Summary Paper for IEEE C37.104 Guide for Autoreclosing on AC Distribution and Transmission Lines

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This paper is a product of the IEEE PSRCC working group D50. The working group consisted of the following members: Manish Patel (Chair), Joshua Lamb (Vice-Chair), Miguel Rios (Secretary), Abu Bapary, Matt Black, Brian Boysen, Alla Deronja, Scott Elling, Rick Gamble, Rafael Garcia, Kamal Garg, Mat Garver, Genariel Hernandez, Brandon Lewey, Bruce Mackie, Jim O'Brien, Greg Ryan

***Abstract*— This paper summarizes the IEEE C37.104-2022, Guide for Automatic Reclosing on AC Distribution and Transmission Lines. Accepted industry practices for application of automatic reclosing on transmission and distribution lines are documented in this guide. The guide discusses fundamentals of automatic reclosing, application considerations, and coordination practices. Application of emerging technologies for automatic reclosing is also discussed. This paper provides a very high-level summary of some of the main topics covered in this guide. Refer to the guide for details and reference material related to automatic reclosing on AC distribution and transmission lines.**

***Index Terms*— automatic reclosing, autoreclose blocking, autoreclose supervision, high-speed autoreclosing, time delayed autoreclosing, fuse blowing scheme, fuse saving scheme**

I. Introduction

IEEE Power System Relaying and Control Committee (PSRC) working group D39 revised *Guide for Automatic Reclosing on AC Distribution and Transmission Lines.* The revised guide was published in April of 2022. This summary paper introduces the revised guide to the industry, now referred to as IEEE Std C37.104-2022 [1].

The guide presents generally accepted industry practices for application of autoreclosing on both distribution and transmission lines. Since most faults on overhead distribution and transmission lines are temporary in nature, the automatic reclosing is commonly applied to quickly re-energize a line to restore system integrity, service to customers, or both.

To apply autoreclosing properly, several factors are considered. Some of the most common considerations are as follows:

- Probability of successful reclosing following a trip
- Potential for damage to equipment by autoreclosing into a fault
- Conditions for which autoreclosing is blocked
- Time-delayed or high-speed autoreclosing
- Number of autoreclosing attempts
- Supervision for autoreclosing
- Consequences of not autoreclosing
- Methods to initiate autoreclosing

Clause 4 in the guide discusses fundamentals of automatic reclosing such as autoreclose settings, autoreclose supervision, autoreclose blocking, and general application considerations on distribution and transmission lines.

Clause 5 in the guide focuses on autoreclosing practices for distribution lines. Distribution lines often contain sectionalizing equipment such as circuit breakers, fuses, reclosers, and sectionalizers to isolate faulted sections of the line. Autoreclosing coordination practices involving coordination with circuit reclosers, automatic line sectionalizers, fuse saving and fuse blowing schemes, etc., are presented. The guide also discusses application considerations for distribution systems containing distributed energy resources.

Clause 6 in the guide discusses autoreclosing practices for transmission lines. Application considerations for high-speed autoreclosing, single-phase tripping and autoreclosing, impact on stability and turbine-generator, series compensated lines, lines with in-series or tapped transformers, multi-terminal lines, line sectionalizing schemes, etc., are discussed in detail.

Clause 7 in the guide discusses application of new/emerging technologies for autoreclosing: Ethernet based protection and control schemes, point-on-wave control, and pulse closing for autoreclosing. An application of using fault location on hybrid or mixed lines for autoreclosing is presented in this clause. The guide also includes an application of multi-phase tripping and reclosing across parallel lines. In case where a fault involves both lines, tripping and reclosing of affected phases only may help maintain system stability.

This is an application guide and may not cover considerations for all scenarios. This guide is intended for engineers who have knowledge of power system protection. Additional reading material is suggested in the Bibliography.

