# NETWORK AUTOMATION WITH RECLOSERS AS NEW COMPONENTS FOR EUROPEAN DISTRIBUTION SYSTEMS

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## *ABSTRACT*

*Reclosers with special protection functionality allow for the utilisation of existing overhead distribution lines beyond the traditional limit. For example, loop automation is used for restoring supply from an adjacent feeder and broken conductor detection enhances the safety in distribution feeders.*

*Beside of the typical application in overhead lines, reclosers are increasingly utilised as feeder breaker in substations. While the commonly employed vacuum technology allows circuit breaker like application, reclosers are tested differently to circuit breakers. The paper discusses differences in testing and consequences for the application.*

## INTRODUCTION

Distribution systems are in transition from simply supplying energy to multifunctional grids with focus on high reliability and efficiency. Reclosers play an important role for overhead systems because of their unique utilization. They are installed in remote locations and act as an "outpost". Based on their good protection, communication and control functions, reclosers can fulfil a number of duties including (i) reacting like a circuit breaker in fault situations, (ii) reclosing and re-configurating the system to restore supply, (iii) monitoring power quality and (iv) controlling the load to stabilize the distribution system.

This paper describes functions which are utilized in modern reclosers for distribution automation beyond the original task of simple breaking and reclosing. This covers protection functions to utilize existing lines up to the thermal limit, load shedding and broken wire detection. They are used to extend the life of existing equipment in order to defer investments for upgrade.

The paper will also cover the use of reclosers as substitute for circuit breakers. This trend is observed because of compact design and easy installation of reclosers. Based on the vacuum switching technologies of modern reclosers the behavior is comparable to circuit breakers. Due to the differences between recloser and circuit breaker standards the testing is different and has to be taken into account for these applications.

## RECLOSERS IN DISTRIBUTION FEEDERS

Reclosers have changed significantly during recent years. Modern reclosers are normally based on vacuum technology with magnetic actuator, which ensures performance comparable to a circuit breaker. The integrated control is often equipped with more functions than the protection relay of switchgear, and is specifically designed for overhead feeders.

### Protection functions for rural O/H networks

Beside of the basic overcurrent protection, reclosers can provide special protection functions required for overhead feeder protection.

#### 1) Long rural lines and its specific characteristics

Long rural feeders have high line impedance due to long feeder lengths, which result in low fault current levels. This makes it difficult to distinguish faults from overload situations with similar current levels, especially in case of distant faults. 50 or 51 overcurrent protection elements may not operate because of the low fault level.

For these special cases the 51V voltage dependent overcurrent function has been developed. It ensures tripping of the recloser only in fault situations. The condition to trip is based on a combination of the current level and the voltage drop level. This distinguishes between fault and overcurrent situations.

Overload situations are common for long rural feeds. They vary in current and length, so it is difficult to set a trip level. Setting the level too low will lead to both unnecessary tripping and power interruption. If the level is too high, it may damage other equipment when the fault lasts too long. The real issue during overload is the thermal stress on lines and transformers. This can be prevented using the 49 Thermal Overload function in the recloser, which calculates the integral heating of line. It takes both the current level and the time for this load into account. High levels of load current will be tolerated if they do not last too long. When the current is low, the overload does not harm the line when it lasts for an extended time. This protection allows the maximum utilization of existing lines without nuisance tripping.

**2) Load shedding in case the demand deviates from the supply to prevent outages**

In the not-so-distant past, blackout prevention was a major topic; however today this issue is rarely discussed. However, reclosers allow smart load shedding schemes using their satellite position in the network. Whenever the network becomes weak, i.e. the demand is higher than the available supply, the voltage and frequency in the network will start to drop. A fast reaction within seconds is required to switch off certain parts of the distribution network in order to reduce the load, keeping the remaining network powered up and stable. The decision about dropping parts of the feeder will be made on utilizing the 81 Under/Over-frequency and 27/59 Under/Over-voltage elements. They will contain settings for which frequency or voltage in the network section shall trip the recloser. When the supply normalizes, the feeder recloser will be switched back on while monitoring for overcurrent issues. [3]
The 51C cold load function makes sure the feeder will not trip immediately after closing. It allows increased current levels for a determined period of time, which is typical for cold start situations.

