Microprocessor-Based Transmission Line Relay Applications

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Abstract

For many years, utilities have used electromechanical relays for power system protection. The result of using electromechanical relays has been an extensive maintenance and design practice. Both the maintenance and design of protection schemes using these relays is expensive and time-consuming.

Over the last ten years, microprocessor-based relays have come of age. Microprocessor-based relays offer many advantages over electromechanical relays. This paper compares a typical transmission line protection scheme in terms of cost, engineering design, and maintenance. The information presented in this paper shows that microprocessor-based relays offer significant savings in cost, engineering design, and maintenance.

The paper concludes by showing many transmission line protection applications for microprocessor-based relays.

Introduction

Protective relays play a critical role in the operation of the electrical power system. The protective relays are designed to take action when abnormal conditions occur on the power system. These abnormal conditions may be short circuits, overload conditions, and loss of system synchronism.

Elaborate protection schemes have been developed to detect these various conditions using trial and error and system operating experience. The protection schemes have typically been made up of discrete components such as overcurrent relays, distance relays, auxiliary relays, and reclosing relays. All of the devices must be wired together to have a complete, functional scheme, which means time and money in the design, development, and installation process.

Due to the number of components that make up these protection schemes, detailed installation tests, and routine maintenance programs must be performed to ensure that the schemes are functioning correctly. Again, this requires a significant investment in time, money, and manpower. For example, a typical step time distance transmission line protection scheme must be maintained every one to three years to ensure that it is performing within specific guidelines.

Microprocessor-based relays offer many advantages over schemes using discrete components. The overall scheme takes up less panel space. The number of components is greatly reduced. The design and wiring is simpler and less costly to implement. Installation testing and maintenance testing can be greatly reduced. Microprocessor-based relays also offer many features and functions in addition to the base protection functions.

Microprocessor-based relays may be used in all electromechanical relay applications. The added benefits of simple scheme design and improved reliability make them a very attractive option.

Microprocessor-based relays also make new applications and protection philosophies available. We can implement more flexible protection schemes, reduce maintenance, obtain more information to increase our understanding of the power system, and improve the reliability of the protection system as a whole at a cost less than conventional electromechanical relays.

COMPARING ELECTROMECHANICAL AND MICROPROCESSOR-BASED PROTECTION SCHEMES

Hardware and Space Requirements

A typical three-zone step time distance scheme consists of instantaneous tripping elements, two levels of time-delayed tripping elements for phase faults and an instantaneous tripping element, and time-overcurrent element for ground faults. For this example, we shall assume that the step time distance scheme uses phase distance and directional ground overcurrent elements. Phase faults are detected using three zones of phase distance relays. Ground faults are detected using a directional ground overcurrent relay which includes a time-overcurrent element and an instantaneous overcurrent element. The protection scheme also includes a single-shot recloser for automatic line restoration after a fault has been cleared.

The electromechanical relay scheme uses three-phase distance relays. These relays may cover all fault types on a per-zone basis or all three zones on a faulted phase pair basis. This depends upon the manufacturer of the distance relays. However, in either case, three distance relays are required. A timer is also required for the time-delayed backup elements. Typically, the time delay is provided from separate timers, so if one timer fails, the entire step time distance scheme is not lost. A single directional ground overcurrent relay shall be used for ground fault detection. A single-shot reclosing relay shall also be provided for restoring the line. A non-directional overcurrent relay shall be used to supervise the distance relays.

The electromechanical relay scheme panel layout is shown in Figure 1. Note that the electromechanical scheme requires nearly all of the space contained in an 84-inch by 19-inch panel.

The microprocessor-based scheme shall consist of a multifunction relay that provides three zones of step time distance protection, three levels of instantaneous or definite time directional ground overcurrent protection, a directional ground time-overcurrent function, and three-shot recloser. The microprocessor-based scheme shall also include a single-zone microprocessor-based relay as a backup in case of failure of the primary multi-zone relay.

Figure 2 shows the panel layout for the microprocessor-based relay scheme. The space requirement for the microprocessor-based relay scheme is much less than the electromechanical relay scheme.

