Analog Simulator Tests Qualify Distance Relay Designs to Today's Stringent Protection Requirements

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***Abstract*—Deregulation, increased loads, and limited resources/rights-of-way available for the building of new transmission lines are routinely pushing modern power transmission networks to operating limits. New generations of microprocessor relays provide design opportunities that help stressed transmission networks meet protection requirements. To verify that increasingly complex microprocessor relays fulfill design specifications and utility protection requirements, China EPRI has designed an analog simulator test system to test many new designs of name-brand microprocessor relays.**

This paper draws upon many years of test experience to provide a summary of the common areas presenting the greatest challenges to distance relay designs. These challenges include evolving faults, faults with high fault resistance, power swing blocking, and reliable fault clearance during system power swings. The paper introduces ways that relay manufacturers have adapted and improved performance of their relays in these problematic areas. The paper compares the differences between analog and digital simulator systems and points out unique characteristics of each system. This paper focuses mainly on distance relay qualifications and applications for high-voltage transmission systems.

I. Modern Requirement for Distance Protection

In the past several years, power transmission systems in China have expanded enormously. Increased power system complexity calls for corresponding protection device improvement.

As the Chinese economy has expanded, transmission lines have needed to transmit more power to satisfy increased load. Following newly established policies of transporting power from western to eastern China and interconnecting regional power networks, transmission lines have become increasingly longer. To improve transmission line capacity, the Chinese have added series-capacitor compensation including Fixed Static Var Compensator (FSC) and Thyristor-Controlled Series Capacitor (TCSC) to the power system.

Distance protection relays, although widely used for transmission line protection, must meet the following stringent requirements of power system development:

- Relay operating time must be less than 20 ms for metallic faults along the entire length of the protected line, which means a sub-cycle tripping time for 50 Hz transmissions systems.
- Transient overreach error of distance elements must be less than 5 percent.
- Relays must correctly identify the faulted phase for single-line-to-ground (SLG) faults.
- Distance relays must not misoperate during power swings. These power swings include those occurring during normal system operations when all three breaker poles are closed or those occurring during a single-phase open period following a successful trip of an SLG fault (phase-open or unsymmetrical power swings).
- Distance relays normally have a power swing blocking (PSB) function to detect power swings and block distance elements. Any PSB must be removed to allow distance protection operations after the relay detects additional faults during a power swing.
- Distance relays must operate correctly for series-capacitor-compensated (SC) systems.
- Relays must correctly identify the faulted phase when there is no overlap between external and internal faults in an evolving fault situation.

Although designing a distance relay to meet all of these requirements is challenging, safe power system operation depends upon such a design. In China, a newly developed protection relay must undergo a comprehensive validation test to verify that it will meet all requirements before the relay can be installed on Chinese high-voltage transmission systems. During the test, a relay is subjected to several thousand faults or abnormal operating conditions. Several different system models are used to generate the different fault scenarios and operating conditions. These simulator tests often reveal design flaws and allow relay manufacturers to correct or improve firmware and algorithms before the relay is placed in service. The simulator test dramatically reduces the possibility of relay misoperations in the actual power system.

II. Analog simulator Test for Distance Protection

In China, qualification testing of protection relays is done mainly through use of an analog simulation system. The dynamic simulation test is essential to determining the overall performance of a protection relay. The test center at the China Electric Power Research Institute (CEPRI) has tested various kinds of distance protection relays. Models that accurately represent the actual power systems and well-designed test cases are the foundation for a comprehensive evaluation of a protection relay.

A. Introduction of test system

To ensure the accuracy of dynamic simulation test results, the model and test plan of the dynamic simulation test system are very important. According to the national power industry standard DL/T 871-2004, "Dynamic simulation test for the protection products in power system," CEPRI has established a series of 500 kV dynamic simulation test systems that include the following models:

- 400 km and 200 km double-line model at 500 kV in Fig. 1.
- Three-terminal ring network short line model at 500 kV in Fig. 2.
- 500 kV Transmission line model with zero-sequence mutual coupling in Fig. 3.
- Series-compensated transmission line model with MOV protection on the capacitors in Fig. 3.

Parameters and performance of the above systems meet all DL/T 871-2004-specified requirements.

