Adaptive autoreclosaure to increase system stability and reduce stress to circuit breakers

Jörg Blumschein[A], Yilmaz Yelgin[A], Andrea Ludwig[B]
[A] Siemens AG, Energy Management Division, Munich, Germany
[B] 50Hertz Transmission GmbH, Berlin, Germany

RESUMEN

El recierre automático es un elemento clave en el concepto de rejillas autosanadas. Según las estadísticas, una gran cantidad de fallas de transmisión y distribución son fallas temporales, las cuales desaparecen cierto tiempo después de la desenergización de las secciones de la red falladas. El recierre automático se utiliza para recuperar el estado original de la red sin intervención humana, y puede ser hecha en tres polos o en uno solo. En este artículo se describe la aproximación utilizada en Alemania, Polonia y Austria para liberar distintas fallas de fase a fase sin tierra, mediante el autocierre de un solo polo. En este caso se pueden llevar a cabo mediciones de voltaje durante el tiempo muerto del polo para determinar si el recierre fue exitoso.

PALABRAS CLAVES

Autocierre automático, autocierre de un solo polo, estabilidad de sistemas.

ABSTRACT

Automatic reclosure is a key element in the concept of self-healing grids. According to statistics, a large amount of faults in transmission and distribution networks are temporary faults. These faults disappear a certain time after de-energization of the faulted sections of the network. Automatic reclosure is used to recover the original status of the network without any human interaction. Automatic reclosure can be done as a three pole autoreclosure or a single pole autoreclosure. This paper describes an approach used in Germany, Poland and Austria to clear such phase to phase faults without ground by the means of a single pole autoreclosure. Also in this case voltage measurements during the single pole dead time can predict whether or not a reclosure will be successful.

KEYWORDS

Automatic reclosure, single pole autoreclosure, system stability.

INTRODUCTION

According to statistics, 80 to 85 percent of faults at transmission and distribution lines are temporary faults. Lightning is the most usual case for temporary faults but there are other reasons too. Swinging conductors contacting each other caused by strong wind or shedding of ice can cause temporary phase to phase faults. Other well known reasons for temporary faults are related to bird streamers or vegetation reaching too close to the conductors due to lack of maintenance. These faults disappear a certain time after de-energization of the faulted sections of the network. Automatic reclosure is used to recover the original status of the network very fast and without any human interaction.

Figure 1 is used to explain the basic principle of autoreclosure. A typical transmission line is connecting two parts of a network which are connected to the busses A and B. In figure 1a fault on the line is detected by the relays at both ends of the line measuring the currents I A and IB and the voltages U A and UB. As soon as the relays A and B detect that the fault is on the protected line they will send a trip command to open the associated circuit breaker CB like shown in figure 1b. At this time the automatic reclosing functions integrated in the relays A and B start the dead time of the autoreclosure. During this dead time the fault has the chance to extinguish. After the dead time is expired, the automatic reclosure function sends a close command to the associated circuit breaker. For transient faults a successful reclosure is mostly obtained with the first reclose cycle like shown in figure 1c. If the fault still persist the protective relays A and B will detect this and send a trip command again. A tree branch falling on a line for instance may need a second reclose cycle to burn up by the arc when the line is re-energized.

For permanent faults caused by a broken conductor, the collapse of a line tower, trees falling onto a line or faults in cables a reclosure is not able to clear the fault. Therefore it is important to detect this condition and send a final trip to the circuit breaker.

Based on experiences the most utilities apply automatic reclosure with one reclose cycle only. This is because the increasing chance to get a successful autoreclosure does not justify the stress to circuit breakers and system due to additional close-open cycles under full fault current in case of permanent faults.

Autoreclosure can be distinguished as three pole autoreclosure or single pole autoreclosure like shown in figure 2. For three phase faults or phase to phase faults with ground all three phases must be isolated to clear the fault. For single phase to ground faults which are the great majority of faults in the transmission and distribution systems a single pole autoreclosure is sufficient to clear the fault. In Section 2 a scheme is described to use single pole tripping and autoreclosure also in case of phase to phase faults without ground like shown in figure 2.