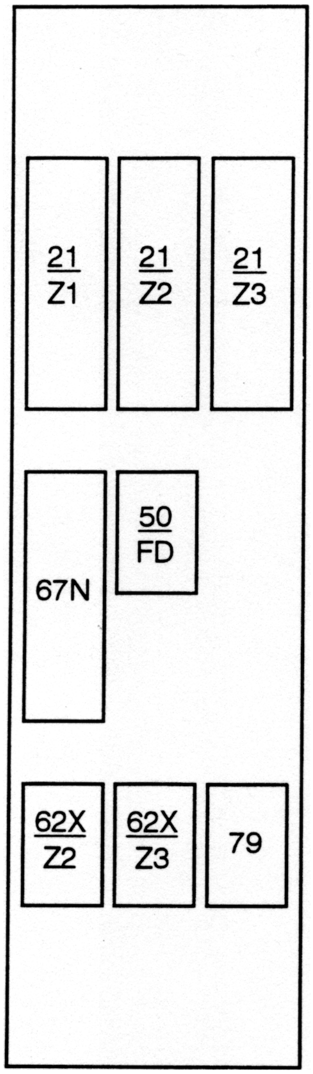

Figure 1: Typical Electromechanical Relay Scheme Panel Layout

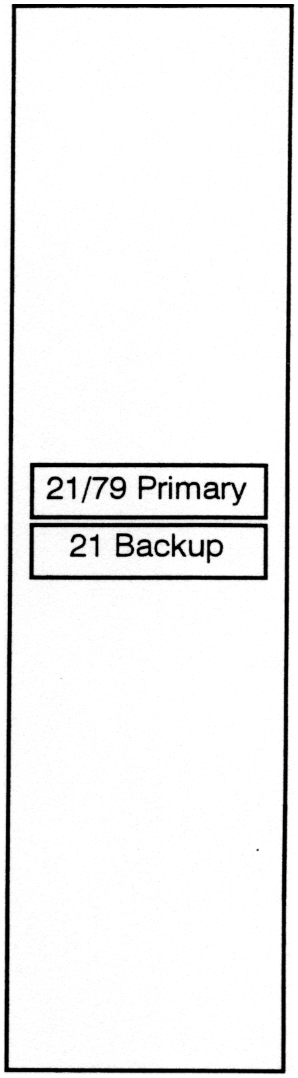

Figure 2: Typical Microprocessor-Based Relay Scheme Panel Layout

Given that the cost of all the relays for the electromechanical scheme is 1 per unit (p.u.), the cost of the microprocessor-based relay scheme is 0.35 p.u.

Design Requirements

The ac and dc circuits for the electromechanical scheme are more complex than the microprocessor-based relay scheme. Figure 3 shows a typical ac schematic, and Figure 4 shows a typical dc schematic for the electromechanical relays scheme. Each discrete relay must be wired to other discrete relays to develop the required protection scheme. The design and installation costs can be quite high due to the number of connection points and the relative complexity of the overall scheme.

