An Examination of Test Switches in Modern Protection and Control Systems

Sam Fulford and Michael Thompson
Schweitzer Engineering Laboratories, Inc.

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Abstract—**Test switches have historically been installed in protection, metering, and control (PCM) system ac and dc circuits for many reasons. This paper reviews the purposes of test switches and examines them in light of the characteristics of microprocessor-based technology that is used in PCM systems today. Testing requirements have changed as a result of continuous self-testing functions in modern IEDs. Isolation of trip signals that travel on communications links is another example of why we need to review the application of traditional test switches. Eliminating test switches can significantly reduce the amount of wiring, space, and cost of PCM panels. In addition to reducing the cost of the PCM panels themselves, space savings on PCM panels can reduce costs by reducing the size of the control building itself. To achieve these savings, it is not sufficient to simply eliminate test switches from the system design. Test switches must be engineered out of the system design in such a way that operational and maintenance requirements are met. This paper offers suggestions for meeting the functional requirements of test switches with lower cost and more reliable alternatives.**

I. INTRODUCTION

Today modern protection, control, and monitoring (PCM) systems consist of microprocessor-based multifunction relays. One relay typically includes all the features and functions of a complete PCM system. The hardware is mounted similar to its predecessor, the electromechanical or solid-state relay, on a control panel. The relay can also be mounted in a 19-inch rack, which appears to be the de facto standard of most equipment manufacturers. Although some of the internal components or boards of the relay may be removed from the chassis, most relays are not equipped with a method to easily isolate the relay from its control circuitry.

Multifunction relays have built-in diagnostics that alarm for an internal failure, an important feature of the relay. However, the relay cannot test for a failure or misapplication of its I/O. Misapplying an output contact can result in a breaker failure to trip, to reclose, or to perform a needed control action. Self-tests also miss human errors, such as applying the wrong voltage for digital input wetting or connecting dc power outside the rating of the relay. Misapplying user programming functions can also cause misoperations [1]. The following are some examples of these errors:

- Failure to program the trip output contact to assert when the relay issues a trip command.
- Wrong relay element programmed in the trip equation.
- Wrong relay elements programmed in a pilot blocking scheme.
- Incorrect logic settings disable sensitive instantaneous overcurrent element for a hot-line condition.
- Incorrect directional element impedance setting in pilot blocking scheme.
- Incorrect phase rotation.

Simply testing all elements in the relay may not improve the reliability of the PCM system. Testing for testing sake is counterproductive. What should be tested are those components of the power system that are known to have failures. What has been proven over and over is that a specific relay element test may not produce the desired results [1]. If the element fails the test, the tester must adjust the test quantities to more closely match that of the actual power system. Then the test will pass.

Outside influences, such as those listed below, may drive the relay owner to perform tests beyond those that may be considered routine or necessary.

- Insurance companies
- Nuclear Regulatory Commission
- North American Electric Reliability Council
- Federal Energy Regulatory Commission
- Regional Reliability Councils, e.g., Florida Reliability Coordinating Council

Test switches are provided for PCM system maintenance technician use. The PCM system may have other switches installed for use by operators and apparatus maintenance technicians, such as control power switches, relay-disabling switches, and feature-disabling switches. An example of a feature-disabling switch is a recloser cutoff switch that is operated when live line work is being performed on the primary circuit. The scope of this paper applies only to test switches that are for PCM system maintenance technician use.

II. HISTORICAL REQUIREMENTS

Test switches have typically been installed in both the ac sensing circuits and dc logic circuits of a PCM device. The characteristics of modern PCM devices are so different from previous technologies that it is important to review the functions that test switches provide and examine their application in a modern PCM system. This section discusses the historical role of test switches in the PCM system design.

PCM panels are installed in electrical substations for mounting all the devices required to protect, control, and monitor the primary electrical circuits and complete the ac sensing and dc logic circuits between the primary electrical devices in the substation and the PCM devices (digital relays). Test switches are installed in the PCM panels to facilitate the commissioning stage of the system, as well as troubleshooting, maintenance, and testing of the system after the electrical substation is in service and operating.