II. Fundamentals and Applications

Fundamental concepts common to automatic reclosing for both transmission and distribution line breakers or other line interrupting devices are discussed in the guide. The four states of reclosing: ready state, reclosing in progress state, lockout state, and not ready state, are presented. There is also a description of how the reclosing relay moves through these states as a circuit breaker operates when trying to restore a distribution or transmission line. Considerations for resetting the reclosing relay are presented. A condition where it may be desirable to prevent reclosing relay from resetting is described. A reclosing relay reset timer starts when reclosing relay closes the breaker. In case of a permanent fault, where a reclosing relay reset time is longer than tripping time delay, reclosing relay resets before breaker tripping. The reclosing relay never advances to the lockout state and the process repeats. To avoid this condition, a longer reclosing relay reset time may be used. Another alternative is to stall reclosing relay from resetting when protective relay element is picked up and timing.

Autoreclosing timing, shots, and open interval nomenclatures are discussed. Automatic circuitry and logic are addressed along with techniques to prevent autoreclosing following manual tripping of breakers. A discussion on selective autoreclosing logic is presented to explain why it could be used as well as a brief discussion on the internal logic of the reclosing controls of a microprocessor-based relay.

Common autoreclosing settings to consider are number of reclosing attempts, dead time, and reset time. The number of reclosing attempts employed depends on several factors, such as available air or gas pressure for breaker operation, system stability, potential equipment damage, and potential adverse impacts to customers. The dead time is set to allow time for the circuit breaker's dielectric strength to re-establish. Another factor to consider is dissipation of ionized gas created by the fault arc. The deionization time depends on the voltage, the conductor spacing, the magnitude of fault current, and the weather conditions [2]. Considerations for properly selecting reset time/delay are also provided in the guide. The reset timer is used to reset the relay after successful autoreclosure of the circuit interrupting device. Also provided are detailing considerations for driving the reclosing relay to the lockout state to prevent reclosing of the interrupting device.

A. *Autoreclosing Supervision*

Autoreclosing supervision serves such purposes as follows:

- Preventing autoreclosing when systems are out of synchronism.
- Preventing autoreclosing that might cause damage to generators or motors.
- Minimizing the number of unsuccessful autoreclosings
- Preventing autoreclosing into faulted equipment such as transformers and reactors.
- Helping to maintain system stability.

The guide discusses the following methods of autoreclosing supervision:

<u>Voltage supervision</u>:

Voltage supervision helps to ensure that voltages on both sides of a breaker are of a desired magnitude prior to autoreclosing. Depending on the system configuration, either single-phase or three-phase voltages are monitored. The following types of voltage supervision are discussed in the guide: dead-line/dead-bus, live-bus/dead-line, live-bus/live-line, and live-line/dead-bus.

<u>Synchronism-check supervision</u>:

Autoreclosing on transmission lines is often supervised by synchronism check. Synchronism check refers to the determination that acceptable voltages exist on both sides of the circuit breaker, and the phase angle and frequency difference (slip) between them is within a specified limit for a specified time. The settings of synchronism-check supervision are designed to reduce impact to the system when the breaker is closed and ensures the instantaneous voltage magnitude across the breaker is within acceptable limits at the time of closing. Guidance is provided to determine limit settings for slip, voltage magnitude difference, and phase angle difference.

<u>Transfer trip supervision</u>:

Transfer trip supervision allows verification of a system configuration and is typically applied on lines with transformers or reactors. Transfer trip supervision is typically applied to block reclosing on transmission lines with transformers or reactors connected without a breaker until it is assured that faulted transformer of reactor is isolated. The transfer trip supervision can also be applied to block autoreclosing for breaker failure operation at the remote terminal.

<u>Parallel line supervision</u>:

This type of supervision is configured to block autoreclosing when a parallel line is out of service and there is a concern with autoreclosing out of synchronism.