Today many utilities use single pole autoreclosure. Single pole autoreclosure has the following advantages compared to three pole autoreclosure:

- Transport of energy possible during the dead time via the two remaining wires.
- No synchronization needed before reclosing.
- Enhanced system stability and reliability.

In general the goal of the autoreclosure is to restore the line to service as quickly as possible. This goal has to be balanced with the negative effects of closing onto a fault which produces a lot of stress to the circuit breaker and the electrical sytem. In Section 2 a scheme is explained how to prevent the closing of the second circuit breaker if the closing of the first circuit breaker was not successful. This scheme can help to reduce the negative impact that failed autoreclosure attempts have on the system. A scheme called "autoreclosure with adaptive dead time" is possible for three pole autoreclosure as well as for single pole autoreclosure like shown in figure 2.

Section 3 will explain methods to improve single pole autoreclosure for single phase to ground faults by detecting whether or not a reclosure will be successful by means of secondary arc detection.

Section 4 will explain the single pole autoreclosure scheme for phase to phase faults without ground and methods to detect whether or not the reclosure will be successful in this case.

AUTORECLOSURE WITH AN ADAPTIVE DEAD TIME

Autoreclosure with an adaptive dead time is a typical autoreclosing scheme for transmission lines also known as "leader follower autoreclosing scheme" [1]. In this scheme the leader is defined as the line terminal that autorecloses first after a fixed dead time. The follower is the line terminal that recloses second and only if the reclosing of the leader was successful.

In this scheme the leader is used to verify whether or not the fault is extinguished during the dead time of the autoreclosure. If the fault still persists the leader will open the associated circuit breaker again. In this case the follower does not attempt the autoreclosure which has the great advantage of reducing unnecessary stress to the circuit breaker at the follower end of the line.

Figure 3 explains the behavior of the scheme in case of an unsuccessful autoreclosure.

In figure 3a a fault condition is shown on a line protected by the relays called L (leader) and F (follower). Both relays detect the fault on the protected line and open the line by means of the associated circuit breakers shown in figure 3b. After the fixed dead time is expired only the leader recloses the breaker to verify

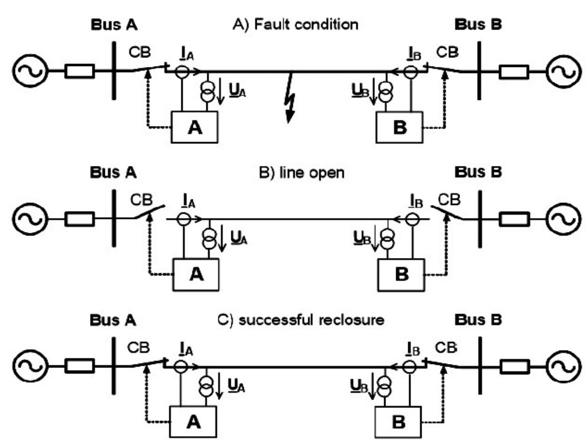

Fig. 1. Basic principle of autoreclosure.

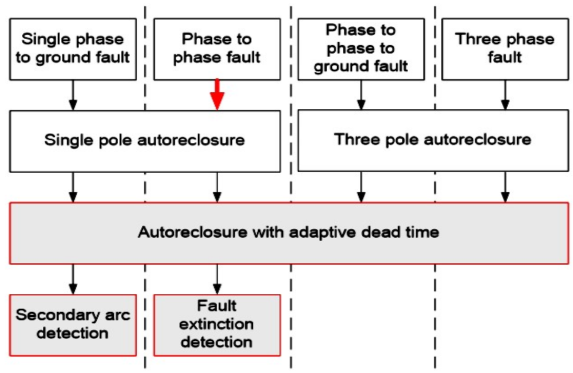

Fig. 2. Autoreclosure schemes for different types of fault.

whether or not the fault still persists. If the fault still persists like shown in figure 3c, the leader opens the circuit breaker to start another autoreclose cycle or send a final trip like shown in figure 3d.