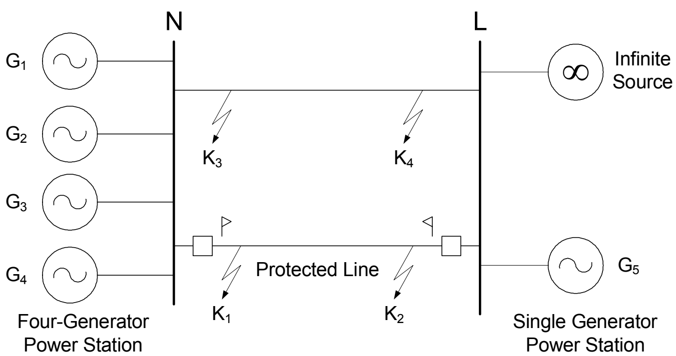

Fig. 1 Double-line model

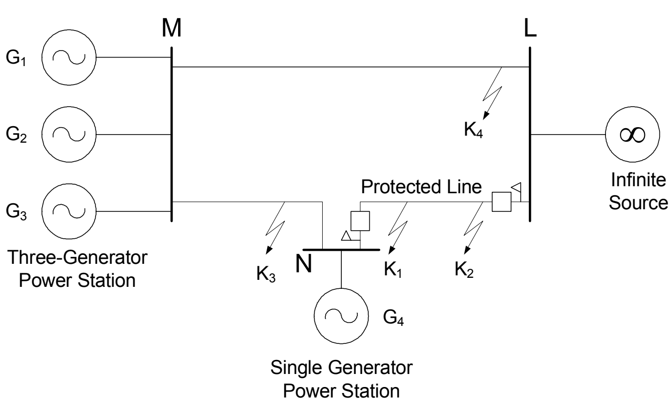

Fig. 2 Short three-terminal ring network

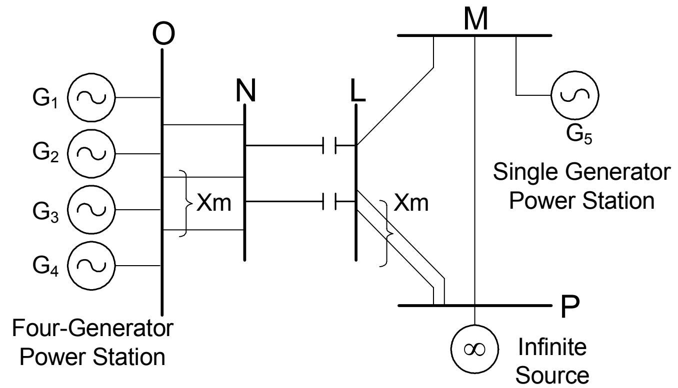

Fig. 3 The system with series compensation

Based upon our experience with relay testing, we consider the following to be advantages offered by an analog simulator in testing distance protection relays.

- Transmission line parameters—A simulation system takes into consideration impedance angle, capacitance, and reactance effects for transmission lines of various lengths and voltages. Reactance effects include harmonics, charging currents, and transient reponses.
- Source strength—The simulation system helps in the consideration of maximum and minimum source capacity by varying fault current levels to help testers determine the worst case operating condition for protection.
- Capacitive Voltage Transformer (CVT) transient response —The performance of distance relays is strongly influenced by CVT transients. Poor CVT transient response often leads to distance element overreaching. Simulation systems help determine the best CVT transient response according to IEC standard requirements.
- Other significant considerations include CT saturation, fault inception angle, and system measurement precision and analysis method.

B. Introduction of test items

The main test items for a distance relay include transient overreach, operating speed, internal and external metallic faults, faults with fault resistance, evolving faults, cross-country faults between parallel lines with zero-sequence mutual coupling, power swings caused by loss of dynamic and static stability, internal and external faults during power swings, switch onto faults, and loss of potential conditions.

In this paper, we shall discuss most of the above test items while keeping in mind such considerations as control of load, fault initiation angle, power swing, current reversal, and evolving fault as follows:

- Different load levels— It is possible to control the simulation model to provide maximum heavy load and minimum light load along the transmission line.
- Different fault initiation angles—Harmonics are most severe when the fault is initiated at voltage angles near 90 degrees. The exponentially decaying dc component,

on the other hand, is most severe when the fault occurs at close to zero voltage.

- Different power swing slip frequencies—Slip frequencies are limited to a range between 0.75 Hz to 4 Hz. The test simulates the power swing resulting from loss of static stability and dynamic stability after a fault. For a fault during the power-swing test, testers can specify the initiation point at different positions on the power swing curve.
- Current reversal—The time difference between fault clearances of relays at both ends of a line will cause current reversal on a parallel line. The test allows current reversal time to be controlled.
- Fault evolving time—Fault evolving time changes from the first fault to the second fault according to fault duration. Normally, the test uses three evolving times. The first time is around 20 ms, so that the fault evolves after a distance relay detects the first fault but before it issues a trip. The second evolving time is around 60 ms, so that the fault evolves just after the breaker opens for the first fault. The third evolving time is around 200 ms, so that the fault evolves well after the relay single-pole tripping action for the first fault.

