

APPLICATIONS ASSESSMENT OF PULSE CLOSING TECHNOLOGY

A Joint Project of the Electric Power Research Institute and Hydro-Quebec

ABSTRACT

Pulse closing is a new technology for overhead distribution system protection. It uses a new method for verifying that a power line has cleared a fault before initiating a closing operation. Pulse closing is an alternative to conventional reclosing. It is expected to significantly reduce stress on system components as well as improve power quality experienced by customers upstream of a fault.

This paper introduces a project initiated by the Electric Power Research Institute (EPRI) to work with electric utilities to assess the performance and benefits of pulse closing technology. The project includes staged fault testing at the Hydro-Quebec IREQ test facility, as well as real-world monitoring of pulsecloser installations on participating utilities' distribution feeders. At the time of this writing, the project is still open to new membership.

INTRODUCTION

This paper describes pulse closing, a new technology for distribution system protection. It is an alternative to conventional reclosers and offers distinct advantages over them. It has recently been introduced in a product form for overhead distribution system protection. It may eventually be used in underground distribution systems as well. The status and features of the technology are described. A program is described for capturing early experience with the technology to help utilities adopt it.

BACKGROUND ON PULSE CLOSING

Conventional reclosers stress the circuit components with fault current every time they reclose into a fault. In contrast, after interrupting a fault, pulse closing injects a low energy current pulse into the line to determine if the fault cleared. By not closing into an existing fault, short-circuit current surges that stress the circuit and components, including substation transformers, are greatly reduced. This mode of operation sets pulse closing apart from other technology in the industry.

The technology has become available from S&C Electric as an integrated package (see Figure 1) which includes the fault-interrupting mechanism as well as control and monitor components which may provide fault isolation and circuit restoration functionality within an overall distribution automation system. The technology can operate as a standalone fault interrupter or can be integrated into a SCADA or a distribution automation system that may support automatic restoration functionality.

Utilities have begun installing the first commercial pulse closing units. A knowledge base on best practices for applications of pulse closing needs to be developed.



Figure 1. Photograph of IntelliRupter[®] PulseCloser available from S&C Electric Company.

FEATURES AND USES OF PULSE CLOSING

Conventional reclosers trip to clear an initial fault, but then reclose several times to determine if the fault has disappeared or if it still remains. If the fault was only temporary, then one of the reclosing attempts will hold closed, and service is restored to the line. If the fault still exists at the end of the reclosing sequence, the recloser locks out, indicating that there is a permanent fault on the line that needs to be removed by a line crew.

A problem with conventional reclosing is that each reclose attempt re-establishes full magnitude fault current until a tripping condition is reached according to the Time Current Characteristic (TCC) curve that has been configured for each operation. Depending on the fault current magnitude and the selected TCC curve, the fault current may flow for anywhere from many cycles to a few seconds. Each conventional reclose attempt reignites arcing at the fault location, potentially causing more damage to power system equipment and nearby surroundings. The bus voltage sags, affecting customers on the faulted feeder and possibly those on nearby feeders as well.

Fault currents create thermal and mechanical stress on all distribution system equipment that carries the fault current, so removing the fault as quickly as possible is critical. Nothing is more sensitive to through-faults than the substation transformer. Each surge of fault current reduces the life of the transformer, so a method of reducing the size and quantity of these surges can result in an economic benefit in terms of asset life extension.



Figure 2. Current versus Time – Conventional Recloser.

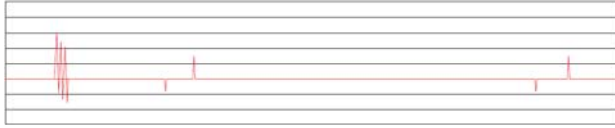


Figure 3. Current versus Time – PulseCloser.

A new technology - pulse closing - can be used to determine if the fault is present without re-establishing fault on the system. After interrupting the initial fault, a small pulse of current can be used to test for fault current before closing. The oscillograms in Figures 2 and 3 show the significant difference in current versus time during fault testing with a conventional recloser and a pulse closer.

Pulse closing is accomplished by a sub-cycle close-open of the switchgear contacts. In fact, the contacts are closed for less than 2 ms. Current flow is established as the contacts close, but the contacts open before the first current zero crossing, at which time the current flow is extinguished. Another important part of the technology is the ability to close the interrupter contacts at a specified point on the voltage wave. The ideal point-on-wave closing angle must generate enough current to measure and analyze, while still keeping the energy let-through into the fault as low as possible.