**3) A broken conductor application with focus on personnel safety**

A broken line situation poses a high risk to personnel working on or around the distribution lines, especially when the line has fallen to the ground. While it is easy in many networks throughout the world to detect downed conductors, it is difficult in the multi-grounded networks common in North America. An excellent solution to detect this fault is through the broken conductor function in the recloser. If a broken conductor is detected, the safe assumption is that it has fallen to the ground. The recloser trips the circuit, and a repair team should be immediately deployed to correct the situation.
A broken conductor can be detected by comparing negative and positive phase sequences in the feeder. A jump in the level indicates a broken conductor, regardless of the upstream or downstream location. Since the same effect happens when a CT or VT fails, there are some additional features to distinguish these faults as well.

**4) Loop automation**

The LOV function is applied by reclosers at the sectioning points along a feeder and by a Normally Open (Tie) Point at the junction of two feeders, see fig. 1. The purpose is to ensure the automatic restoration of power to as many customers as possible. Cain [4]
Following the permanent-fault lockout of a source, not only the faulted section will lose, but also the downstream healthy sections of the network. Automatic network reconfiguration improves system availability and reduces Customer Minutes Lost and SAIDI by automatically isolating a faulted section and then quickly restoring service

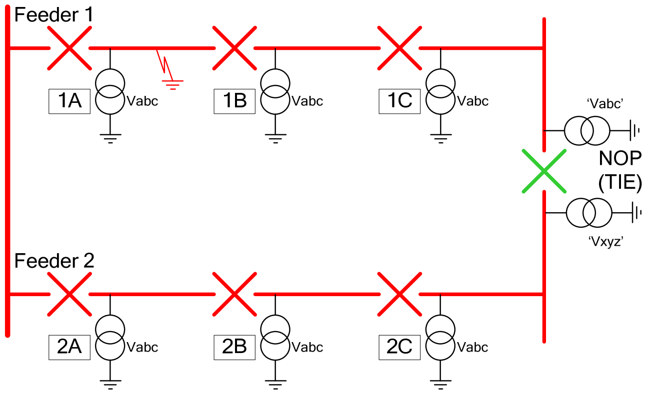


Fig. 1: System diagram showing ring (loop) with normally open (TIE) point

to the unaffected healthy sections of the system. This is achieved by sequential opening of the downstream recloser, which has not seen fault current, thereby isolating the faulted section and then closing a Normally Open/Tie Point to back feed the healthy sections. Automation is normally applied in areas where there are Normally Open/Tie Points to other feeders to enable system restoration via back feeds. Controller protection settings must, therefore, be bi-directional with forward and reverse settings to enable grading in either direction independent of system configuration.

## RECLOSERS AS FEEDER BREAKERS IN SUBSTATIONS

Circuit-breaker for medium voltage application and recloser use similar technology. Vacuum interrupters are the heart of both devices. Despite the use of the same basic technology, circuit-breakers and reclosers are tested according to different standards including different test duties. Circuit-breakers are tested according to IEC 62271-100 or IEEE C37.09 but recloses are tested according to the dual standard IEEE C37.60 / IEC 62271-111.

### Comparison between short-circuit testing on circuit-breakers and reclosers

The first difference is that circuit-breakers use a shorter operation sequence. It usually consists of 3 open operations, and the time between the second and the third breaking operation is significantly longer than the first time difference. A common sequence is O - 0,3s – CO - 3min - CO. Reclosers usually have 4 open-operations in an operating sequence, and the time delays between the second and following open-operations are usually shorter than for a circuit-breaker. A typical sequence is O - 0.2s - CO - 2s - CO - 2s – CO. Due to the shorter time between the CO-operations the vacuum interrupter in the recloser will have a higher stress than a circuit-breaker.