<u>Supervision for high-speed reclosing</u>:

High-speed autoreclosing is typically fast enough that supervision may not be necessary or applied. However, some utilities apply some degree of supervision. For example, the designated lead terminal could reclose without supervision, but autoreclosing of the follow terminal is only allowed after voltage has been restored.

<u>Supervision following automatic load shedding</u>:

Autoreclosing is typically blocked if tripping is initiated automatically via underfrequency load shedding (UFLS) or undervoltage load shedding (UVLS) schemes. However, if automatic reclosing is used for restoring loads, supervision using voltage, frequency, time etc. is considered to prevent additional load shed during the restoration process.

B. *Autoreclose Blocking*

There are several conditions for which blocking of autoreclosing is desirable, and they are discussed in the guide.

Autoreclosing is generally blocked and driven to lockout for the following conditions: manual or SCADA trip of a breaker, voltage unbalance, breaker failure to trip/close, discontinuity in trip circuit, high fault currents, cumulative operations exceeding a pre-set threshold, receipt of transfer trip, tripping by a time delayed backup relay element, tripping resulting from a three-phase fault, or tripping via underfrequency, undervoltage, out-of-step relay elements etc.

Delayed reclosing is used until desired system conditions are met and this is briefly discussed in the guide. However, if desired system conditions are not met within a predefined time, reclosing is typically driven to lockout.

Stall reclose is a feature that may be used to block reclosing until the trip signal is removed. This prevents reclosing on a permanently sealed trip signal. For example, when sync check supervision is applied, reclosing is stalled to allow voltages on either side of the open breaker to come within the predefined bounds.

Reclose initiate supervision is used to initiate reclosing for desired conditions rather than blocking reclosing for undesired conditions. With the abundance of microprocessor-based relays on the system, reclose initiate supervision is widely applied.

C. Application Considerations

The guide discusses various considerations to take into account when applying autoreclosing to a line. Some of those are briefly summarized below:

Lines with underground cables:

Faults involving underground cables are often permanent. Lines that utilize underground cables for a portion of their total length present a special concern as to whether or not to apply autoreclosing. The guide notes that transient overvoltage studies may need to be performed to identify any problems that may occur if the line with cables is autoreclosed. The autoreclosing is typically not attempted on lines entirely made of cables [3].

Limitation of circuit breakers and other interrupting devices:

Circuit breakers and interrupters require a minimum time between the initiation of tripping action and the initiation of the closing operation to allow for the dielectric strength within the interrupting device to recover to a point where the device can interrupt a fault current again upon reclose. Another consideration is the time needed for the interrupting device's stored energy mechanism to recharge following a trip.

Effects of autoreclosing on disk type overcurrent relays:

In case of electromechanical disk type overcurrent relays, when the current level is above the pickup, the disk begins to turn and continues to turn until the current drops below the pickup value (either due to opening of an associated breaker or operation of downstream protection). For a permanent fault, if the circuit is energized before the disk is fully reset, then the disk does not have as far to travel as during the initial fault. This could lead to a loss of coordination and may result in an unnecessary trip. This effect is discussed in detail and guidance is provided to address resulting coordination issues. The guidance provided also applies to microprocessor or static relays set to emulate electromechanical reset.

Lines with automatic sectionalizing:

Automatic sectionalizing is typically applied to isolate faulted section of lines. Proper coordination of automatic reclosing at source breakers with line sectionalizing schemes is necessary. Guidance for both distribution and transmission lines with line sectionalizing schemes is provided.

Reclosing on motor loads:

When an induction motor is disconnected from the system, the trapped flux in its rotor decays with time and produces residual voltage. For small induction motors, residual voltage decays in a few cycles, but cases with large induction motors may take up to a few seconds. Synchronous motors have an added complication as they have their own excitation. These effects are considered when applying autoreclosing on lines with motor loads. The guide offers solutions to avoid problems arising from presence of motor loads on a line.