Figure 4 explains the same scenario for a successful autoreclosure. Different to figure 3c is that the fault does not persist after reclosing of the leader side shown in figure 4c.

If there is a communication channel between the relays at both ends of the line the leader can send a "remote close command" to close the circuit breaker associated to the follower at the remote end of the line as shown in figure 4d. [2]

Another solution for an autoreclosure with adaptive dead time without communication channel is explained in figure 5. A fault occurs at a transmission line like shown in figure 5a. Both relays detect the fault and open the associated circuit breaker like shown in figure 5b. Autoreclosure with fixed dead time is started at the leaders end only. After the fixed dead time is expired the leader closes the associated circuit breaker as shown in figure 5c. If the fault does not persist anymore the follower will detect a healthy voltage which indicates that the line was successfully re-energized from the remote end. Consequentially the autoreclose function in the follower device can close the circuit breaker like shown in figure 5d.

This kind of adaptive autoreclosure requires that:

- The voltage transformers are located on the line side of the circuit breaker at the follower end like shown in figure 5,
- The leaders end of the line is strong enough to maintain a healthy voltage after reclosure.

At 50 Hertz transmission the follower releases the close command if a voltage greater than 70% of nominal voltage is measured for more than 300 ms.

SECONDARY ARC DETECTION

A successful autoreclosure requires a dead time which exceeds the de-ionizing time, the time needed for the fault to extinguish. This time required for the de-ionizing of the fault path depends on several factors including:

- Arcing time (fault duration).

- Fault current.
- Weather conditions like wind, air humidity and air pressure.
- Circuit voltage.
- Capacitive coupling to adjacent conductors.

In general the circuit voltage is the predominating factor influencing the deionizing time. For single pole autoreclosure there is another effect which has a significant influence to the success of the autoreclosure. The primary arc current is interrupted by disconnecting the faulted phase from the sources by opening the circuit breakers at both ends of the line. After this a secondary arc can prevent the fault clearance. During the single pole dead time capacitive and inductive coupling from the other two phases induces a voltage into the open phase conductor which

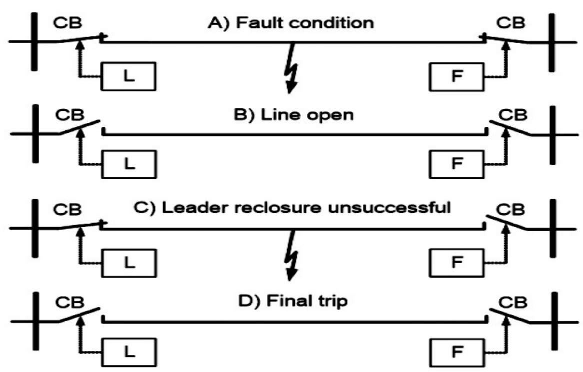

Fig. 3. Unsuccessful autoreclosure.

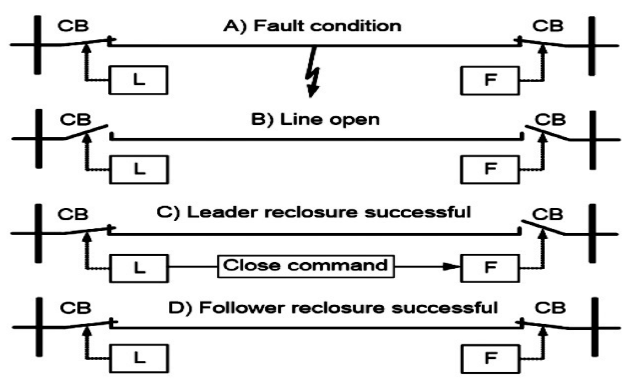

Fig. 4. Successful autoreclosure using a remote close command.

feeds the secondary arc like shown in figure 6. The success of a single pole autoreclosure depends on the extinction of this secondary arc. On transmission and distribution lines the coupling between the two remaining phases and the open phase can be sufficient to maintain the secondary arc in the ionized air of the primary arc path. Depending on the above mentioned influencing factors like fault duration, fault current, atmospheric conditions and constructive parameters of the line the secondary arc may take longer to extinguish. In worst case the secondary arc does not extinguish at all during a single pole autoreclosure and reclosing in the presence of the secondary arc will only re-energize the fault.

