

Ancillary Protective and Control Functions Common to Multiple Protective Relays

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Abstract--The IEEE/PSRC Substation Protection Subcommittee Working Group (WG) K5 on Ancillary Protective and Control Functions Common to Multiple Protective Relays have produced a document that addresses the considerations in applying the ancillary protection, control and monitoring functions that are commonly available in multiple relays and the integration of these functions into the overall protection system. Modern protection schemes are designed with fully integrated protection, control and monitoring functions to accommodate the implementation of many different design requirements. These functions can be used to achieve reliable protection and control solutions. Implementing these designs can be an exhilarating and very satisfying challenge to the engineer's imagination. This summary paper addresses subjects related to specific protection and control topics with application examples which were covered in the special PSRC publication.

Key words-- breaker failure schemes, automatic reclosing, monitoring schemes, control function schemes, event and fault recording, testing, documentation, maintenance.

I. INTRODUCTION

The applications of duplicate protective schemes in modern protection is of significant interest to users as almost all protective relays now give the user the ability to either modify the existing protection and control logic inside the relay or add specific logic tailored to the user's requirements. This advancement in the state of the art has enabled the user to implement a whole host of tripping, monitoring and control schemes as part of custom logic inside the main protective relay thus allowing the elimination of stand-alone relays, auxiliary relays, timers, and wiring. Whether they are installed in new substations or as retrofits in old substations, multifunction relays can be successfully applied to satisfy the protection and control requirements of the power system equipment. The choice of implementing protection and control functions depends largely on the equipment to be protected, the power system operating requirements, and the owner's comfort level with multifunction relays.

Virtually no limits exist to the variety of new protection

schemes that can be designed to satisfy specific application requirements. A major challenge for the engineer is to balance redundancy of functions against the requirement to *keep the system simple*.

Application examples of improved protection and control schemes have been documented in the special publication of the PSRC Working Group K5 in the areas of breaker failure scheme logic, line reclosing scheme logic, synch check, and interlocking. Programmability gives the multifunction relay powerful monitoring and alarming capabilities, such as breaker trip coil and loss of potential. Monitoring the status of terminal components for the purposes of modifying protection schemes, such as for open terminal conditions or to provide stub bus protection when the line disconnect switch is open, are also excellent examples of the enhanced monitoring features of multifunction relays. Event data recorded in microprocessor-based relays, both analogs and status, is an important tool for the post event analysis of power system disturbances.

II. BREAKER FAILURE

In breaker failure (BF) schemes, relaying philosophy and maintenance practice significantly impact the selection of a BF scheme. Factors to consider are:

- Preferred degree of security and reliance on remote versus local backup.
- Degree of integration of the fault detection and BF functions on a single multifunction relay.
- Existing maintenance/testing practice, willingness and capacity to adjust.
- Preferences with respect to simplicity and cost targets.

Figure 1 presents six approaches to distributing the fault detection (FD) and BF functions between multiple relays. For this figure, FD represents the relays that detect faults in one of the two power system zones separated by the circuit breaker and initiate tripping of that circuit breaker. It does not represent the fault detector function of the breaker failure protection system. For simplicity, multiple fault detection relays for each of these power system zones are not shown in the figure.

Figure 1(a) is a traditional scheme with a dedicated BF relay. Figure 1(b) presents a simple scheme with an integrated BF function per each fault detection function. No external breaker failure initiate signals are used.

This summary paper is a result of WG K5 of the Substation Subcommittee of the Power System Relaying Committee. The complete special publication is approved by members of the WG, members of the Substation Subcommittee and the main officers of PSRC.

Figure 1(c) shows a cross-check scheme. Each fault detection function is initiating the BF function in the other relay so that a cross-check is made between detecting the fault and detecting the BF condition. This scheme calls for the communication of the BFI signals between the relays.

Figure 1(d) shows the cross-check scheme with fail-over to its own BF function upon failure of the other relay. This scheme requires cross monitoring of the relay fail safe outputs.