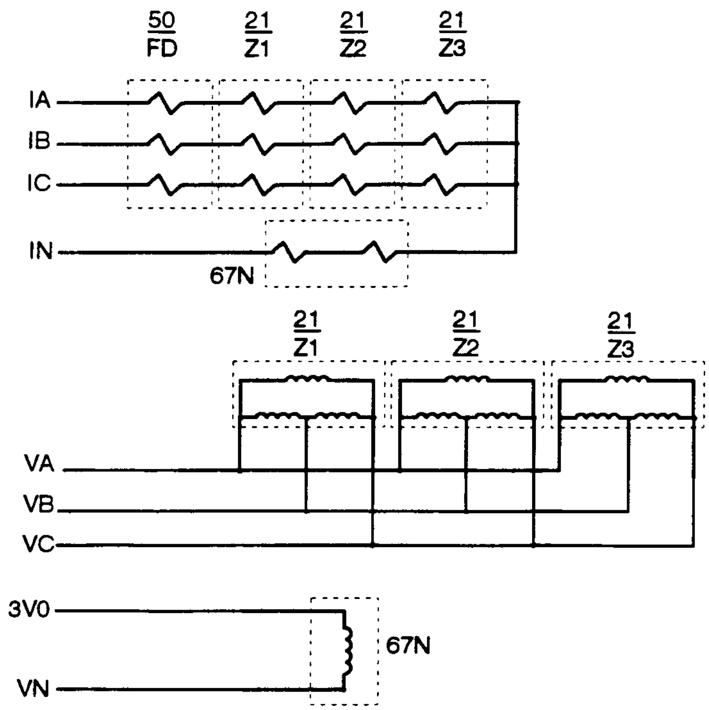

Figure 3: Typical Electromechanical Relay AC Schematic

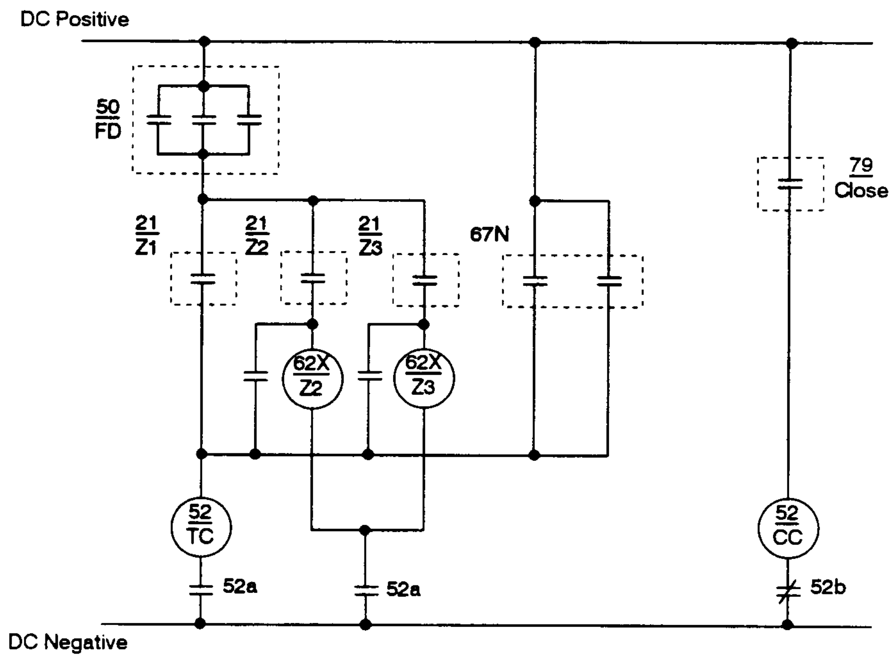

Figure 4: Typical Electromechanical Relay DC Schematic

Figure 5 and Figure 6 show the ac and dc circuits for a microprocessor-based relay scheme. Note that even with the redundant relay used for backup protection, the number of connections and complexity is very low. Therefore, the design and installation costs are reduced significantly.