There are several methods to detect the presence of the secondary arc. All these methods are based on the simplified equivalent circuit shown in figure 7.

The secondary arc is an arc between the open phase and ground which is fed by the two healthy phases via capacitive coupling. The voltage UM , measured at the disconnected phase is characterized by the ohmic nonlinear behavior of the secondary arc.

If the secondary arc is extinguished the equivalent circuit is changing to a different model like shown in figure 8. The voltage UM , measured at the disconnected phase after extinguishing of the secondary arc is characterized by the linear capacitive behavior of the phase to ground capacitance of the open conductor.

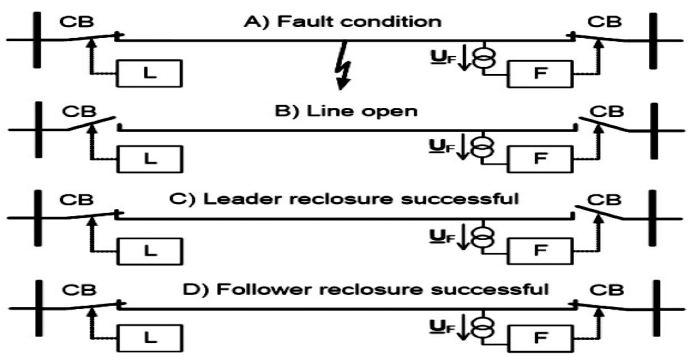

Fig. 5. Successful autoreclosure using line side voltage measurement.

Figure 9 shows the current and voltage for a successful autoreclosure after a single phase fault on a transmission line. After tripping the line we can see that the fault current disappears. At the same time the voltage starts the typical nonlinear behavior of arcing. At a certain time the secondary arc extinguishes and the voltage is changing to a linear capacitive behavior. Finally voltage and current goes back to normal conditions after successful reclosing.

Figure 10 however shows a case where the secondary arc does not extinguish during the single pole dead time. After reclosure the fault still persists which leads to a final trip of the protection.

In [3] a method is described to detect the presence of the secondary arc using the relation between the fundamental com- ponent and the harmonics of the phase to ground voltage of the open phase. Figure 11 shows the harmonic content of the open phase voltage during the presence of the secondary arc on a 400 kV transmission line. Due to the nonlinear characteristic of the secondary arc there is a huge portion of 3rd, 5th and 7th harmonic.

After the secondary arc is extinguished the voltage is rising up to 42 kV but without any harmonics like shown in figure 12.

In [4] a method is described detecting the secondary arc based on the angle of the open phase voltage in relation to the other phase to ground voltages. Figure 13 shows the phasor diagram of the phase to ground voltages during the presence of the secondary arc for the same fault record of a 400 kV transmission line. Due to the ohmic characteristic of the secondary arc the voltage of the open phase lags the voltage phasor of the pre-fault voltage by 90°. After the secondary arc is extinguished the voltage phasor is rising in magnitude and is located between the two healthy voltage phasors like shown in figure 14.

Another method is given in [5] which detect the extinguishing of the secondary arc by evaluating the amplitude of the third harmonic component of the zero sequence voltage.

All three methods were applied to a set of 46 fault records captured by real events from the transmission system of 50Hertz. At this time 50Hertz Transmission was using adaptive autoreclosure with a fixed dead time of 1.2 s for the leader for single phase faults. According to figure 15 the secondary arc was already extinguished after 0.2 s in many cases. Only in 3 cases the secondary arc needed 0.8 s to extinguish. By using adaptive autoreclosure with secondary arc detection the fixed dead time of 1.2 s for the leader could be reduced significantly in most cases.