Figure 1(e) presents a solution with a single BF allocated statically to one of the relays.

Figure 1(f) shows an integrated and single BF but in a switchover scheme. Normally both relays initiate the same integrated BF (one internally and one externally). Upon the failure of the relay normally performing the BF function, the other relay switches to its own integrated BF element.

Of the six schemes illustrated in Figure 1 schemes (b) and (e) are the least complex. If separation of the current sensing function between fault detection and BF functions is deemed desirable, then (c) may be applied, even though it increases complexity. If the system designer wishes to cover the double contingency of simultaneous failure of a relay and failure of the circuit breaker, scheme (b) may be applied or schemes (d) and (f) with switchover could be used with corresponding increases in complexity.

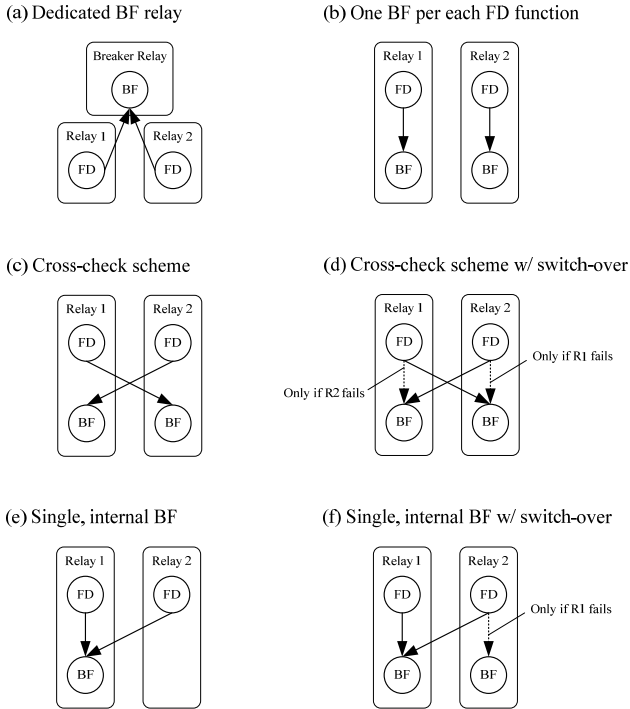


Figure 1 - Possible allocations of the Fault Detection (FD) and BF functions between two relay systems. In each case the protective zones of the two relays intersect at the same circuit breaker.

The special publication includes examples illustrating application of the concepts. Examples include applications where all fault detection relays (typically two on each side of the breaker) that trip the breaker include the capability to provide breaker failure protection, as well as, applications

where some of the fault detection relays are not able to provide integrated breaker failure protection and therefore must initiate BF in one of the other relays. It further includes examples for several bus arrangements which will have a major influence on how the breaker failure protection system is designed.

III. RECLOSING SCHEMES

Modern integrated multifunction protective relays incorporate the automatic reclosing function (ANSI device 79). Whether automatic reclosing is implemented as a dedicated reclosing relay or as an integrated function within a multifunction protection relay, several external input signals may be required for successful implementation, depending on the design requirements of the reclosing scheme. Typical input signals required by reclosing relay schemes include but are not limited to reclose initiation, breaker status (open or closed), drive to lockout, pause, and voltage or synchronism check supervision.

Figure 2 shows a case where redundancy of the 79 function is required. In this scheme, both primary and backup tripping relays are equipped with a 79 function. Being a control function with a relatively complex sequence of steps, the 79 function is typically not allowed to have multiple operational instances. Therefore, one of the 79s is selected as the normal (master) device, and the other is enabled only if the master device is not operational. This is typically done via hard-wiring of the fail safe relay of the master device. Such a scheme can be referred to as “hot standby” meaning there is a second copy of the function, purposely inhibited due to coordination concerns, but in service without time delay should the primary function become unavailable.