The target range for point-on-wave closing is shown in Figure 4. The interrupter contacts are closed after the voltage peak with the intention of creating an asymmetrical current, but with the first loop being a minor loop. Since the contacts part before the zero crossing, only the first minor loop of current is allowed to flow. Therefore, the peak magnitude of the current is reduced and the duration is limited to 3 – 8 ms. This minor loop of fault current is the pulse used for testing the line.

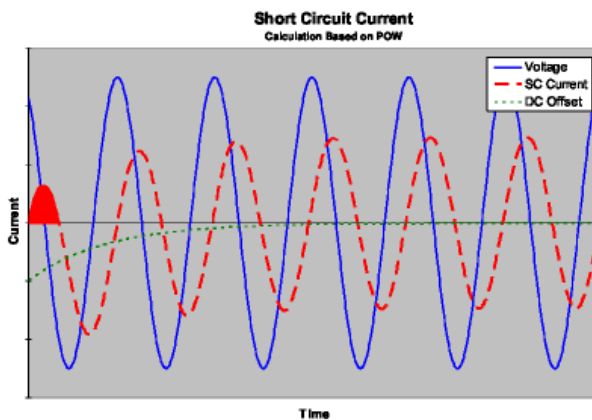


Figure 4. The pulse is a minor loop of fault current. Only the first minor loop of current (shaded area) is allowed to flow.

The current pulse waveform reveals the system conditions and can be analyzed to detect whether or not the line is faulted. If the predicted symmetrical current is less than the specified fault current threshold, the pulse closing algorithm concludes that there is no fault and closes the pole. Conversely, if the predicted closing current is equal to or greater than the fault current threshold, the process concludes the feeder segment is faulted and the pole being pulsed is not closed and any poles that had previously closed are opened.

Occasionally, the aggregated trapped residual flux in downline transformers may result in a large inrush of current upon closing. When the pulse predicts that the line is faulted, an additional pulse in the opposite polarity can be performed to accurately distinguish between system faults and magnetizing inrush. The pulse and inverse pulse can be seen in Figure 3. If the inverse pulse predicts load current, then it is determined that the first pulse experienced high current due to magnetizing inrush, and that it is acceptable to close the pole. In Figure 3, the fault is permanent, so both the pulse and the inverse pulse detect the high fault current level and avoid closing the pole.

The relative let-through energy, in I^2t , of a pulse closing operation is typically less than 2% of a conventional reclosing operation. An example for a 5,000 ampere fault is displayed graphically in Figure 5. To calculate the conventional reclosing energy, a common delayed TCC is used, and it will allow a 5,000 ampere fault to remain on the system for 0.160 seconds. The equivalent I^2t is approximately 4,000,000 A^2s . Pulse closing does not use a TCC curve for testing. Instead, a pulse of current lasts for approximately 5 ms, and due to precision point-on-wave closing, the RMS equivalent fault current is limited to approximately half that of the symmetrical fault current experienced with conventional reclosing. So, the I^2t for a pulse is approximately 30,000 A^2s , which is 0.75% of the energy associated with a conventional reclose.

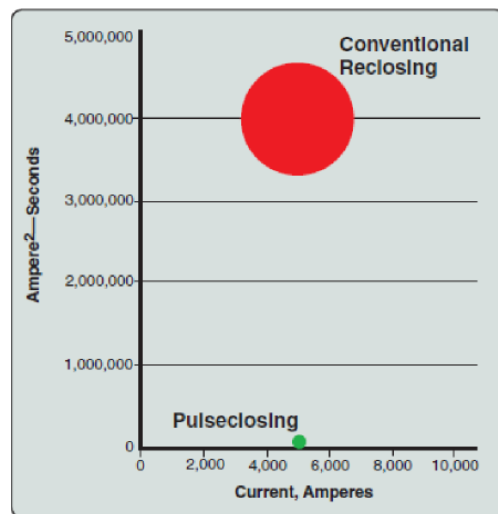


Figure 5. Relative let-through energy for a typical 5000 ampere fault.

The pulse closing technique acquires the same key information as conventional reclosing – determining whether the system is faulted or not – but it does so while minimizing harmful side effects. Pulse closing can be applied on any type of distribution circuit, from the simplest radial circuit, to looped distribution systems, to the most advanced multi-source network.

TESTING AND EVALUATION PROGRAM

General need

As a new technology, pulse closing needs to be assessed to quantify the benefits and the requirements for integration with other active components in smart power distribution systems. This assessment will help obtain maximum value in a rapid manner from the new technology. The results of the assessment will support applications development for pulse closing and integration of pulse closing with other new technologies that are part of the evolving picture in smart distribution systems.