A. Commissioning Stage of System

During the commissioning stage, all ac sensing and dc logic circuits must be verified to ensure that they are wired correctly and function as expected. Once a new or revised system has been fully checked, it should not be necessary to verify these circuits again until the next time they are disturbed or modified. Of course, it is not unusual to discover a problem that was missed during commissioning when troubleshooting an in-service system. This type of testing still falls under the commissioning stage even though it is delayed.

1) AC Sensing Circuits

Test switches have historically been installed in ac sensing circuits to facilitate the following commissioning tests:

- Point of current and voltage injection testing to calibrate the protective elements in the PCM device by injecting simulated power system quantities.
- Point for testing to verify ac sensing circuit connections prior to initial energization and loading of the primary equipment.
- Point for taking meter readings after initial loading of the primary equipment to verify proper magnitude and angle readings in the ac sensing circuits.

2) DC Logic Circuits

Test switches have historically been installed in dc logic circuits to facilitate the following commissioning tests:

- DC circuit tests, including trip and close circuits.
- Point for monitoring PCM device outputs during protective element calibration.
- Point for verification of PCM device output contacts.
- Point for isolation of PCM device while verifying functional logic programming, SCADA system, and other higher-level system tests.

B. In-Service Stage of System

Once a PCM system has been verified and the system has been placed in service, test switches have historically allowed taking specific PCM equipment out of service for maintenance, testing, troubleshooting, and repair without requiring that the primary power system circuits be removed from service. Important circuits typically have adequate redundancy such that there is protection and control when one PCM system is disabled. This is usually the requirement for utility power systems. The use of test switches in industrial power systems is less prevalent where maintenance is typically only performed during outages.

1) AC Sensing Circuits

Test switches have historically been installed in ac sensing circuits to facilitate the following functions after the system is in service:

- Point of current and voltage injection testing to check or calibrate the protective elements in the PCM device by injecting simulated power system quantities.
- Isolation of VT circuits and isolation and shorting of CT circuits for replacement and repair of PCM devices without de-energizing primary circuits.

2) DC Logic Circuits

Test switches have historically been installed in dc logic circuits to facilitate the following functions after the system is in service:

- Point for monitoring PCM device outputs to check or calibrate protective elements.
- Isolation of dc logic circuits for replacement and repair of PCM devices without de-energizing primary circuits.
- Point for isolation of PCM device while modifying and verifying functional logic programming, SCADA system, and higher-level system tests.

III. NEW TECHNOLOGY

We need to examine each of the above historical requirements for test switches in light of the characteristics of PCM systems built around modern technology. How are modern PCM systems different from previous electromechanical and analog discrete component technology?

A. Systems Are Built Using Numerical PCM Devices

In the past, protective relay measuring elements and logic circuits consisted of individual components, such as coils, induction units, analog comparator circuits, etc. Each protective or logic element was a separate circuit that could individually fail. To verify such a system, each individual element had to be tested. If the A-phase high-set overcurrent element was functional, it had no bearing on whether the A-phase low-set overcurrent element was also functional, because the two elements were made up of separate circuits.

With numerical relay technology, each protective element is not an individual circuit. It is code running on a microprocessor. The A-phase current, for example, is sampled and measured, and this measurement is used by all functions within the multifunction PCM device that require it. If the function of the A-phase current measurement is verified once, all elements that use it will also function.

For example, to check the timing of an overcurrent element, you program a spreadsheet on your computer to calculate the expected time to trip. You expect that every time you open the spreadsheet and enter a specific multiple of pickup that you will get the same time-to-trip value. Implementing a numerical relay overcurrent timing function is similar. Every time you apply a multiple of pickup to the input of the relay it will give the exact same time-to-trip value because a microprocessor is running a program to calculate the timing. The only difference is that in the spreadsheet, you enter the current value directly into the cell. The numerical relay must measure the input current value for use in the calculation. So, it is important to verify that the current value is measured properly to ensure that the time is calculated correctly. But, there is little added value to verifying that the program that calculates the timing function has not changed.