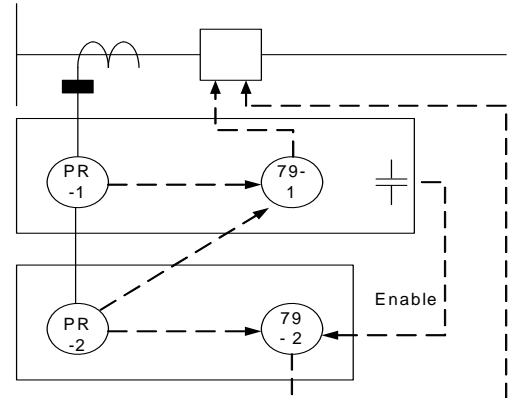


Figure 2 – Redundant device reclosing scheme

IV. OTHER INTELLIGENT ELECTRONIC DEVICE (IED) CONTROL & PROTECTION FUNCTION ISSUES

The degree of integration practiced by the user may range from fully integrated, where the relays provide not only local and remote breaker control but also status, alarm, and metering information, to partial integration in which the relays provide only local automation such as in automatic transfer and isolation schemes. For example, the switchyard condition measurement, scheme logic, initiate signals, supervisory

signals, and control outputs required by a breaker control scheme can be consolidated into a single multifunction relay. The scheme may then be duplicated in a second device, as shown in Figure 3.

Redundancy

Typical design decisions define which hardware platforms or devices will contain the activated integrated functions and the type of redundancy to apply. Types of redundancy include:

- Failover Redundancy (also called hot standby), in which the two control devices operate independently and share no common elements. Only one device is active at a time. When failure of the active device is detected, that device is disabled and the second device is put into service automatically.
- Parallel Redundancy, in which the desired control function is activated simultaneously within each of two or more independently operating devices or schemes.
- Non-redundant Secure Scheme, in which the desired control function is activated within two or more different devices with operation of both or all devices required to initiate the function.
- Triple Modular Redundancy, in which three independent devices operate in a voting scheme to activate the desired function.

The WG report includes an annex with many application examples. Some of the annex sections include thorough discussions on IED control function schemes used in modern multifunction protective relays where point to point wiring associated with the cascading device outputs of a traditional scheme might be reduced or eliminated. Control system architecture will depend upon the required redundancy, and the choice of which hardware platforms are to contain the line, transformer, bus, or breaker failure protection.

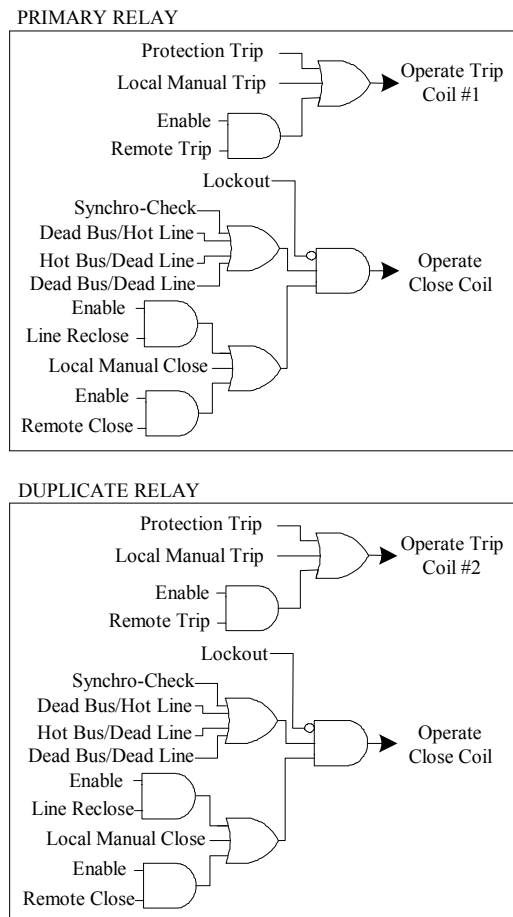


Figure 3 - Duplication of integrated control of a single breaker

Control schemes that only require analog measurements and statuses from only a single power station can be migrated from remote manual or automatic to local automated control. The resulting simplified schemes have fewer components that can fail due to elimination of the telecommunication channel and the potential for human error is reduced. Remote arming or manual backup to this automated control may be included. One example is the automation of switching of a shunt capacitor bank to control local voltage. A relay that is applied to protect the capacitor bank can also measure the bus voltage, make a control determination, and initiate switching. This fully automatic control scheme can be removed from service at any time by a remote SCADA operator.