Because a relay could perform differently for different models and simulations, any test must be as comprehensive as possible.

III. Qualify Relay Designs to Meet Requirements

A. Performance of distance protection during evolving faults

For distance relays using one permissive trip communication signal, it is difficult to select the faulted phase during evolving faults on a double-line system, especially when the external fault and internal fault overlap in time. In this case, one cannot avoid a three-phase trip of the remote-end relay. However, if the internal and external faults do not overlap in time, the relays at both line ends should only trip the faulted phase.

The following two examples help illustrate some of the issues involved.

Example I:

Issue: During a test, a relay misoperated and tripped three phases during an evolving fault without time overlap.

Test: Refer to Fig. 2, in which an external B-phase-to-ground fault at K_4 evolves into an internal C-phase fault at K_2 within 200 ms. The load on the protected line is 0.8 A. The CT nominal current is 1 A. There was no time overlap between the external fault and the internal fault. The close-in relay (L terminal) operated within 37 ms to trip three phases. The operating time is measured from the start of the internal fault.

Event analysis: During the process of a current reversal following the external fault, the measured impedance moved to the power-swing blocking area. As shown in Fig. 4, the distance relay uses the power swing blocking principle of concentric impedance characteristics. The PSB signal asserted with a set time delay after the impedance entered the region between Zone 3 and the PSB outer detection characteristic. Following the PSB signal, the internal fault occurred. The relay logic detected a sudden change of current on more than two phases, determined that there must be a multi-phase fault, and tripped three phases.

Improvement: Although changing the PSB and Zone 3 impedance settings can remove this misoperation, the relay logic in this example will cause problems in the field.

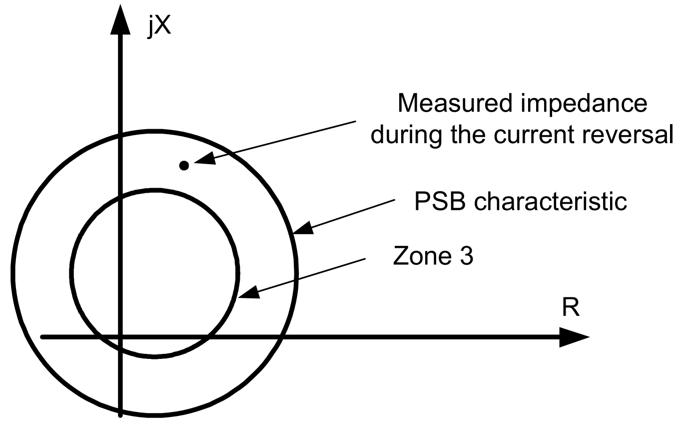

Fig. 4 The location of measurement impedance

Example II:

Issue: There are some distance relays that delay trip operations so that, in most cases, relay logic can select the faulted phase for the internal fault during evolving fault situations when the internal and external faults overlap in time. If there is a period during which the internal fault and external fault exist together, the remote-end relay will wait 120 ms after it detects a phase-phase-ground fault. The relay should select the correct faulted phase during this period after the relay on the adjacent line clears the external fault. If the external fault persists during this set time, the relay on the adjacent line either did not detect the fault or it operated with a long delay. The remote-end relay then trips three phases.

Test: Refer to Fig. 2 to see an external A-phase-to-ground fault at K4 evolving into an internal B-phase-to-ground fault at K2 after 20 ms. The close-in (L terminal) relay on the adjacent line tripped the A-phase in 64 ms, and the remote-end (M terminal) relay on the adjacent line tripped the A-phase in 154 ms. The close-in (L terminal) relay on the protected line tripped the B-phase in 21 ms, and the remote-end (N terminal) relay on the protected line tripped three-phase in 79 ms.

Event analysis: Distance relays operated in this manner because the voltage of N terminal was 31 V after the L terminal cleared the external fault. The setting value of the undervoltage element at N terminal is 32 V, so the A-phase undervoltage element operated and caused a three-phase trip. Fig. 5 shows the operating sequence. The lesson from this example is that one must select the value of the undervoltage element after careful consideration of all system conditions, especially when a current reversal occurs after the relay clears an external fault.