B. Modern PCM Devices Have Continuous Self-Testing Functions

Discrete component devices almost universally had no way of running tests to verify their own circuitry. Numerical relays, on the other hand, can run processes that verify most of the subsystems that support the microprocessor in providing the functionality of the PCM device. Well designed modern PCM systems must monitor the “Relay Fail” output contact. Statistical analysis indicates that reducing the amount of routine, in-service testing actually improves reliability when using relays equipped with continuous self-test and monitoring the “Relay Fail” output contact [2]. For this reason, most routine testing activities that were required with older technologies should be reconsidered.

It is safe to assume that the only items that the PCM device cannot verify by continuous self-test are its interactions with the outside world. When we accept this, it is no longer necessary to disable and manually test the individual functions of the modern PCM device.

Continuous self-test functions cannot directly verify that the binary and analog inputs they are reading actually represent the state of the power system they are monitoring. Or, that when it commands a breaker to operate via an output contact, it will actually close the circuit and energize the trip or close coil of the circuit breaker. The following items need to be independently verified beyond the relay’s continuous self-test [3]:

- Are the current- and voltage-sensing circuits correctly measuring? Is a measurement of 5 amperes really 5 amperes, or is it something different?
- Are the contact sensing input circuits correctly reporting the state of the contact? Is a breaker open, or has a contact or connection failed in the circuit?
- Will the output contacts operate their circuit? When the relay asserts its contact, does it really close? Does it really trip the circuit breaker?

Obviously, the above functions can be verified by traditional testing means, such as removing the device from service and testing by signal injection and trip testing. However, by doing so, the relay must be removed from service, and there is no guarantee that a problem will not occur immediately after the test and will not be detected until either an undesired operation occurs or the next periodic test interval comes along. In a modern PCM system, it is possible to build continuous self-test features into the PCM system itself to eliminate the few mentioned holes in the device continuous self-test capability.

C. Modern PCM Systems Also Can Have Continuous Self-Testing Functions

Reference [4] provides detailed suggestions for building robust, fault-tolerant systems that require little maintenance. The more the system continuously monitors itself, the less it has to be periodically inspected and/or tested. If problems are detected immediately, they can be corrected before an improper operation can occur. The time to detect and correct failures directly affects reliability [5]. Therefore, immediate detection via self-test dramatically improves system and service reliability.

Building reality checks into the PCM device logic to alarm for anomalies can validate most signals required by the relays to function properly. Reference [4] gives several examples of designing reality check alarms into the system. Simply monitoring alarm features built into modern PCM devices can also validate signals [6]. A classic example of a reality check that most readers are familiar with is the loss-of-potential (LOP) logic built into many modern relays. This logic typically compares the magnitude or change of unbalanced voltage to the magnitude or change of unbalanced current. If the voltage becomes unbalanced but the current does not, it means that the unbalanced voltage is most likely a result of a problem in the VT circuit, such as a blown fuse, instead of an actual fault or unbalance on the power system. Similar approaches can be taken to verify most other readings made by the relay. These techniques have the further advantage of verifying not only the PCM device measurement circuits but also the instrument transformers and circuits. This will be discussed in more detail elsewhere in this paper.

Perhaps one of the most powerful reality checks available is to use metering and status data from the relays for local HMI and remote SCADA. The data are visible to the ultimate reality check—system operators who are monitoring the system 24/7. This is an often overlooked and extremely important benefit of integrating relay data for SCADA purposes. If critical current, voltage, and status signals required by the relay to detect faults have a problem, it is much more likely that the problem is going to be detected immediately if the system operators use these same data.

An example that applies to output contacts is to combine all of a circuit’s output signals in logic before programming them to an output contact. That way, the “connections” are within the relay’s continuous self-check monitoring. For example, by combining the manual trip functions with the protective trip functions on the same contact, every time you manually open the circuit breaker, the trip circuit is also verified. This has the desirable effect of a failure becoming known during a manual opening operation instead of when the power system is faulted.

When continuous self-test features are built into the PCM system as a whole, one important role of test switches in an in-service PCM system is virtually eliminated.