Despite the higher stress from the operating sequence, the following investigation evaluates the total number of operations at different current levels. The duty class E1, defined for circuit-breakers in IEC 62271-100, contains one operation sequence for each test duty. The stress on the equipment under test is obviously less than the tests according to the recloser standard. Because of this fact, this investigation will only compare the duty defined for E2-class circuit-breaker with the duty defined in the recloser standard.

Table 33 of IEC 62271-100 contains 3 different test methods for testing class E2 circuit-breakers, and refers to the calculation between the methods in reference [5].

Vacuum interrupters are usually tested according to list 3. Some types of vacuum interrupters can withstand a significantly higher stress than is defined in list 3. Since list 3 exceeds the contact wear generated from list 1 testing by 34% according to the calculation in [5], the comparison is performed on the test duty given in list 3 only. It contains one full sequence (3 times open) of T10 and T30, 15 single open operations of T60, 15 full sequences (3 times open) of T60 and 2 full sequences of T100.

The recloser test according IEC 62271-111 uses different percentages of the rated short –circuit current. Instead of 10, 30 and 60 and 100% as used in 62271-100, the recloser standard tests with 20, 50, and 100%. Details are given in table 1.

| Test Object | % of rated s.c. current | Operating sequences | Test sequences | Total # of breaking ops |
|---|---|---|---|---|
| Circuit-breaker (IEC 62271-100 list 3) | 10 | O – 0,3 s – CO – t – CO | 1 | 3 |
| | 30 | O – 0,3 s – CO – t – CO | 1 | 3 |
| | 60 | O | 15 | 15 |
| | | O – 0,3 s – CO – t – CO | 15 | 45 |
| | 100 | O – 0,3 s – CO – t – CO | 2 | 6 |
| Recloser (IEC 62271-111 tab.6) | 20 | O - 0.2s – CO - 2s - CO - 2s – CO | 11 | 44 |
| | 50 | O - 0.2s - CO - 2s - CO - 2s – CO | 14 | 52 |
| | 100 | O - 0.2s - CO - 2s - CO - 2s – CO | 4 | 16 |

Table 1 – Operating sequences E2 circuit-breakers and reclosers

Different methods are used to calculate the contact erosion or duty. In [5] the equivalent number of operations is calculated using

$$N = (0.5 * \frac{I_{SCr}}{I_{SC}})^{1.7}$$

With $I_{SCr}$ = rated short-circuit current and $I_{SC}$ = applied short-circuit current

In addition, a 2-step model is proposed, where the equivalent number of operations for current below 35% of the rated short circuit current is determined with an exponent of 3. For higher currents between 35% and 100%, an exponent of 1.7 is used. This investigation was done on a $SF_6$ buffer circuit-breaker. Vacuum circuit-breaker are usually characterized with much higher short-circuit interruption capacity; therefore this 2-step model may not be applicable for vacuum circuit breakers. In [7] an exponent of 1.5 is discussed, together with an exponent of 1 for smaller currents. In general it should be taken into account that all these methods are models designed to provide guidance on electrical life measured by contact wear, using data from a limited set of current interruption tests. Ref. [6] describes the influence of different contact designs. The arc between the contacts in vacuum results in contact erosion and the amount of metal vapor and metallic particles depends on the contact material. Different models of contact erosion all use the general method to calculate the equivalent number of operations. The choice for the exponent is based on past experience, and ranges in value from 1 up to 2. To understand the effect of the exponent value, the comparison between the circuit-breaker and the recloser tests was done for two exponents. It is very likely that all the different interrupter designs fall into this range of exponent variation. The exponent variation range was set to 1.5 - 1.9.

## Calculation

Fig. 2 shows the number of breaking operations vs. the breaking current. In multiple test series, and also in [5], [6] and [7], it was found that the relation between the number of full short circuit breaks and the number of rated continuous current breaks at the M2-level (10000 operations) creates a line in a double logarithmical diagram. For a linear equation in a double logarithmical diagram, the slope of the line is equal to the exponent.

Similar to mechanical engineering, the wear is considered as a wear rate $V_i$ .The wear produced during a test is a function of the number of operations, the contact erosion rate and the current.

$$V_i = N \alpha I^{\beta}$$

where N is the number of operations, $\alpha$ is the erosion rate, I is the current and $\beta$ is the exponent discussed previously.