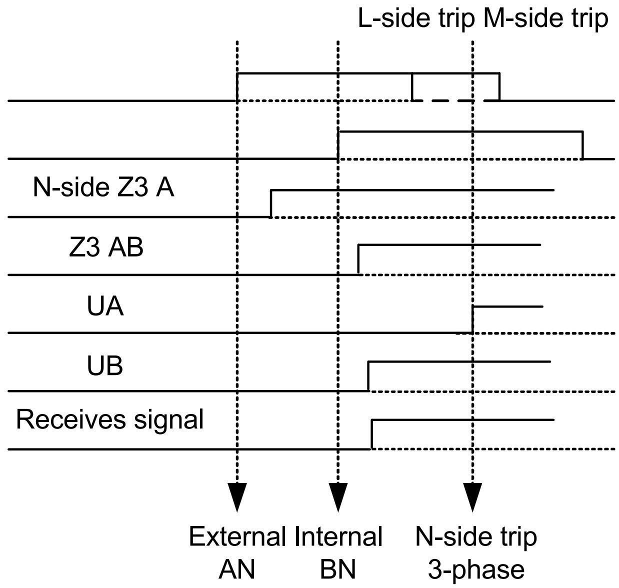

Fig. 5 Sequence of protection elements in Example II

Improvement: To improve relay performance for evolving faults, some relay designs provide users with choices of multiple permissive trip signals to ensure that the relay can trip the faulted phase correctly and without tripping delay in any evolving faults [5].

B. Ground faults with fault resistance

Without some special designated logic, it is difficult for a distance relay to select and trip the faulted phase. Some distance elements can provide only limited fault resistance coverage for the correct phase selection. Once the measurement impedance moves outside the distance element operation area, such relays trip three-phase.

The Chinese specification states that a distance relay should clear ground faults with a maximum of 300 Ω fault resistance for the 500 kV systems and 100 Ω for 220 kV or 110 kV systems. For 500 kV and 220 kV systems, the distance relays should only trip the faulted phase. When fault resistance causes the measured impedance to fall outside the operation zones of distance protection, other protection elements must ensure that the protection relay correctly selects the faulted phase and trips single pole. For ground faults with high fault resistance, protection must allow sequential trips.

Let us consider a distance relay designed to single-pole trip. The relay uses multiple communication channels. One of the channels is dedicated to the zero-sequence overcurrent element for three-pole trips. To avoid misoperation of the zero-sequence overcurrent element during a pole-open period, the relay blocks the zero-sequence overcurrent element right after the distance element picks up and issues a trip. For a high-resistance ground fault close to one terminal, the distance element of the close-in relay issues a trip and blocks the zero-sequence overcurrent element. The remote relay only picks up the zero-sequence overcurrent element and sends out a three-phase permissive trip signal. Because the local relay disables the zero-sequence overcurrent elements after distance element operation, it inhibits the echo of the received permissive trip signal. In this condition, the zero-sequence overcurrent element at the remote side cannot operate without receiving the echo signal. The relay at the local terminal trips the fault, but the relay at the remote end cannot operate at a high speed.

C. Power Swing Blocking

It is obvious that distance elements can misoperate during a power swing when the swing center falls on the protected transmission line. The distance relay can use PSB logic to prevent such misoperations. The PSB logic in the distance relay is an overall and complex logic. To ensure that a relay not only reliably blocks its distance elements during power swings, but also removes blocking properly when a fault occurs during a swing, one must calculate PSB logic settings carefully. This is especially the case for those relays that use concentric circles or polygons in PSB logic. Furthermore, one must consider various factors during power swings such as different start times for power swings and different types of faults that take place at different points of a power swing cycle.

Example I:

Issue: Because of an improper power swing blocking time delay setting, a relay tripped very slowly under a switch-onto-fault situation. When a local breaker system reclosed into a phase-phase permanent fault, the local-end relay tripped three phases after a delay of 210 ms.

Event analysis: For the first fault, the Zone 1 phase-phase element operated correctly and tripped three phases. When the system reclosed into a permanent fault, there was no voltage at either end of the line. The Zone 1 phase-to-phase distance element could not operate. The relay tripped upon the switch-onto-fault (SOTF) logic. Because the SOTF logic pickup time was 1 ms slower than the power swing blocking time, the power-swing blocking signal blocked relay tripping.

Improvement: To resolve the problem, the relay should have a 5 ms delay in the PSB blocking logic.

Example II:

Issue: A distance relay experiences a faulted-phase selection problem during power swings and trips three phases for a single line-to-ground (SLG) fault and large machine angle difference.

Event analysis: The phase selection logic in the relay uses the angle difference between the zero-sequence current, I0, and the negative-sequence current, I2. When the angle difference is small and the BC-phase distance element operates, the relay declares a BC-phase fault and trips three phases. Otherwise, the relay logic determines that an A-phase ground fault occurred and the relay trips the faulted phase. This kind of phase selection logic works well even for high-impedance faults. However, when machine angle difference is large during a power swing, and an SLG fault occurs, the related phase-phase distance element can also operate. For example, with an A-phase SLG fault, the BC distance element can operate and cause the relay to initiate a three-pole trip for the SLG fault.