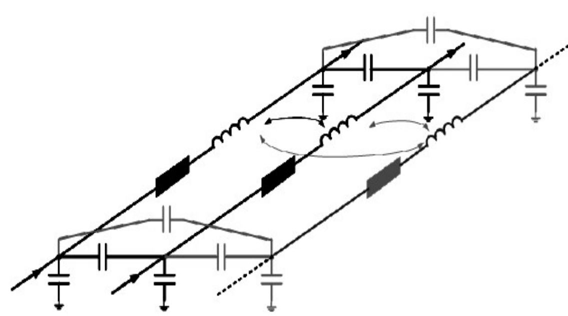

Fig. 6. Capacitive and inductive coupling between the three phases of a transmission line.

There are other cases where the secondary arc does not extinguish even after 1.2 s. But secondary arc detection is also important for these cases. As soon as it is clear that a secondary arc and not a permanent fault was the reason for the unsuccessful reclosure, a manual closing of the line is permitted without a time consuming line patrol in advance.

SINGLE POLE TRIPPING FOR PHASE TO PHASE FAULTS WITHOUT GROUND

Under extreme weather conditions line swinging can cause an increasing number of phase to phase faults. These faults are mostly flash-arcs between two wires of a transmission or distribution line. Figure 16 shows a simplified equivalent circuit for such kind of faults.

In [6] a scheme was protected by patent to clear phase to phase faults without ground by means of a single pole autoreclosure. It is obvious like shown in figure 17 that a single pole trip will clear a temporary phase to phase fault in most cases.

In such schemes there are two options for single pole tripping in case of phase to phase faults without ground: trip leading phase or trip lagging phase. It must be ensured that all protective relays in a given network use the same phase preference for single pole trip in case of phase to phase faults. This scheme is successfully applied in Germany, Poland and Austria for many years to take the advantages of single pole autoreclosure also for phase to phase faults without ground.

Figure 18 shows a fault record for a successful single pole autoreclosure for a phase to phase fault on the 220 kV system in Germany. After tripping of phase C the fault current in phase A and phase C disappears at the local end. Approximately 300 ms later also the voltage UC goes down indicating the isolation of the fault. Finally a successful reclosure brought the system back to normal conditions.

According to [6] a successful isolation of the arc between the two faulted phases is given if the phase to ground voltage of the tripped phase is measured to be below a certain value for a given time like shown in figure 18.

Figure 19 shows an unsuccessful single pole autoreclosure of phase C for a fault between phase A and phase C.

Different to figure 18 the phase to ground voltage of the tripped phase C does not fall below a certain value for a given time. Detecting this condition an unsuccessful autoreclosure could be prevented in the future. Here also voltage measurements during the single pole dead time can predict whether or not a reclosure will be successful.

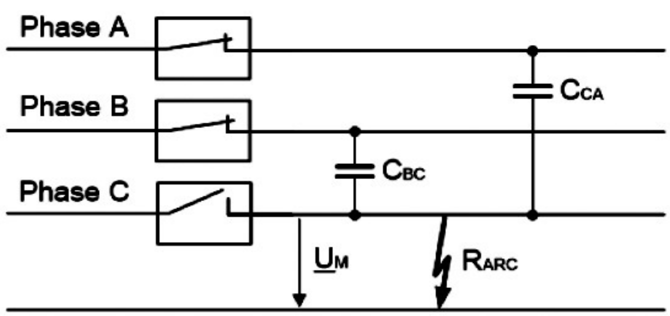

Fig. 7. Simplified equivalent circuit of secondary arc, fed by capacitive coupling from the two healthy phases.

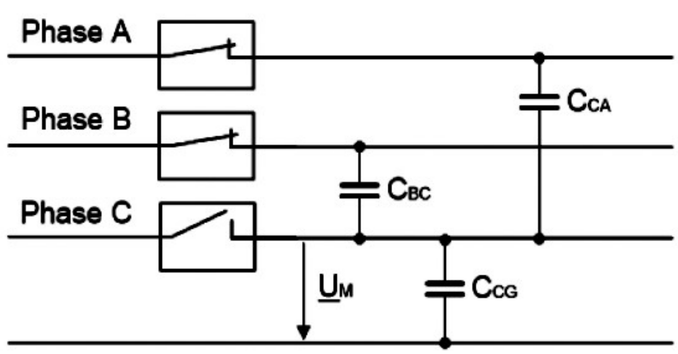

Fig. 8. Simplified equivalent circuit after secondary arc is extinguished.