If redundancy has already been provided to satisfy protection requirements, the dependability, security, availability and simplicity of control schemes may be improved without much additional cost, but the new techniques may require changes to the internal process of a power company.

Maintenance Considerations

In this report, maintenance is also considered. Physical switches for isolation (make-before-break), injection testing, and cutting the relay out of service may be provided at the option of the utility. Connectorized cables might be applied to

the control circuit outputs for possible disconnection. Virtual switches that reside as logic elements within the IED can prevent unwanted transmission of alarms during maintenance. The test switch variable may be “set” by switching on the control voltage to a device input by the same physical test switch that is operated to remove the device from service. This test switch variable can be combined with the control logic result for each alarm or output as inputs to the AND gate function. A virtual test switch may be used to prevent unwanted alarm signals from being sent to the control center during device testing and can be used to test changes to relay or control logic by blocking the device output. This is especially useful when the outputs are over a communication network rather than over traditional wiring.

Recording

Event and fault recording are helpful tools when analyzing faults on the electric system. Most microprocessor-based relays provide these tools in some form. The WG report describes situations where multiple relays are used for protection, control and monitoring to retrieve event or fault data from multiple sources. The ability to compare records from several sources may prove useful. Different relays handle frequency response of the recording circuitry, record length, triggering, record storage, setting files, software, off-nominal frequency, and other issues in different ways. One may be able to gain a better understanding of events by gathering records from multiple relays. The use of time synchronization helps one obtain the full benefit of these comparisons. The usage of an IRIG-B signal from a global positioning system (GPS) time source can provide the necessary time synchronization between relays.

Another useful method to ensure more data is collected during events is cross-triggering or cross-initiation. Cross-triggering or cross-initiation is the function where one relay senses an event and sends a signal to other relays so they can begin their event and fault capture as well. The benefit is that all relays provide data so that analysis of an event can be accurately interpreted. The cross-triggering or cross-initiation can be accomplished by hard wiring an output of one relay to the input of other relays or it can be accomplished via communications.

Applications where this can be particularly helpful are those in which two relays are providing protection for the same zone, such as primary and backup or Set A and Set B relays on a line terminal, transformer, or bus. Having data from both relays can often be of assistance in trouble shooting should one of the relays operate falsely or fail to operate. Comparison of the two sets of event reports also provides an opportunity to verify that current and voltage signals are interpreted consistently in both relays, and allow identification of CT or VT connection errors or setting errors even if both relays operated for a fault.

V. TESTING ISSUES

Commissioning multifunction digital relays that perform protective and control functions offers some unique challenges to the user. Multifunction relays have protective functions that interact with each other, making testing more complicated.

They can also be programmed to do control logic, which also requires verification. In addition, digital relays can have multiple setting groups, which may be selected to address varying system conditions.

Disabling Settings for Testing

It may be necessary to disable settings of other functions different from the one to be tested. Care should be exercised when a protective function is tested by disabling others that the relay is returned to normal configuration before it is returned to service. It may be prudent before testing to make a copy of the in-service settings and when the testing is completed, download the original settings into the relay.

Testing Setting Group Change

Multiple setting groups are generally available in multifunction relays, with only one active at a given time. Unused setting groups could be loaded with the default, most-of-the-time active setting group to avoid useless or damaging behavior of the relay if the setting group is inadvertently switched.