Project overview

A utility-sponsored project has been organized to assess the effectiveness of pulse closing technology and evaluate its possible impacts on distribution system operations. The project will evaluate pulse closing technology in a laboratory and in field application experiments. System integration issues will be identified and assessed. Evaluation methodology will be developed to assess the technical and economic impacts of the technology. The project results may be used by utilities to identify candidate feeders where the new technology may significantly improve power quality and/or reduce premature aging of substation transformers or distribution system components.

Project activity description

The project consists of the following activities. The lab and field testing are being done in parallel over an extended period of time.

1. Webcast planning and coordination meetings with sponsors.

The sponsors' planning and coordination processes are conducted via webcast meetings. The test team performs the work at the laboratory and field locations.

2. Preparation for laboratory testing on pulse closing.

Three pulse closing units will be obtained for test and evaluation in a laboratory setting at the Hydro-Quebec IREQ test facility near Montreal. The unit will be purchased, leased, or rented, depending on the plausible arrangement with the supplier. Needed specification information to support the testing will be obtained from the supplier. EPRI and Hydro-Quebec will develop a plan for testing the unit in the laboratory. The test plan will be reviewed with the sponsors in a webcast coordination meeting before implementation. The tests to be performed will include those targeted at quantifying the performance characteristics of the pulse closer. Subsequent analysis of the test results will be used to help utilities make decisions on application of pulse closing technology.

3. Preparation for field testing on pulse closing.

A plan will be developed for testing at several units in different application situations in the field. These field tests will be performed by utilities, which will procure and install the pulse closing units and monitoring instruments, and then take the data in the field. The test plan will be reviewed with the sponsors in a webcast coordination meeting before implementation. EPRI will provide engineering support to the host utilities to prepare for the testing. The testing will involve both some staged testing and some operational run-time testing.

4. Assessment methodology development.

Assessment methodology will be developed to evaluate the life cycle costs and benefits when replacing a traditional recloser with the new technology. Key contributors may include equipment costs, deferred capital costs as a result of avoided aging effects in line and substation equipment, and increased power reliability and quality. Methodology development will address:

- Requirements to represent the pulse closing technology in existing models and distribution system simulation tools. Perform initial modeling work that can be done with existing tools in support of the testing work. Also, identify needs for new modeling and simulation tools pertaining to pulse closing that may be the basis for development in a follow-up project.
- Analysis and assessment methods to examine the effectiveness of the technology for various feeder configurations, including determination of the fault distance for which pulse closing is effective.
- Methods to assess and quantify the avoided stress on line equipment and substation transformers by not reclosing into an existing fault, and to analyze the potential economics of reducing aging effects by eliminating current surges when reclosing into an existing fault.
- Methods to assess power quality impacts of the new technology on customers, including voltage sags caused by reclosing into existing faults.
- Methods to identify system integration issues for using pulse closing in conjunction with other active components in a distribution system and proposed resolutions for any key system integration problems that may be identified. The need for follow-up project work will be determined.

5. Conduct lab testing.

The laboratory testing will be performed in accordance with the predetermined test process from Step 2 above.

6. Conduct field testing.

The field testing will be performed in accordance with the predetermined test process from Step 3. Both staged and operational run-time testing will be included.

7. Perform data analysis and technical and economic assessments.

The analysis and assessments will be performed using the methodology from Step 5 and the results from the laboratory and field testing. The analysis and assessment

work will begin as the data begins to flow from the laboratory and field and continue in parallel with completion of the run-time testing on field units.

8. Document results and methodology.

A final report will document the laboratory and field experience with the technology, the assessment results, the methodology, and the application guidelines. EPRI will conduct a workshop with the sponsors to review the project results, get feedback, and explore possible follow-up projects. Additional technical papers will be published.

BENEFITS OF PULSE CLOSING AND THE ASSESSMENT WORK

Benefits to the public

The benefits of pulse closing technology to the general public are:

- Improved power distribution system reliability, reducing consumer inconveniences and costs associated with power outages.
- Improved power quality and reduced disturbances during outage recovery processes, due to use of pulsing to test before reclosing rather than reclosing directly into circuits which may still be faulted.
- Reduced risk of igniting fires caused by arc energy released during fault events.
- Lower consumer electricity costs due to the extension of distribution equipment life that will be possible with pulse closing.

Benefits to electric distribution utilities

The benefits of the pulse closing technology assessment to electric distribution utilities are:

- Understanding of applications and limits of a new technology, pulse closing.
- Identification of impacts of a new distribution protection technology (pulse closing) on distribution automation systems.
- Understanding the technical and economic impacts of reclosing into existing faults on line and substation equipment life.
- Acceleration of the efforts of utilities to advance automation of distribution systems.

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