Reclosing near inverter-based resources:

The guide addresses application of autoreclosing on a line directly connected or electrically close to inverter-based resources (IBRs), i.e., solar photovoltaic, type III and IV wind turbine generators, and energy storage or combinations of such. The application of autoreclosing on network electrically close to IBRs involves coordination with IBR's ride-through capability.

Substation Controller and SCADA:

A substation controller is an intelligent device used to control operation of the circuit breakers within the substation and could be used for autoreclosing. Supervisory control and data acquisition (SCADA) offers another dimension to autoreclosing. Benefits of using substation controller and SCADA for autoreclosing are presented in the guide.

III. AUTORECLOSING ON DISTRIBUTION LINES

Reclosing is almost universally applied on overhead distribution lines. Most utilities apply at least one and up to four automatic reclose attempts on overhead distribution lines. Reclosing is generally not applied on lines with no overhead exposure such as fully underground lines, because faults on underground cables are generally permanent. Reclosing practices and application considerations for autoreclosing to distribution lines are presented in detail in the guide and are summarized below.

A. Autoreclosing Practices

The guide provides insight to the common autoreclosing practices on the distribution system. It discusses subjects such as common criteria for setting up the autoreclosing scheme. One important subject is selecting the number of shots used in a scheme [4]. Another is coordination concerns that are considered when choosing the open interval between shots. A table that gives typical open interval times used in industry practice is provided. Also mentioned is autoreclosing used for restoration after distribution bus faults.

B. Coordination Practices

The guide discusses coordination practices with various devices on the distribution system including reclosers, sectionalizers, and fuses. The definitions of circuit reclosers and sectionalizers are provided. The IEEE Std C37.60 and the IEEE Std C37.63 are referenced for further information on reclosers and sectionalizers respectively. Reclosing relays and automatic sectionalizers are used together to isolate a faulted portion of a distribution circuit. The guide includes an example of a pulse-counting sectionalizing scheme, including considerations for proper coordination between the upstream recloser and downstream series sectionalizers.

Fuse saving schemes are used to avoid permanent outages when temporary faults occur beyond tap fuses on a distribution system. A fuse saving scheme employs fast clearing time overcurrent or low set instantaneous overcurrent elements at the source breaker. After one or two operations on the fast tripping curve, the next trip of a source breaker is set for a delayed tripping allowing the fuse to operate first. An example showing coordination of a source breaker with a fuse is included in the guide and is shown in Fig 1.

The fuse blowing schemes are used to reduce the impact of a fault on the total feeder by allowing a fuse time to interrupt a faulted tap or lateral. The source breaker overcurrent protection is set with a sufficient time delay allowing the fuse to operate before the source breaker is tripped.

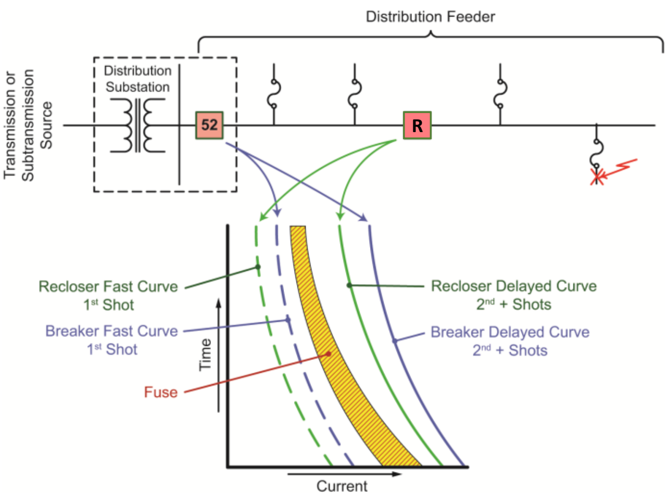

Fig. 1. Coordination diagram for fuse saving scheme

Sequence coordination is a control function that can be included in an electronic recloser or microprocessor-based feeder relay package. This feature is applied to improve the service continuity on lines when two (or more) autoreclosing fault interrupting devices are used in series. The guide discusses sequence coordination in detail and provides an example comparing coordination between two interrupting devices with and without sequence coordination.