Improvement: One solution is to improve differentiation between ground and phase distance elements that share the same I0-I2 phase-selection region. Fig. 6 shows the logic, using A-phase as an example. The logic is enabled when I0-I2 phase selection has indicated either an A-phase-to-ground or a BC-to-ground fault. With this logic, the relay can successfully single-pole trip for SLG faults even when the machine angle difference is large during a power swing.

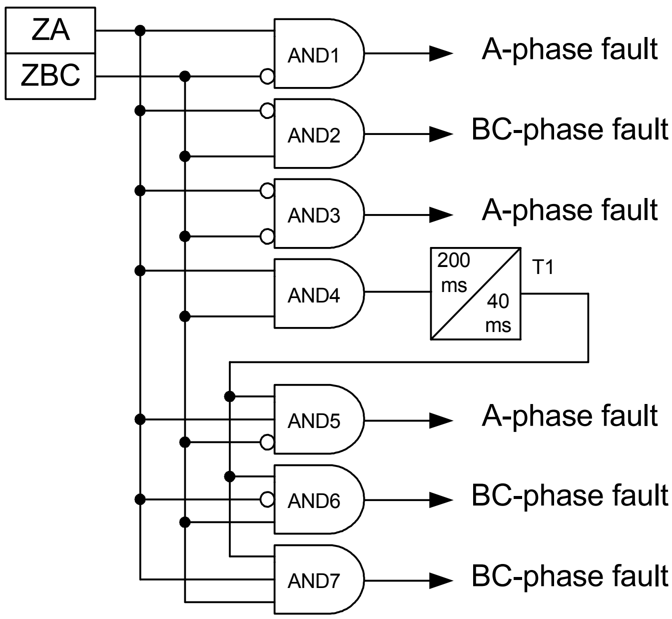

Fig. 6 Logic diagram for faulted phase selection during power swings

Example III:

Issue: A distance relay misoperated for a power system recovering from an out-of-step (OOS) condition. As Fig. 7 shows, the relay tripped three phases in the second stable swing cycle.

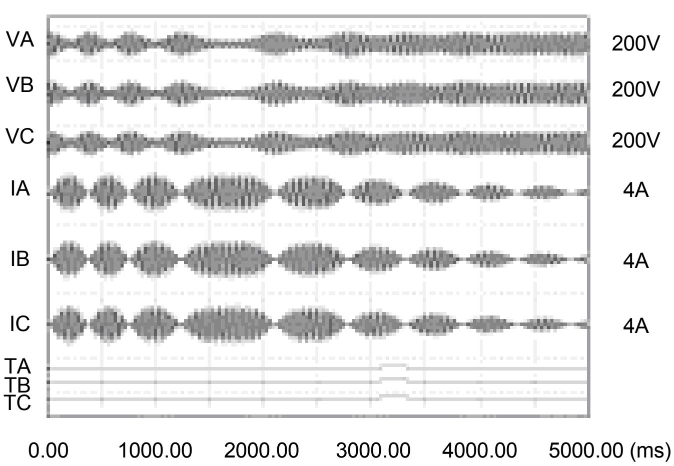

Fig. 7 Misoperation when the power system recovers from a swing

Event analysis: The relay uses an impedance rate-of-change element to reset the PSB element. The rate-of-change element will not reset PSB during unstable system swings. The element operates and resets PSB for slow power angle changes such as when a stable swing reaches to the point that the equivalent machine angle is maximum (a quasi-balance operating point). The relay uses a combination of a fixed threshold and a floating threshold so that the rate-of-change element operates correctly even when impedance changes slowly. This design has a solid theoretical foundation.

Improvement: The root cause of the relay misoperation was a floating threshold setting error. Proper setting of the floating threshold value resolved the problem.

D. Loss-of-potential logic

Issue: Because the loss-of-potential logic in a distance relay was inadequately designed, the relay failed to operate when a phase-phase fault occurred while the system was recovering from a power swing. As Fig. 8 illustrates, two relays failed to operate at both ends of a line.