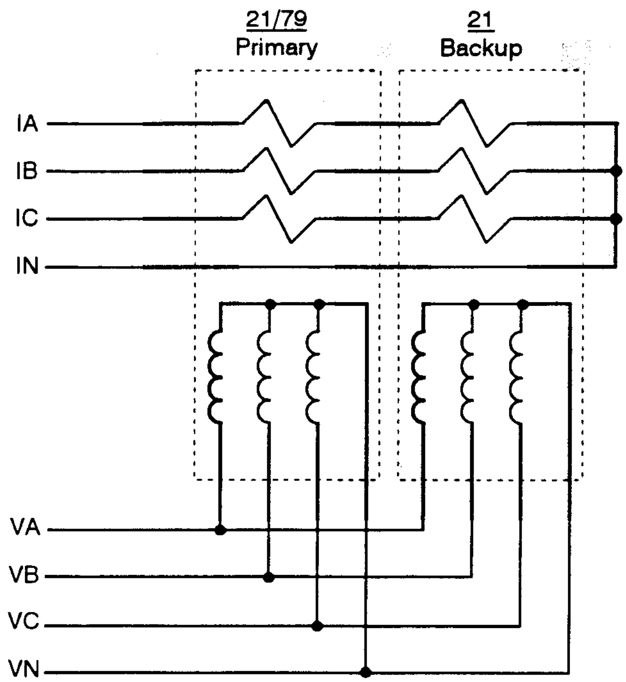

Figure 5: Typical Microprocessor-Based Relay AC Schematic

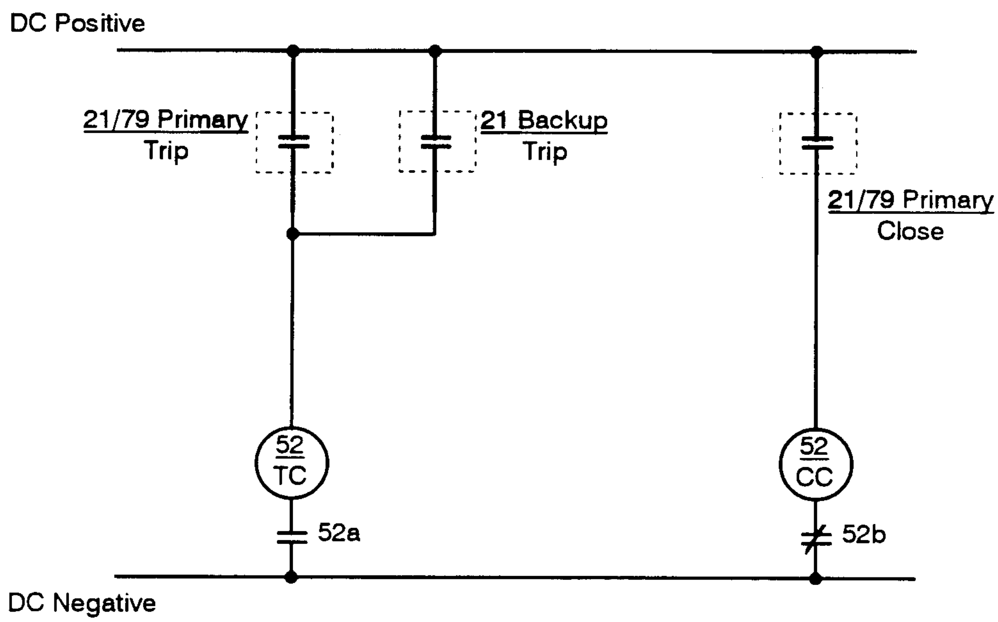

Figure 6: Typical Microprocessor-Based Relay DC Schematic

Given that the cost of design and installation of the electromechanical relay scheme is 1 p.u., the cost of design and installation of the microprocessor-based relay scheme is approximately 0.5 p.u.

Installation Testing

Installation tests are used to verify that the relays are set correctly and that the scheme is designed correctly for the intended application. Routine tests are performed to ensure that the relays are functioning within established specifications.

A scheme designed with electromechanical relays requires a large number of tests during installation to ensure that the overall scheme is functioning properly. Each discrete relay must be tested and calibrated.

For the step time distance scheme example, at least seven discrete relays must be tested. The testing of each relay requires that the relay be connected to the test equipment, the various setting adjustments are made, and the relay is tested per an established test routine. If the relay test results are outside established guidelines, the relay must be calibrated. The calibration routine can be very time-consuming.

After each relay has been tested, the scheme must be "trip-checked" to ensure that all of the wiring and trip circuits are correct. Many times, trip-checking an electromechanical scheme is a simple matter of manually closing an output contact. Therefore, the trip-checks can be very simple. However, due to the many discrete devices used in the scheme, the trip-checks can be very time-consuming and, in case of an incorrect design or wiring error, require many hours of trouble shooting when searching for problems.

A microprocessor-based relay scheme is very simple to test and verify. A microprocessor-based relay operates using software programming. The operation of the various functions and logic has been fully verified and tested by the relay manufacturer. In many cases, the utility has also tested the relay to ensure that the relay conforms to the specifications stated by the manufacturer. Once the relay has been fully tested, the software that defines the operating characteristics of the relay has been verified. Therefore, it is not required to fully test each relay given that the relays are of the same type and software version.