Testing Programmable Logic

Testing the programmable logic in a multifunction relay is similar to following the wiring of functional schematics of traditional relay panels. Figure 4 shows a typical programmable logic scheme. High levels of detailed documentation in schematic diagrams are required describing the programmed logic in the relay. Every feature of the logic is usually tested to confirm that all inputs, outputs, relay function blocks, controls, alarms perform as intended.

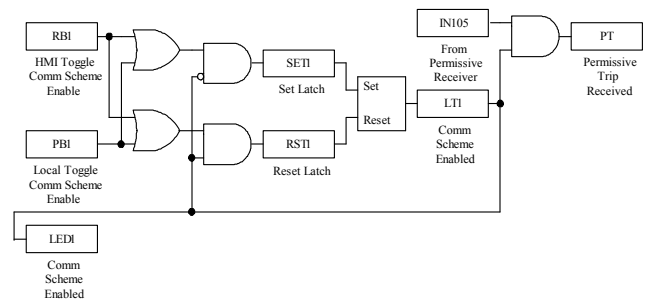


Figure 4 – Example of programmable logic

Testing External Inputs

Opto-isolated inputs are used by multifunction relays to monitor binary signals, such as breaker position. Externally wetted inputs require an external DC voltage while internally wetted inputs use the relay internal DC source. When using externally wetted programmable inputs on ungrounded battery systems it is good practice to confirm that the inputs will not operate for a positive or negative battery ground (half voltage). After testing these inputs for proper operation at normal battery voltage, the test may be repeated at half battery voltage to confirm that the externally wetted contact will not mis-operate.

Testing Targets and Output Contacts

Output contacts of multifunction relays are generally damaged when trying to interrupt trip circuit currents, thus when testing the functionality of the different output contacts this should be kept in mind. Once a trip or close output has been initiated it is important that logic be included to cause the contact to remain closed long enough to complete the circuit breaker operation. Consider confirming the proper functioning of this logic during the commissioning process. (Note – In electromechanical relays, there is a “seal-in coil in series with the trip circuit. This coil keeps the trip contacts closed until the 52a contact on the circuit breaker mechanism interrupts the trip coil current.)

Using the Digital Relay as a Commissioning Aid

Metering of known voltages and currents in multifunction relays can be used to assist in relay testing. Magnitudes, angles and negative sequence measurements can be used to confirm phase sequence and instrument transformer wiring. Oscillographic information can also assist.

Checking Directional Relay Polarization

Verifying the operation and proper connection of directional elements in relays requires knowing the polarities of the terminals, trip direction and operating characteristics of the element. The correct configuration of the relay is normally identified by the relay manufacturer.

Firmware Revisions

It is a good practice to document the firmware revision level on the settings file for each individual relay. By tracking the evolution of the firmware upgrades of a multifunction relay an evaluation can be made if new features or bug fixes are absolutely needed. When new firmware is installed in the relay, it may be necessary to perform all commissioning tests again. In many cases, changes to the software will be minor, but re-commissioning confirms that there were no unintended consequences of the firmware change. For this reason, firmware changes are made only when absolutely necessary.

VI. DOCUMENTATION

With multifunction IEDs in the substation, several processes can be running in an IED using the same inputs. The wiring diagrams may not describe in detail the functionality and the purpose of the internal logic in the devices. Moreover, with the powerful programmable logic available and customized programming in these devices, it is a challenge to document the functionality when several IEDs are involved.

Programmable logic in IEDs can simplify the number of auxiliary relays and the wired logic needed. Documenting internal logic used in IEDs should provide better understanding of the interlocks, control sequences and protection logic implemented in each IED.