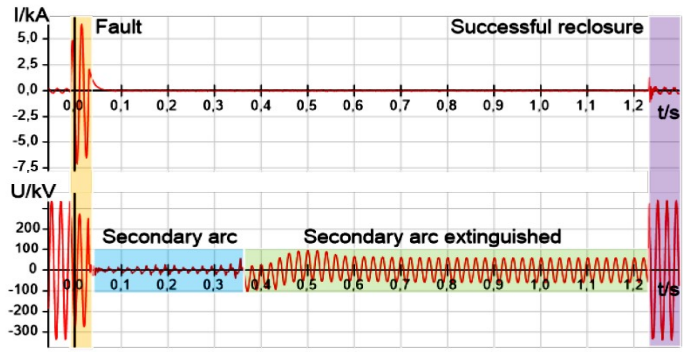

Fig. 9. Secondary arc extinguishing during single pole dead time.

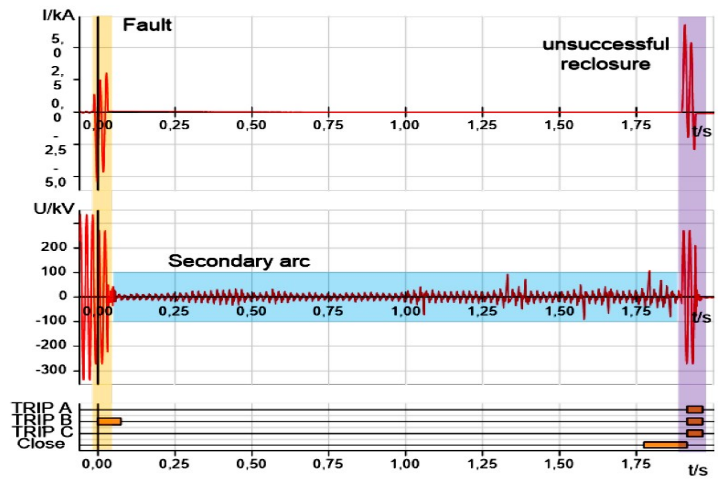

Fig. 10. Secondary arc not extinguishing during single pole dead time.

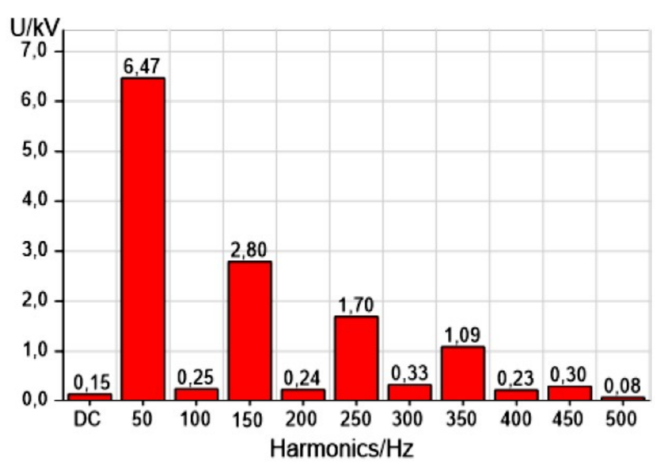

Fig. 11. Harmonic content of voltage during the presence of the secondary arc.

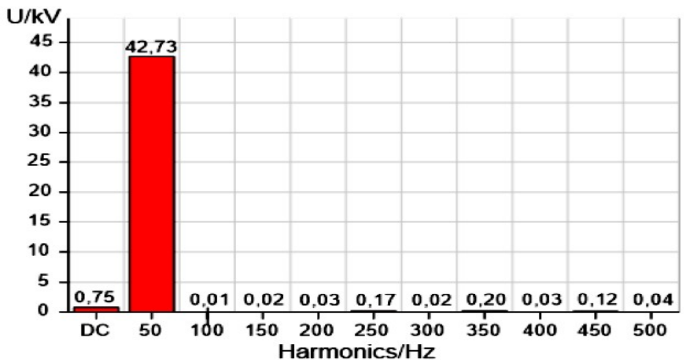

Fig. 12. Harmonic content of voltage after secondary arc is extinguished.