IV. DESIGNING OUT TEST SWITCHES

It is not recommended to simply eliminate test switches from the design. This may accomplish initial savings but result in operational and maintenance costs over the life of the PCM system. It is necessary to design the test switches out of the system and provide only the necessary functionality. To do this, procedures, record keeping, training, etc. must also be examined and adjusted, in addition to the actual PCM system design.

A. Isolation for Repair

When PCM systems consisted of single-function electromechanical or static relays, each relay was constructed so it could be easily removed from service for calibration, maintenance, or repair. This feature consisted of either a disconnect plug/paddle or a series of knife disconnects to isolate the relay, which was mounted in a cradle that could be drawn out of the case without disturbing the panel wiring. Because most modern relays do not have built-in isolation, most users added this feature externally, thinking the requirements were the same.

There are several methods available so that a modern relay can be easily removed from the system for repair and replacement. Some of these options are as follows:

- Relay with quick-disconnect terminals – Some PCM devices are provided with easy-to-disconnect terminal blocks, as shown in Fig. 1. Isolating the digital inputs and outputs is straight forward, as is isolating the dc supply and ac potential inputs. However, isolating the CT circuit is not as direct. Before isolating the CT circuit from the PCM device, the secondary of the CT circuit must be short-circuited. Some modern PCM devices are equipped so that the quick-disconnect terminal blocks not only isolate the device but also short circuit the CT, functionally similar to the design of drawout case relays.
- CT shorting blocks – The standard CT shorting block, familiar to all, can also be provided where the circuit enters the relay and control panel. This way, prior to removing the PCM device, the CT circuit can easily be short-circuited.
- Knife blade terminal blocks – These blocks, similar to test switches, are used to terminate the incoming circuits to the relay and control panel but are not as conveniently located as test switches. However, during the few times that they are required over the life of the PCM panel, convenience is not very important. These blocks can have all the features and functions of the test switch. Because these blocks are physically larger than regular blocks, mounting may present other issues.
- Sliding link terminal blocks – These blocks are physically similar to the knife blade terminal blocks except a hand tool is required to loosen and move a sliding link to isolate the field side from the panel side of the terminal block. A provision to short-circuit a CT is not provided. Because each terminal is typically a reasonable length stud, a shorting jumper wire can be stacked on top of the source-side CT circuit with an additional nut to easily short this circuit. Opening the sliding link will then isolate the circuit.
- DIN rail-mounted terminal blocks – These European-style terminal blocks have the most flexibility in designing out test switches. The blocks are readily available in various wire ranges and configurations. In addition to a feed-through block, they are also available with a multitude of disconnect methods, including switches and sliding links. Accessories include shorting bridges for CT circuits and test point adapters for connecting test instruments. These blocks are compact, so each relay can have its own set of terminal blocks with minimal space requirements. Fig. 2 shows an example of this type of terminal block.
- General wiring – Lastly, how the panel is physically arranged and wired should be considered. This can be as simple as how the various circuits are daisy chained around the panel, how the harness is bundled, and the ease of physically removing the PCM device. For easy removal, a panel-mounted device should be arranged with adequate clearance for removing the mounting bolts or screws, typically from the rear. A rack-mounted device, normally front connected, would typically be easier to remove than a similar panel-mounted version.