C. Application Considerations

In distribution systems containing distributed energy resources (DERs), the reclosing times are coordinated with DER tripping times and fault-ride-through capability. The automatic reclosing of a source breaker onto a circuit remaining energized by the DER may expose utility, customers, and the DER equipment to undesired conditions. The guide recognizes DER performance requirements specified in the IEEE Std 1547-2018 and provides considerations for applying autoreclosing on the utility source breaker connected to a line with DERs. The guide also discusses possibility of formation of an island when the connected DER is comparable to the load on the distribution line/system. The guide presents additional security measures, such as, blocking of autoreclose when voltage is detected on both sides of an open interrupting device, to avoid out-of-phase reclosing. The guide also discusses application of direct transfer trip to disconnect the DER upon opening of the utility source breaker.

Reclosing considerations are presented for cases when shunt capacitors are installed on distribution buses and lines. The guide emphasizes that depending on the location of a shunt capacitor and the point-on-wave of the interruption of the source to the capacitor, the potential of trapped charge in the shunt capacitor is considered.

Also discussed is exposing the load tap changer to a through-fault while reclosing a feeder breaker fed from a transformer during a tap change operation.

Conditions could exist that may require blocking or disabling of autoreclosing on distribution lines. They include tripping of distribution circuits by underfrequency or undervoltage load shedding schemes, detection of downed phase conductor, and faults on underground section of distribution feeders.

IV. AUTORECLOSING ON TRANSMISSION LINES

Autoreclosing of a transmission line is used to increase system reliability and to reduce any economic impact that may occur due to an extended outage of a transmission line. High-speed and time-delayed autoreclosing methods are widely and effectively used today due in part to the increased amount of information that is available via various means such as SCADA. Methods of autoreclosing and the consideration of system elements that affect the application of autoreclosing to transmission lines are presented in detail in the guide and are summarized below.

A. Autoreclosing Methods

High-speed autoreclosing is the automatic closing of a circuit breaker with a very short delay, allowing for fault arc deionization. High-speed autoreclosing provides fast restoration of power to tapped customers, can help maintain system stability, and provides fast restoration of the line to maintain system capacity and integrity. High-speed tripping is often implemented to enable high-speed autoreclosing schemes. In some cases, high-speed autoreclose is the first shot in a multiple-shot autoreclose sequence followed by a time-delayed autoreclose. The guide discusses several factors to consider reducing potential adverse consequences of high-speed autoreclosing. Those are briefly summarized here:

- Monitoring the voltages on both sides of the breaker as well as the phase angle across the breaker in cases where large motors connected to the line maintain voltage on the load side following a trip.
- Impact of an unsuccessful high-speed autoreclose attempt, particularly following a three-phase fault close to generating plant on torsional fatigue on the turbine-generator shafts.
- Timing of breakers at each end of the line.

- Clearing time of a fault from each terminal to avoid extending the fault duration in cases where staggered high-speed reclosing is employed.

- Inserting appropriate delay in breaker mechanism or reclosing relay to allow dissipation of ionized path before reclosing.

- Tapped load that depends on local switch operation via direct transfer trip, high-speed ground switch, or motor operated disconnect switch operation for a transformer fault.

The guide also discusses time-delayed autoreclosing. Time-delayed autoreclosing can be used when high-speed autoreclosing restrictions exist or following an unsuccessful initial high-speed autoreclose attempt. Typically, the initial time-delayed autoreclose dead time can be anywhere from a second to tens of seconds, depending upon system stability, breaker duty, or coordination with autosectionalizing schemes.