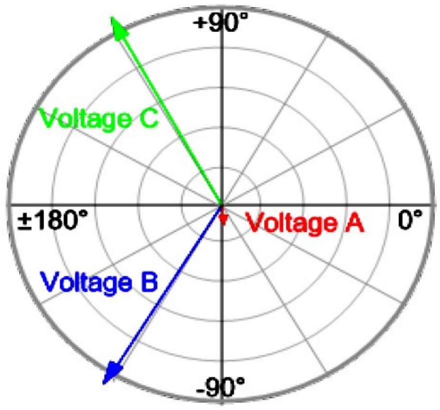

Fig. 13. Phasor diagram of voltages during the presence of the secondary arc.

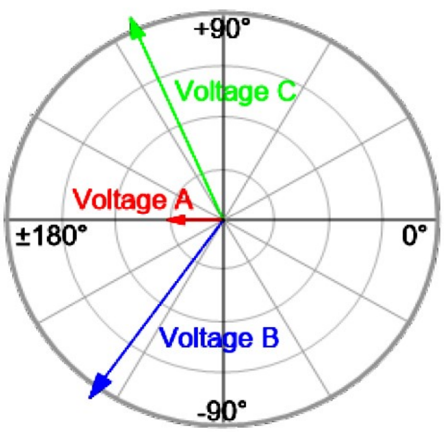

Fig. 14. Phasor diagram of voltages after the secondary arc was extinguished.

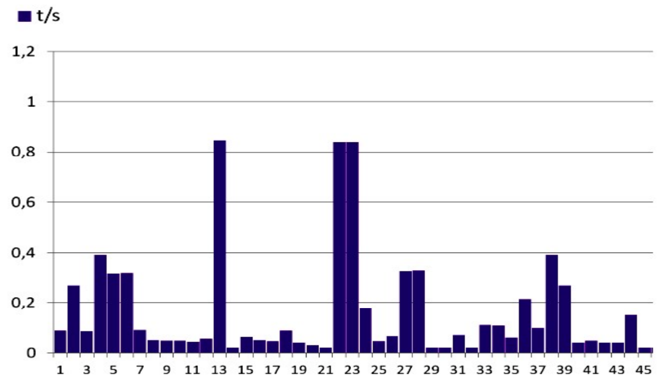

Fig. 15. Time needed for the secondary arc to extinguish during the single pole dead time.

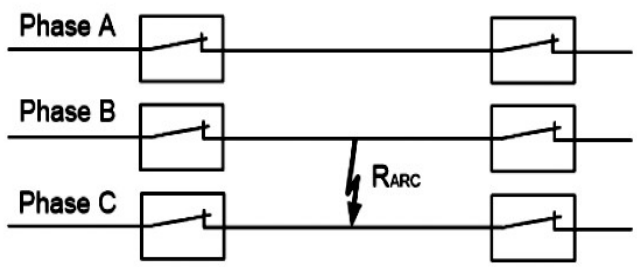

Fig. 16. Simplified equivalent circuit for a phase to phase arcing fault without ground.

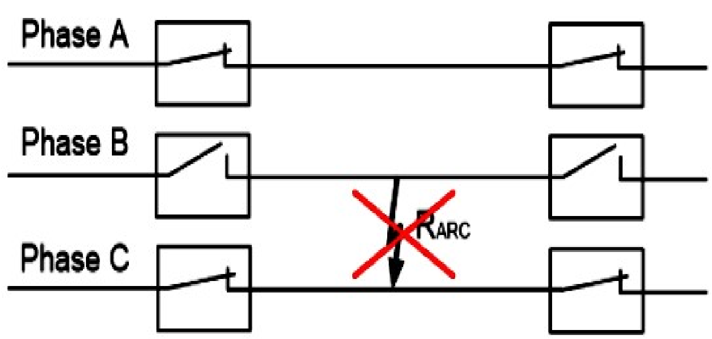

Fig. 17. Simplified equivalent circuit for a single pole trip for a phase to phase fault without ground