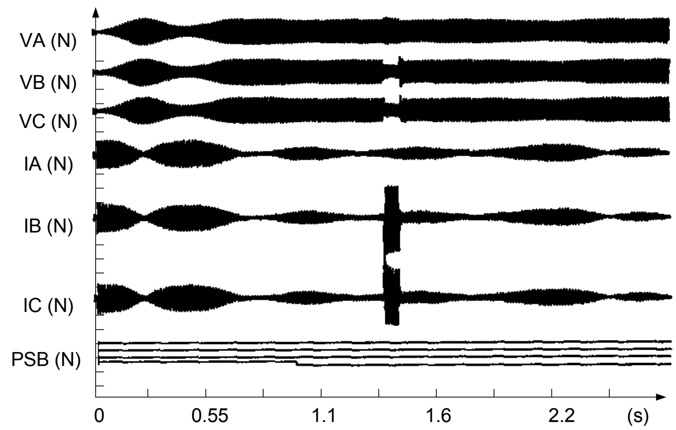

Fig. 8 A loss-of-potential problem caused failed operation for a fault

Event analysis: Post fault analysis revealed why the relay failed to operate. The PSB signal of the relay reset after the system recovered from unstable power swings and during stable swings. The loss-of-potential logic inadvertently asserted at the minimum of the swing voltage. In this condition, a misoperation of the loss-of-potential logic blocked relay operation.

Improvement: The relay manufacturer resolved the problem by modifying the loss-of-potential logic.

IV. ACTUAL SYSTEM TESTS FOR DISTANCE PROTECTION

To ensure that a distance relay can meet 500 kV transmission project requirements, many power utility companies have arranged for the performance of analog dynamic simulation tests at CEPRI with their actual system data and requirements. In these tests, CEPRI sets analog model systems according to data from the real system on which the relay is to be installed. It is necessary to set up the model to match the actual system as closely as possible.

In the past several years, we have been involved in many analog dynamic simulation tests to help utilities verify distance relay performance for various important projects. These projects include the Yangcheng 500 kV SC line protection test for State Power Grid Co., the Fengzhen to Yongshenyu 500 kV transmission line protection tests for North China Power Grid Co., the TianGuang 500 kV transmission SC line protection test for Southern Power Grid Co., and the 750 kV line protection test for a new 750 kV demonstration project. CEPRI has offered important and credible verification tests with our complete analog model to end users needing to select suitable products and obtain relay performance data prior to system installation.

V. Analog Simulator System and Digital Simulator System

After decades of real-time digital simulator developments, there are more frequent applications of digital simulation systems in research, development, and manufacturing of protection relays. The analog simulator and digital simulator have their own features and advantages.

The analog simulator represents physical phenomena more accurately than the digital simulator. Such simulations are suitable for researching original phenomena and characteristics of power apparatus, and for qualification testing protection relays and automation control devices. However, the analog simulator is complicated to build and costly to maintain. Equipment size and the number of components in the analog simulator limit the scale of power systems to be simulated.

The digital simulator, in contrast, is flexible, simple to build, and easy to fault at any designated locations or points. The digital simulator also has some limitations. The digital-to-analog (D/A) conversion degrades the accuracy of digital systems for small signals, amplifiers can saturate and flattop waveforms for large signals, and numerical oscillation can exist. The simulation accuracy of a digital simulator depends directly on the accuracy of mathematical power apparatus models. Although digital simulators have good repeatability, they lack the randomness and surprise events sometimes necessary in testing protection relays.

We foresee that the analog simulator with a complete data collection and analysis mechanism will remain as a main tool for Chinese utility companies to certify new protection relays for future transmission systems. The digital simulator is a powerful tool on new product developments.

VI. Opportunities for Relay Design Improvement

CEPRI routinely tests all types of relays and knows how to design test systems and parameters to reveal relay design weaknesses. While CEPRI analog simulator tests qualify protection relays for Chinese utilities, these tests also provide opportunities for relay manufacturers to verify and improve relay designs.

Chinese power systems are not as closely interconnected as North American systems. These relatively weak Chinese power systems demand unique protection requirements so that power supplies are as reliable as possible under multiple contingencies. Some of these unique requirements include single-pole tripping for high-impedance ground faults, reliable PSB to prevent distance element misoperations, reliable removal of PSB when internal faults occur during a power swing, and dependable single-pole tripping for an evolving fault condition.

In this section, we introduce how a modern microprocessor relay meets the challenge of satisfying these stringent protection requirements.

A. Single-pole tripping for high-impedance ground faults

When a ground fault involves a high fault resistance and a relay distance element is unable to detect the fault, protection engineers routinely rely on a residual overcurrent element for backup protection and accept that three-pole trips might be necessary. A recent argument, however, is that modern relays can reliably trip a single pole for more damaging high-current metallic ground faults, so these relays should also be able to single-pole trip for low-current, high-impedance ground faults. Avoiding a three-pole trip and loss of an entire transmission line greatly reduces negative impact to the power system.

With the flexibility of modern microprocessor relays, this new protection requirement can be satisfied readily without revising relay firmware. In the relay this paper discusses, it is straightforward to use relay programming to design the necessary logic. CEPRI simulator testing successfully used the relay logic shown in Fig. 9 to provide single-pole tripping capability for high-impedance ground faults.