Single-phase tripping and autoreclosing is also briefly discussed in this guide. Given that majority of faults on transmission system are single line-to-ground faults, single-phase tripping and reclosing may be beneficial to improve system stability margins. During the open-phase period, two remaining phases transmit approximately half of the power that was being transmitted just prior to the fault. When single-phase tripping is used, only the faulted phase is tripped and will attempt autoreclose. Single-phase tripping involves complex protection and control system that can distinguish between single phase-to-ground and multi-phase faults as well as circuit breakers with segregated poles with separate trip and close mechanism for each phase. With a single phase open, a voltage is induced in the isolated phase due to coupling between phases. This coupling has an effect of prolonging the arc deionization time, referred to as the secondary arc current. The secondary arc current is proportional to the circuit voltage and transmission line length. The minimum dead time is determined based on the duration of secondary arc current. One common method to reduce the dead time is by applying shunt reactors including neutral reactors. Typical single-phase autoreclose times can be anywhere between half a second to two seconds. Single-phase reclosing time is set faster than the breaker pole discordance and less than the fastest operating time of unbalance protection on nearby elements.

B. Application Considerations

Autoreclosing application considerations for various conditions is discussed and briefly summarized below.

Turbine-generator considerations:

Manual closing or autoreclosing without synchronization supervision may subject turbine-generators to excessive shaft torques and winding stresses. An unsuccessful autoreclose attempt for three-phase faults close-in to a generating plant can contribute to accelerated torsional fatigue on the turbine-generator shafts. [5] This could result in loss of life of the turbine-generator system. Considering the risk to turbine-generator life, autoreclosing practices may be modified to incorporate one or more of the following:

- Supervising autoreclose with synchronism check
- Allowing a minimum delay prior to any dead line autoreclose attempt
- Applying single-phase tripping/reclosing
- Disabling autoreclose for multi-phase faults
- Disabling autoreclose near generating plants

Coordination with fast valving:

There is a need to coordinate line autoreclosing in close vicinity of a generating plant with fast valving schemes to achieve acceptable system stability performance. Fast valving is used on some large thermal generating units to assist in maintaining transient stability. The fast-valving scheme rapidly closes and opens steam valves to reduce machine's accelerating power following detection of a severe transmission system fault.

Multiple-breaker line terminations:

Considerations for multiple-breaker line terminations, such as ring bus, double bus/double breaker, or breaker-and-a-half schemes are discussed in the guide. Since simultaneous closing of all breakers is difficult to achieve, a preselected breaker at a terminal with more than one breaker per line is closed first. Following a successful autoreclose operation of the preselected breaker, other breakers associated with the line terminal may be autoreclosed. Voltage or synchronism check supervision may be applied.

The guide also discusses benefits of applying a reclosing relay per line or circuit over reclosing relay per breaker. In case where a breaker is shared by multiple circuits, the reclose requirements (e.g., supervision requirements, number of reclose attempts etc.) may differ depending on which circuit resulted in tripping of a breaker. The reclosing logic for both circuits considering various scenarios may be difficult to implement in a reclosing relay dedicated to a single breaker. Application of a reclosing relay per circuit capable of reclosing multiple associated breakers help simplify the design and implementation.

Series-compensated lines:

Series compensation (capacitive) on extra-high voltage lines is used to increase power transfer capability. Factors such as system stability, single-phase or three-phase tripping, communication means, short-circuit levels etc. are considered in determining autoreclose philosophy on series compensated lines.

Setting synchronism check:

Autoreclosing on transmission lines is often supervised by synchronism check. Synchronism check refers to the determination that acceptable voltages exist on both sides of the circuit breaker, and the phase angle and frequency difference (slip) between them is within a specified limit for a specified time. The guide provides considerations for determining limit settings for slip, voltage magnitude difference, and phase angle difference.