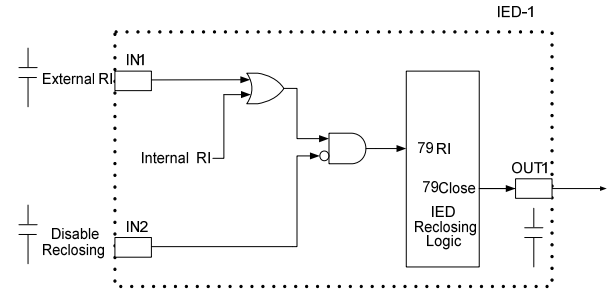


Figure 5 – Example of documentation of internal IED reclosing logic

Figure 5 illustrates a documentation example of reclosing logic in a feeder application. The internal reclosing logic is documented as a block in the drawing with the specifics documented in the instruction manual of the IED. What are not documented in the instruction manual are the inputs to the reclose cycle initiation function (79RI). That logic can be documented in a drawing as shown in Figure 5. It is also conceivable that the IED settings be part of the internal IED logic documentation. It may be beneficial to record revision of the IED instruction manual in order to keep the documentation coherent should the manufacturer make changes or expand on their documentation.

Documentation Issues of Protection and Control Functions in different IEDs.

The use of dedicated serial communication channels to exchange logic bits plus the use of protection and control messages over a switched substation network (Ethernet), such as the IEC 61850, to create substation functions distributed in several devices is a documentation challenge as well.

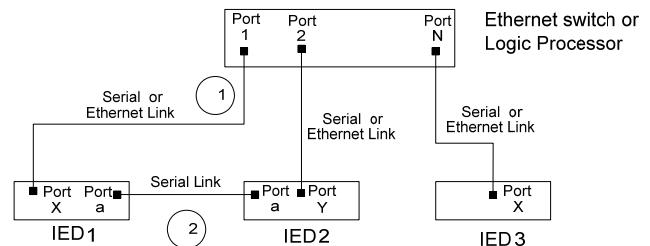


Figure 6 – Example of documenting IEDs' communication links

Documenting the communication links may have the format shown in Figure 6 in which the physical connections of the communication links are shown. The port numbers are clearly identified as would be the case on any other wiring diagram. Whether it is serial communications architecture to a logic processor or an Ethernet network connection to a switch, it is important that it be documented in some fashion. Serial communications for protection and control is also possible between IEDs and may also be documented as shown in Figure 6.

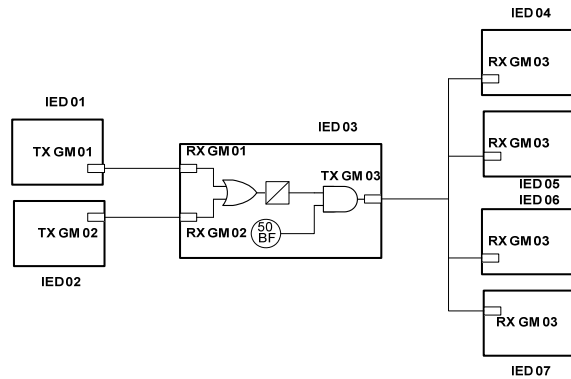


Figure 7 – Example of documentation of serial or Ethernet network messages

The logic implemented in different IEDs can be documented as shown in the simple example in Figure 7. In the figure, IEC 61850 GOOSE messages (GM) are being used as examples of transmitted messages in a network. The origin of the message is shown in the figure with the ‘TX’ marking. The data reception is shown with the “RX” marking. Figure 7 is a simple example of a BF scheme in which the primary and secondary protective relays initiate the breaker failure timing in the BF relay (IED_03). The breaker failed message (TX_GM_03) is then distributed to other IEDs who have subscribed to this message.

VII. CONCLUSION

This paper is a summary of the IEEE Power System Relaying Committee Working Group K5 report relating to considerations in applying ancillary protection and control functions that are available in multiple relays and the integration of these functions into an overall protective relay system. The paper gives the reader insight into the full document which addresses subjects and application examples related to specific topics such as: breaker failure, automatic reclosing, synchronism check, voltage status monitoring, breaker controls, event and fault recording, testing, maintenance and documentation of protection and control functions in different IEDs. Applications of redundant protective relaying schemes are discussed with special considerations for security and dependability, while taking into account human factors in relation to testing and maintenance.