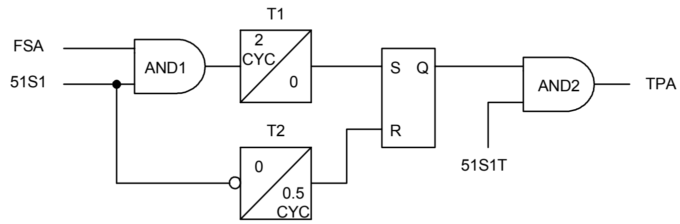

Fig. 9 Single-pole trip logic for high-impedance ground faults

The input FSA in Fig. 9 is the A-phase output from the faulted phase selection logic. When FSA and the residual time-overcurrent pickup, 51S1, both assert for more than two cycles, the set-reset flip-flop asserts its output. The value 51S1T is the output of the residual time-overcurrent element. The combination of the flip-flop output with 51S1T yields a signal for A-phase trip, TPA. Although not indicated in the figure, it is possible to program 51S1T as a traditional three-phase backup trip without any faulted phase selection outputs.

B. Reliable single-pole operation for evolving faults

For a double-line transmission system, two line circuits often share the first few towers leaving a generation station or a substation. This configuration sometimes results in evolving faults. An evolving fault starts from a single-phase-to-ground fault on one of the line circuits and eventually evolves to a second ground fault, often on a different phase, on the other line circuit. Some refer to these types of faults as cross-country faults because they involve more than one line circuit.

Evolving faults bring a unique challenge to single-pole trip applications. Fig. 10 shows one example of such faults. When two ground faults overlap in time, the relays at the remote end (relays 1L and 2L in this case) detect faults as phase-phase-ground faults. With the traditional permissive overreaching transfer trip (POTT) scheme, which uses only one permissive trip signal, there is no way for remote relays to differentiate the internal single-phase ground fault from a multi-phase fault. When the remote relays receive the single permissive trip signal, they will trip all three phases, a severe system security problem.

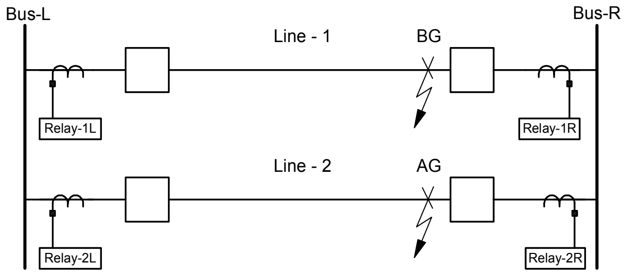

Fig. 10. Evolving fault on a double-circuit system

One way of solving this problem is to add another permissive trip signal. For compatibility with existing POTT schemes, one POTT signal (PT1) is the same as the traditional signal. The other POTT signal (PT3) provides the local relay with indication of a multi-phase fault detection. When the local detected fault type disagrees with received permissive trip signals, the relay withholds its trip until an agreement occurs. In the example, Relay-1L detects an ABG multi-phase fault while it receives only the PT1 permissive signal. The relay delays tripping until Relay-2R trips out the AG fault that is external to Relay-1L. Relay-1L then changes its fault detection from ABG to BG and agrees with the permissive trip signal PT1. This agreement allows both Relay-1L and Relay-2L to successfully single-pole trip.

Two permissive trip signals work well to achieve single-pole tripping in evolving fault situations. There is one drawback: remote relays must delay their trips until close-in relays operate. This delay increases the overall fault clearing time. The addition of one more permissive trip signal achieves a complete POTT faulted phase selection and eliminates any delayed trips [7]. Modern Mirrored-Bits® relay-to-relay communication technology makes a multiple-channel POTT scheme feasible.

C. Advancements on PSB functions

Distance protection relays can misoperate during a power system swing if the swing impedance falls inside the protection characteristics of these relays. Distance relays normally use PSB logic to detect power swings and block distance elements. The PSB function is traditionally difficult to set. However, a properly designed and set PSB function makes it relatively easy for one to use PSB logic for reliable swing detection and distance-element blocking functions. Compared with detecting swings and blocking distance elements, it is more challenging to detect faults during a power swing, reliably remove power-swing blocking, trip dependably for internal faults, and retain single-pole tripping capability while also remaining secure against external faults.

Chinese requirements for system protection against faults during power swings are particularly stringent. While most other authorities have no special relay requirements when a system is in a swing condition, Chinese utilities require that a distance relay satisfy the following conditions:

- When internal faults occur during power swings, the distance relay may trip with a time delay;
- Distance relays should trip only the faulted phase if a single-phase-to-ground fault occurs during power swings;
- Distance relays should dependably trip for all internal faults during power swings;
- Distance relays should not operate when external faults occur during power swings, except for external three-phase faults;
- Distance relays may trip for external faults during power swings when the line is in the single-pole open period.