Leader-follower autoreclosing of transmission lines:

The leader-follower autoreclosing scheme is one of the commonly used schemes on transmission lines. The leader terminal is the line terminal that autorecloses first, and the follower terminal is the line terminal that recloses second. An example showing sequence of events depending on timing of the reclosing relay at both ends for a leader-follower scheme is included in the guide. Considerations for applying voltage or synchronism check supervision are also provided. Finally, the leader-follower scheme can also be applied to a line that terminates into multiple breakers at each end. An example is shown in Fig. 2. In this example, terminal A is the leader terminal; however, breakers 1 and 2 do not reclose simultaneously to test the line. Typically, only one breaker is selected to autoreclose first, for instance breaker 1 in this example. The remaining breakers are designated as followers. The guide provides a couple of options as to in which order follower breakers are reclosed following a successful autoreclosing of breaker 1.

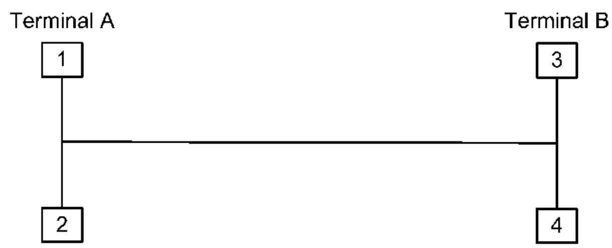

Fig. 2. Line terminating into two breakers at each end

Weak source/strong source considerations:

Typically, the weaker of the two ends is selected to test the line in the leader-follower transmission line autoreclosing practice. This is preferred to reduce stress on the power equipment as well as to limit extent of a disturbance on the power system. On lines with tapped load, using the stronger source to test the line may be preferred as testing a line from weaker end may result in problems such as slow voltage recovery, power quality etc., especially when the test is successful.

Transformer considerations:

The guide discusses considerations for applying autoreclosing on transmission lines involving in-series and tapped transformers. Figure 3 shows an example of transformer in-series with a transmission line, i.e., line terminated in a transformer. In this case, if breaker 2 is chosen to autoreclose for line faults, then the worst- case fault currents and respective clearing times are compared to transformer damage curves. This is of importance when the line is not protected using a pilot scheme, as clearing time for faults close to breaker 1 could be high. Whenever possible, breaker 1 is preferred to autoreclose and test the line.

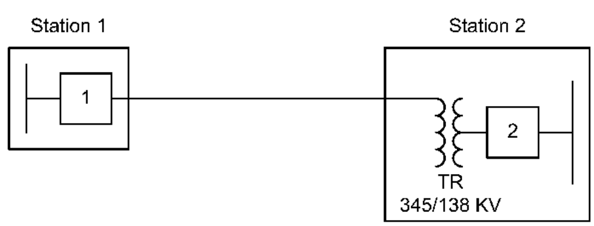

Fig. 3. Transformer in-series with transmission line

A tapped transformer arrangement shown in Fig. 4 is commonly used to serve load along a transmission line. If the tapped transformer is not equipped with a high-side interrupting device to clear transmission faults, then the remote breakers 1 and 2 are tripped to clear bank faults. If autoreclosing of breaker 1 or 2 is allowed, it is only enabled after the trip signal has been reset. The guide also discusses application of motor-operated air switches and grounding switches on the high-side of a tapped transformer and coordination of those with autoreclosing from remote breakers. Considerations for applying autoreclosing when a line fault is sourced by the transformer are also provided.

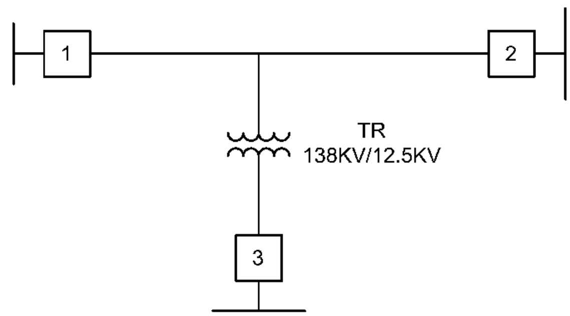

Fig. 4. Transformer tapped on transmission line

Interfacing with automatic sectionalizing schemes:

Transmission lines can be tapped to serve load along the transmission path. Line sectionalizing devices (i.e., motor-operated disconnects) are commonly installed at key strategic points along the line, to sectionalize the faulted portion of the line and to energize the unfaulted line section to pick up the tapped load following permanent faults. The guide provides two examples of sectionalizing schemes and timing charts for each for faults on various sections of the line. Typical breaker open interval times and sectionalizing device operating times are also provided. Coordination of sectionalizing device operating time and breaker open interval time is necessary for proper operation of a sectionalizing scheme.