For a complete test series, the wear is

$V_{it} = \sum V_{iTx}$ in which $V_{iTx}$ is the wear rate produced during the different test duties.

For the circuit-breaker test this formula results in

$$V_{iCB} = V_{iT10} + V_{iT30} + V_{iT60} + V_{iT100}$$

and for the recloser test

$$V_{iRC} = V_{iT20} + V_{iT50} + V_{iT100}$$

From the circuit-breaker wear rate and the recloser wear rate a quotient is made

$$Q_{V\,i} = \frac{V_{iRC}}{V_{iCB}}$$

A recloser with the ratings 12.5kA, M2 class (10,000 mechanical operations) was calculated. We found a higher stress of about 14% for the test according to the recloser standard IEC 62271-111 as compared to the test according to list 3 for an E2 circuit breaker in IEC 62271-100. The difference between exponents of 1.5 and 1.9 was minor, with a difference of ~1% between the 1.5 and 1.9 exponents.

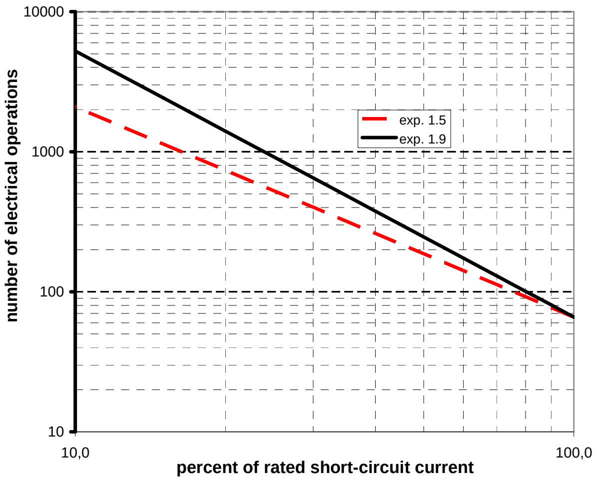


Fig. 2: number of breaking operation in dependence from applied short-circuit current

## CONCLUSION

Reclosers combine fault interruption with long electrical and mechanical life, together with control systems that allow for sophisticated fault detection and protection. This combination allows reclosers to protect feeders in ways far beyond the traditional duty of interrupting high short-circuit current faults. This performance, combined with the small size and easy installation, make reclosers an attractive alternative to substation circuit breakers. The recloser short-circuit test duty in IEEE C37.60 / IEC 62271-111 is about 14% more strenuous than the E2 short-circuit duty according to list 3 in IEC 62271-100. Therefore, reclosers can be used as an alternative to standard circuit breakers.

## REFERENCES

[1] K. Brewis et al, 2009, “21st Century Protection, Control and Automation of Auto-Reclosing on Distribution Networks”, SEAPAC 2009, Melbourne

[2] R. Wolff, 2010, “Integrated logic schemes for protection and control of rural distribution feeders”, CARILEC 2010, St. Maarten

[3] C. Heinrich, 2008, “Uninterrupted supply in rural overhead distribution networks by means of recloser application”, CEPSI, Macao

[4] G. Cain et al, “Application of reclosers for reliable supply in rural overhead distribution networks”, CIRED, Prague, May 2009

[5] A. Pons, A. Sabot, G. Babusci; Electrical endurance and reliability of circuit-breakers. Common experience and practice of two utilities. IEEE Transactions on Power Delivery, Vol. 8, No. 1, January 1993

[6] Paul G. Slade, R. Kirkland Smith, "Electrical Switching Life of Vacuum Circuit Breaker Interrupters," Proceedings of the 52th IEEE Holm Conference on Electrical Contacts, 2006, pp. 32-37

[7] P. N. Stoving, J. F. Baranowski: Interruption life of vacuum circuit-breaker, Proceedings IEEE 19th International Symposium on Discharges and Electrical Insulation in Vacuum, Xi’an China, 2000