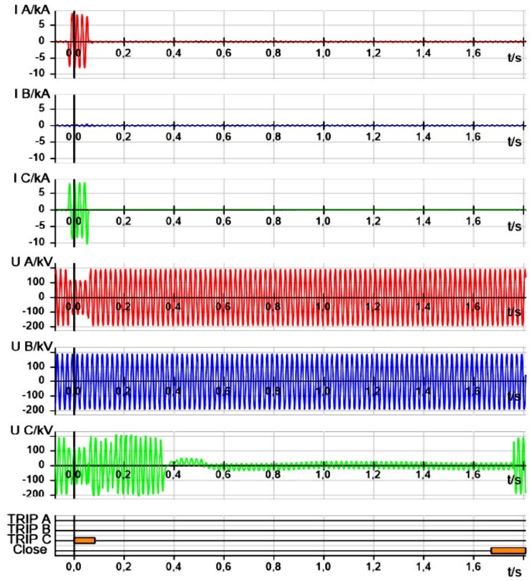

Fig. 18. Fault record of successful single pole autoreclosure for a phase to phase fault.

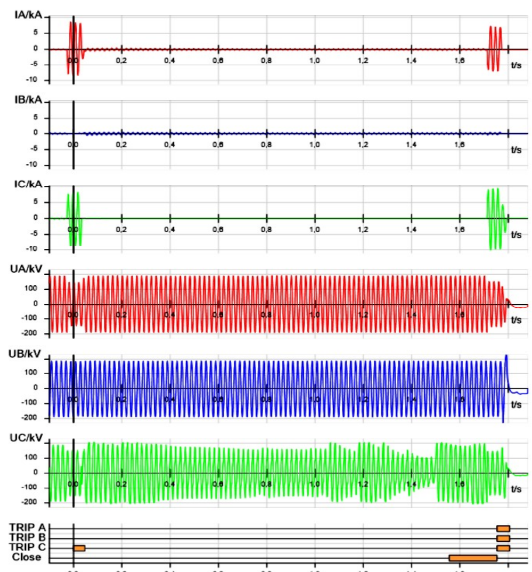

Fig. 19. Fault record of unsuccessful single pole autoreclosure for a phase to phase fault.

CONCLUSION

It was shown that using adaptive autoreclosure the system stability can be increased by adaptively shorten the dead time of the autoreclosure and prevent unnecessary reclosing onto faults. Several different methods were explained how to use voltage measurement during the single pole dead time to reduce unnecessary stress to the circuit breaker by reclosing onto faults.

REFERENCES

1. "IEEE Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines," IEEE Std C37.104-2012 (Revision of IEEE Std C37.104-2002), pp. 1–72, 2012.
2. "SIPROTEC 5, Distance and Line Differential Protection, Breaker Management for 1-Pole and 3-Pole Tripping," Siemens AG, Tech. Rep., 2015.
3. R. Luxenburger, P. Schegner, and A. Ludwig, "Beurteilung der Lichtbogenlöschung bei der einpoligen AWE in Höchstspannungsnetzen," in Internationaler ETG-Kongress 2005, Dresden, 2005, pp. 1–9.
4. A. Guzmán, J. Mooney, G. Benmouyal, N. Fischer, and B. Kasztenny, "Transmission line protection system for increasing power system requirements," in Proceedings of the International Symposium Modern Electric Power Systems (MEPS), 2010, Wroclaw, Poland, 2010, pp. 1–11.
5. S. Jamali and A. Parham, "New approach to adaptive single pole autoreclosing of power transmission lines," IET Generation, Transmission & Distribution, vol. 4, no. 1, p. 115, 2010. [Online]. Available: http://digital-library.theiet.org/content/journals/10.1049/ iet-gtd.2009.0058
6. "Schaltungsanordnung zur Beseitigung zweipoliger Lichtbogenkurz- schlüsse in Hochspannungsnetzen," 1972.