The installation tests for a microprocessor-based relay should be designed to verify that the relay settings have been entered correctly. The test series should be designed to check the relay pick-up at critical points. For example, the distance element should be tested at the angle of maximum torque and ±30 degrees off the angle of maximum torque. These test points verify the distance element settings. Overcurrent elements should also be tested using a very simple test routine.

Trip checks using a microprocessor-based relay are very simple due to the fact that there are fewer contacts to check and less wiring to verify. In many cases, a software command may be used to close specific output contacts. Using a software command to close relay outputs is simpler than connecting voltage and current test sources to the relay to perform fault simulations.

Routine Tests

Routine tests must be performed on electromechanical relays to verify that they are operating within specified guidelines. These tests may be at one to three year intervals for distance relays based upon the specific utility's practice. The routine tests performed on an electromechanical relay are very similar to those done during the installation process. The relays must be thoroughly tested to verify that all of the internal components are operating within specified tolerances. Routine tests also confirm that all contacts and external circuits are functioning properly.

Most microprocessor-based relays perform routine self-checks to ensure that the critical circuitry in the relay is functioning properly. Two earlier papers [1][2] describe microprocessor-based relay testing philosophies and self-checking effectiveness.

Microprocessor-based relays continuously run the same software routines. Therefore, if the relay is functioning properly, the relay algorithms shall operate correctly. Routine maintenance in a microprocessor-based relay consists of verifying that the inputs, outputs, and data acquisition system are functioning properly. If the relay is properly measuring the analog currents and voltages and the self-check status show that the relay is healthy, the relay shall function correctly. The only other checks necessary are to verify that the output contacts and logic inputs are operating correctly.

Given the microprocessor-based relay includes sufficient self-checking and a common data acquisition system is used for relaying as well as metering, routine maintenance can be significantly reduced. Many utilities have extended the routine maintenance cycle of microprocessor-based relays from one and one-half to three times that used on electromechanical relays.

Other Features of Microprocessor-Based Relays

Microprocessor-based relays offer many other features that electromechanical relays do not offer such as fault locating, event reporting, advanced metering functions and control capability.

Fault locating has become a standard feature in nearly all microprocessor-based relays. The fault locating information reduces patrol time on permanently faulted lines. The fault locating information can also be used to evaluate problem areas on transmission lines.

The event record provides data on the internal relay element operation and the currents and voltage waveforms at the time of operation. This is similar to having a fault recorder on every breaker where a microprocessor-based relay is installed. The event data is an invaluable tool in evaluating relay and system performance.

The microprocessor-based relay also provides analog metering quantities such as three-phase currents, voltages, megawatts, and megavars. In many cases, analog transducers are not required. The data can also be directly interfaced digitally to the SCADA RTU. You can also send the fault locator information to the system control center for dispatching a patrol crew.

MICROPROCESSOR-BASED RELAY APPLICATIONS

Microprocessor-based relays may be used in virtually any application in which electromechanical relays are used. This section presents many of those applications.

Retrofit of Older Relay Schemes

As electromechanical relays fail or become maintenance intensive, it can be cost justified to replace them. Microprocessor-based relays are perfect for replacing existing protection systems. The microprocessor-based relay uses much less panel space than the existing electromechanical relays. The schemes and operating principles are nearly identical. The wiring is simplified and can be easily modified to accommodate the new relay. The replacement cost is also very low with respect to replacing all or, in some cases, even one electromechanical relay.

Since the microprocessor-based relay uses the same operating principles as electromechanical relays, you have the option of replacing one terminal of the transmission line. You may consider this option when the line connects to another utility or when the relays at one end are failing, but the other terminal relays are still good.

New Installations

When building new substations or transmission lines, it is very easy to justify microprocessor-based relays. They are very cost-effective. They can be integrated into virtually any protection scheme or philosophy. Reducing the panel wiring and space requirement can also result is significant cost savings when building new substations.

In many cases, when new transmission lines are built into existing substations, the panel board space is very limited. Again, since microprocessor-based relays provide full scheme protection using very little space, they are perfect for this application.