V. New Technologies and Special Considerations

A. New Technologies

The guide discusses new technologies that have been developed and applied for autoreclosing.

Ethernet based applications to autoreclosing have been developed due to the advent of IEC 61850, distributed network protocol (DNP), IEEE Std 1851, and many other standards for IEDs that are Ethernet related. Since the data are available on the network, changes to reclosing schemes can be initiated easily if the health of breakers and other equipment dictate a need for the change. The guide provides several examples of how these protocols and standards could be used in autoreclosing logic schemes. Use of these technologies also allows to change autoreclosing logic in real time.

Point-on-wave (POW), or controlled autoreclosing, is sometimes applied with autoreclosing. This form of autoreclosing involves processing information from voltage transformers on each side of the circuit breaker to enable each pole to autoreclose at the optimum moment to reduce overvoltages and stress to equipment. In some cases, POW autoreclosing is applied in combination with line-connected surge arresters to reduce switching surges, particularly if breaker closing resistors are not applied.

An alternative and patented approach to conventional reclosing, called pulse closing [6], has been deployed in medium-voltage systems. Pulse closing produces a minor loop or pulse of current by initiating a rapid, single-phase, controlled POW close-open operation using conventional vacuum bottle contacts. This POW operation is initiated after a system voltage peak such that the duration of the resulting minor loop of current is between approximately 1/4 and 1/2 cycles. The resulting minor loop of current is then analyzed to determine if a fault is present or not. The energy represented by the minor loop or pulse of current is appreciably less than the energy resulting from conventional reclosing.

B. Special Applications

Typically, autoreclosing is not applied for an underground cable or a hybrid line consisting of both overhead and underground sections. Some applications may have a considerably shorter underground section as compared with the overhead sections. In these cases, autoreclose may be desired to recover from temporary overhead faults, thus helping to reduce outage durations.

The difficulty for applying autoreclosing on a hybrid line is to be able to determine if the fault is in the overhead section, where reclosing is permitted, or in the underground section, where reclosing is prohibited. Several fault locating algorithms such as PMU-based or traveling wave-based fault locators [7] have been developed to provide more accurate fault location to achieve desired autoreclosing on the hybrid lines. The guide discusses these technologies and application with autoreclosing schemes. These technologies could also be applied for selective reclosing on tapped lines.

In case of double circuit lines, a single fault that involves both lines, can result in three-phase tripping on both lines. This disrupts power transfer through the transmission path and could lead to a major system disturbance. On double circuit lines, if two phases are faulted on one circuit, it would be beneficial to keep the parallel circuit in-service. If a fault involves both circuits, there may be at least two different unfaulted phases on both circuits. Having two healthy phases in-service during a disturbance may help maintain system stability. Multi-phase autoreclosing attempts to keep as many phases as possible connected to maximize system stability and execute high-speed re-closing for multi-phase faults without the need for synchronism or voltage check. [8]

VI. Summary

This paper provides a very high-level summary of some of the main topics covered in the IEEE Std C37.104-2022 – Guide for Autoreclosing on AC Distribution and Transmission Lines. The guide describes benefits of automatic reclosing and includes application considerations for proper coordination with other system controls. The guide contains a number of figures, tables, and graphs which aid in the understanding of autoreclosing concepts outlined in the summary paper. Refer to the guide for additional reference material related to automatic reclosing on AC distribution and transmission lines.

VII. References

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