okla. ; V. M. Hines. "Reclosing relay for ring bus substations". *AIEE Power Apparatus 1961. AIEE (Volumen 80)*. pp. 1188-97.

[8] *Network Protection & Automation Guide*, 2nd ed., Alstom Grid., UK, NC, May 2011, pp. 14.1–14.15.

[9] Work Group K Reduce Outages; "Reducing Outages through Improved Protection, Monitoring, Diagnostics, and Autorestoration in Transmission Substations (69 kV and Above)," finished. *IEEE Transactions on Power Delivery (Volume: PP)*, pp. 1 - 9.

[10] G. Gutierrez, W. Hernandez "Study for the Renewal of Relay 67/67N and Implementation of the Reclosing Scheme at Ring Substation 66 kV," I S A - Intercolombia, Medellin ANT. GO-DO 1058, Mar. 2015.

G. Gutierrez received the B.S. degree in Electrical Engineering from Universidad Nacional de Colombia, Medellin - Colombia, in 1997 and the M.S. degree at Universidad Pontificia Bolivariana, Medellin - Colombia 2002.

Since 2004 he has been working at GRUPO ISA, Colombia, and nowadays he is working as a Specialist of Protection Engineer at ISA-INTERCOLOMBIA in Medellin - Colombia. His research interests include electrical studies for power

system, protection scheme assessment, relay settings, protective relay tests, and fault disturbance analysis in power systems. Some his publications are “Analysis of a differential busbar protection operation at 220 kV substation”, SIPSEP XII Iberoamerican Symposium on Power System Protection, February 2015. “Control of unsymmetrical overvoltages during open pole condition on overhead transmission lines compensated at one end”, IPST International Conference on Power Systems Transients, Vancuver, Canada, July 2013. “Temporary measures taken as consequence of the augment of non-linear loads at a petroleum facility” Invention 2007 Conference Poland – October 2007.

W. Hernandez. He received his B.S. degree in electrical engineering from Universidad Nacional de Colombia, in 2011.

Since 2011 he has been working at GRUPO ISA in Colombia and nowadays he is working as a Protection Engineer at ISA-INTERCOLOMBIA in Medellin - Colombia. His research interests include protection schemes assessment, setting of relays and fault disturbance analysis in power systems. His publications comprise “Analysis of a differential busbar protection operation at 220 kV substation”, SIPSEP XIII Iberoamerican Symposium on Power System Protection, Monterrey, Mexico February 2015.