Communications-Aided Schemes

Many microprocessor-based relays include communications scheme logic. In most cases, the relays include all of the required logic to operate in a particular communications-aided scheme. This saves design and materials cost since external auxiliary relays are not required for the scheme operation. The microprocessor-based relay also includes much of the logic that would be provided in the communications equipment. Using the relay's internal logic can reduce the cost of the communications equipment since extra modules may not be required.

The relay also offers selection of the different communications-aided tripping schemes. This means that you can standardize on one relay for all applications.

Line Substitute Breaker

On many lower voltage applications, it is not justified to apply multiple breaker schemes. When a breaker is removed for maintenance, it is desired that the line remain in service. In many cases, the substation bus is configured to allow a substitute breaker to operate on the line in place of the line main breaker [3]. Figure 7 shows a typical main and transfer bus arrangement, where the bus-tie breaker can be used as a substitute for the three transmission line breakers shown in the diagram.

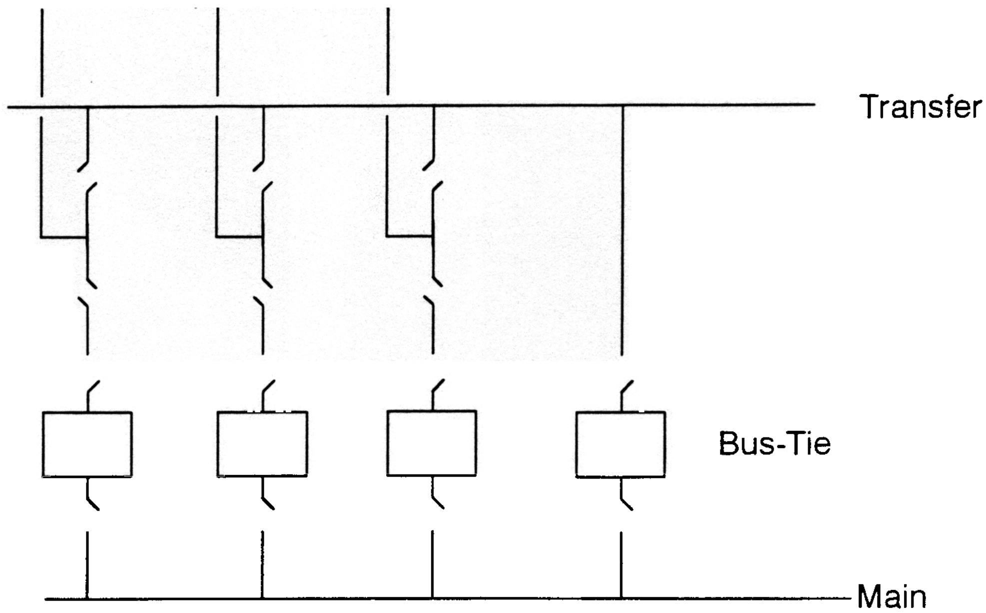

Figure 7: Main and Transfer Bus

Referring to Figure 7, it appears that unique relays must be used on the bus-tie breaker for each line. Another option is to use one set of relays with common settings and change the apparent potential ratio at the relays using a potential range change selector switch [3]. However, the potential range change switch is expensive and does not always result in the best setting for the line.

Some microprocessors-based relays offer multiple setting groups within a single device. The relays allow a number of independent settings for applications such as a bus-tie breaker. The multiple setting groups mean that you have a number of independent relays within the single relay. Therefore, a single relay may be applied on the bus-tie breaker and each unique line setting may be entered into the relay. The protection of the line is not compromised using the bus-tie breaker since the settings match those of the primary line relays.

Change Relay Settings Based on the System Configuration

In any distance-based protection scheme, there must be an overreaching element to protect for faults on the line section that is not covered by the instantaneous tripping element. In some line configurations, the line impedance may change under certain switching conditions.

Figure 8 shows a transmission line that has a looped distribution load station. Normally, both breakers at the looped station are closed. In some situations, one breaker may be removed from service, and the station bypass switch is closed. The change in the line impedance now prevents the Zone 2 element at the source station from covering the entire line section.