One challenge is for a distance relay to remove PSB in a timely fashion when an evolving three-phase fault occurs during a power swing. A simple solution is to reset the PSB function when impedance resides inside a distance characteristic for a set time. Because this set time must coordinate with the slowest possible power swing, one must establish a conservative time and, therefore, delay a trip longer than necessary for most evolving three-phase faults during power swings. An adaptive inner blinder logic estimates unstable swing periods each time impedance goes through the PSB detection regions [4], calculates a time that the impedance should stay inside an inner impedance blinder region at the estimated slip frequency, and monitors impedance movement. If the impedance stays inside the inner impedance region longer than a time determined by the logic, the relay declares a three-phase fault situation and PSB resets without any unnecessary delay.

Conventional faulted phase selection logic can fail for SLG faults during power swings, especially when the fault is remote to the relay. If the SLG fault occurs when the power swing current reaches maximum (when the swing impedance is inside the distance characteristics of all phase loops), removal of PSB will result in a relay three-phase trip. A special faulted-phase selection logic increases the dependability of single-pole trip applications during power swings [5].

The traditional PSB function that uses concentric impedance characteristics may not dependably block distance elements when a power swing results from a prolonged clearance of an external fault adjacent to the relay. These types of power swings can cause blocking difficulties for any types of PSB functions, because the power system is already swinging during the external fault. The generator rotor angle difference of equivalent subsystems is increasing. However, with the external fault still on the system, this swing activity is masked and the relay does not detect it. At the moment that the fault finally clears, the rotor angle difference may be so large that the impedance the relay measures jumps suddenly from the external fault point to inside the distance element characteristics, bypassing the PSB detection region. A dependable PSB logic [6] overcomes this difficulty and reliably blocks distance elements when a swing impedance already falls inside the distance protection zone after a severe external disturbance.

VII. Conclusion

China EPRI has built a complete set of analog simulators and uses this analog model simulation system to qualify distance relays as well as other relay types to be used in transmission systems nationwide in China. The simulator system can faithfully simulate a power transmission system with voltage as high as 750 kV. All protection relays receive testing with the same system models and the same well-designed test items. Evolving fault and power swing tests are normally the most difficult for distance relays and reveal the most distance relay design problems.

Other than providing utilities with objective relay selection information, the simulator test presents a new set of protection requirements and provides opportunities for relay manufacturers to improve relay designs and innovatively use existing functions.

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IX. Biographies

Zexin Zhou received her BS from North China Electrical Power University in 1991 and her Master's degree from EPRI of China in 1994. She has experience in the field of power system simulation and protection testing. She has been working at EPRI of China since receiving her Master's degree. She has experience developing PSASP and with protection relay testing and research. She is now in charge of protection relay dynamic simulation testing. Her special research field focuses on analysis and testing of different protection relays. She is a senior engineer and has presented several papers on power system analysis and protection topics.

Xiaofan Shen received his BS from North China Electrical Power University in 1981. He has many years of protection relay research experience and is now a senior engineer with EPRI of China. His research field focuses on the analysis and testing of different protection relays.

Daqing Hou received his B.S. and M.S. degrees in Electrical Engineering at the Northeast University, China, in 1981 and 1984, respectively. He received his Ph.D. in Electrical and Computer Engineering at Washington State University in 1991. Since 1990, he has been with Schweitzer Engineering Laboratories, Inc., Pullman, Washington, USA, where he has held numerous positions including development engineer, application engineer, and R&D manager. He is currently a principal research engineer. His work includes system modeling, simulation, and signal processing for power systems and digital protection relays. His research interests include multivariable linear systems, system identification, and signal processing. He holds multiple patents and has authored or co-authored many technical papers. He is a Senior Member of IEEE.

Shaojun Chen has a B.S. in the Electrical Engineering Branch School of Shanghai Jiaotong University in 1983 and M.S. in the Business School of Shanghai Jiaotong University in 1995. From 1983 to 1996, he was employed as a System Protection Engineer and a System Protection Department Manager for East China Electric Power Administration Co. Since 1997, he has been with Schweitzer Engineering Laboratories, Inc. in Pullman, Washington, USA, where he served as a Project Engineer and later as a Field Application Engineer. He presently holds the position of Regional Sales and Service Manager with SEL, and he is responsible for technical support, application assistance, customer training, and sales in East Asia including China, Taiwan, and Korea.