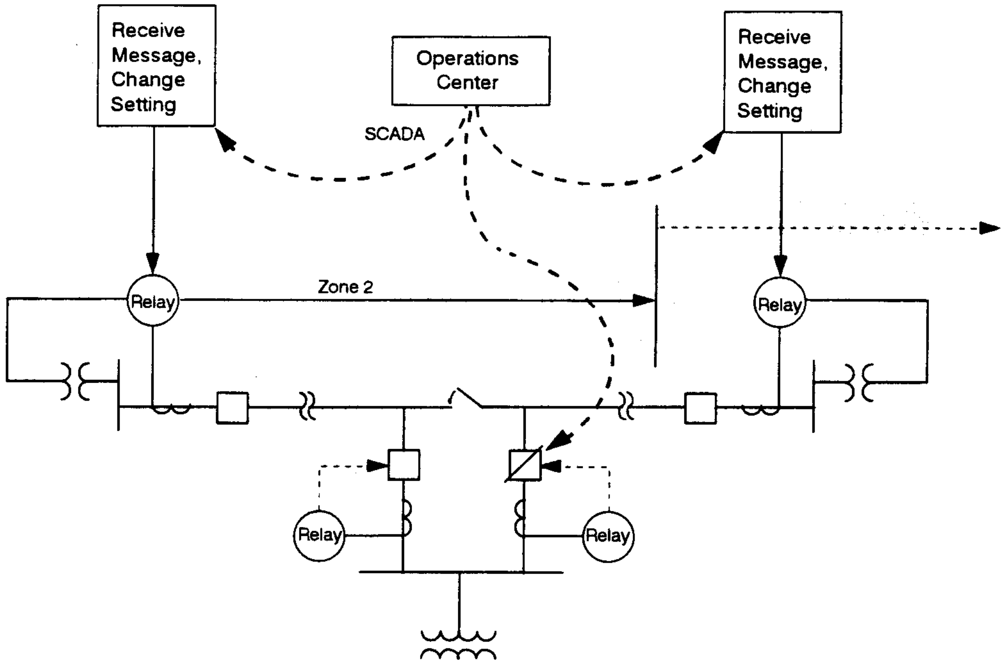

Figure 8: Change Relay Setting to Accommodate Line Changes

With relays that offer multiple setting groups, the settings may be changed at the source stations without sending out a technician or operator. The settings for both line configurations are entered into two separate relay setting groups. Under normal configurations (all breakers closed) the relays are selected for Setting Group 1. When the loop station bypass switch is closed, the relays at the source stations change to Setting Group 2. The setting change may be done via a command from the operations center or may be done automatically [4].

System Wide Application

Microprocessor-based relays now offer programmable logic. The programmable logic allows the user to define the operation of the relay and invent unique protection schemes. The relays also offer a large variety of protection elements and schemes. The flexibility offered in these relays allows application at many voltage levels. In many cases, utilities have standardized on a single relay for all voltage applications from 69kV to 500kV.

Power System Analysis

Most microprocessor-based relays record the system conditions when protective elements operate or when user-defined conditions occur. The event recording tool is invaluable in power system and relay performance analysis.

The event data should be used to evaluate the relay performance. Reviewing the event data is a valuable maintenance tool. The event report shows the ac and dc signals the relay measures during the disturbance and also shows when the relay closes the circuit breaker trip contact [2].

Analyzing the event data is more useful and accurate than simulated tests because the relay is responding to an actual system fault. Therefore, the true relay performance can be better evaluated. The event report can also show problems in control inputs and outputs. Analyzing the event reports can also provide valuable information leading to improvement in the overall protection scheme [5].

CONCLUSION

Microprocessor-based relays offer many advantages and benefits over electromechanical relays:

1. Reduced installation costs
2. Reduced maintenance cost
3. Application flexibility
4. Improved monitoring and control functions

The use of microprocessor-based relays has become very common. Many utilities are taking advantage of the new features and innovations offered in these relays.

New developments in microprocessor-based relays offer added benefits by further reducing costs by improving the relay functions and features.

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