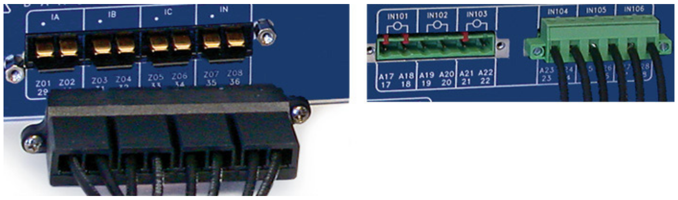

Fig. 1. Relay Equipped With Quick-Disconnect Terminals

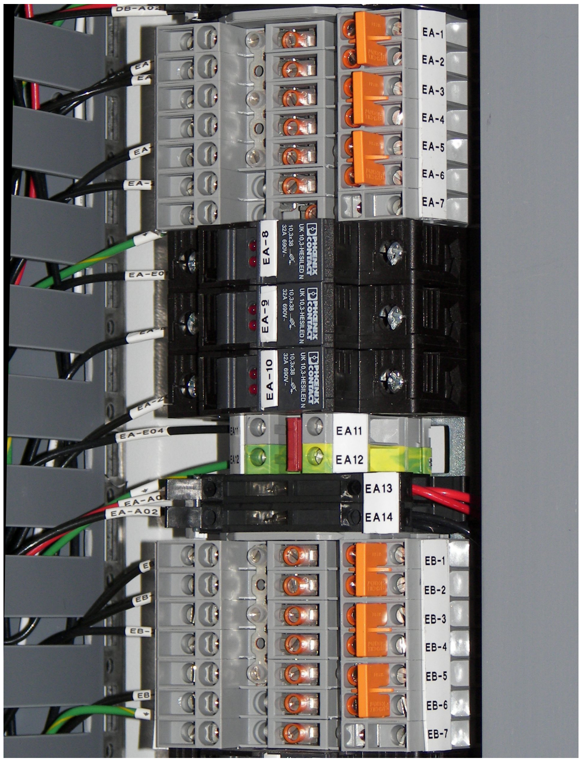

Fig. 2. DIN Rail Multifunction Terminal Block

B. Calibration Testing

In the past, many relay elements had to be calibrated by adjusting potentiometers, time levers, etc. It was necessary to inject a calibrated signal into the relay and adjust until the device operated at the proper value. With numerical relays, calibration settings are made by entering an exact value into a field. Therefore, calibration of elements by injection of known signals is not required.

If performed correctly, calibration testing can be used to verify that the values were typed into the relay settings file correctly, e.g., the technician or settings engineer didn't accidentally type 15.0 instead of 1.50 for a pickup value. However, there are other, less complex and more secure ways of verifying the integrity of the settings values in the relay (e.g., having a peer review of electronic settings files to verify that they match the standards and settings calculations). Simply reading settings from a relay and using injection testing to verify that those are the settings that are in the relay is of little value. If individual element testing is to be used to validate a settings file, it is necessary for the tester to go back to the original source data to get the test values to test against if the testing is to be useful.

Using concepts discussed in [4], verifying the calibration of the actual measurement functions in the PCM device can be accomplished by comparing metering values and/or using synchrophasor measurements between multiple devices reading the same primary power system quantity. This can be done manually on a periodic basis or continuously by a computer in the substation.

On rare occasions when it is useful to inject a known test signal, relays equipped with quick-disconnect terminals (Fig. 1) or multifunction terminal blocks (Fig. 2) can easily provide that access. For example, when quick-disconnect terminal blocks are used, the panel wiring harness can be disconnected and a spare wiring harness that is connected to the test set can be connected in its place.

C. In-Service Readings

Taking in-service readings upon first loading is probably the single most important commissioning test. This test ensures that the PCM system is properly measuring the power system that it is intended to protect. Test switches provide a convenient point for inserting meters to take current and voltage magnitude and angle readings in a new or revised circuit. This is required with older technology devices. However, this test could miss a wiring error between the test switch and relay. It could also miss a design error where the ac elementary diagram is incorrect. The external meter may only prove that the circuit is wired per the design.

Using the metering functions of modern PCM devices to verify that they are reading the power system quantities correctly is superior to using a separate meter because the relay tells you what it is seeing, and that is what it is going to operate on to protect the power system. Using this superior technique eliminates the need for physical test switches to cover this function.

Synchrophasor measurements, relatively new and available in many popular PCM devices, take relay measurements one step further. Synchrophasors provide a measurement of the magnitude and angle of the fundamental component of the power system currents and voltages related to an absolute reference time. The time reference requires synchronization from a high-accuracy global positioning system (GPS) satellite-synchronized clock.

This allows comparison of measurements between multiple PCM devices. By triggering a synchrophasor measurement in two devices to occur at exactly the same time, it is possible to verify that the A-phase voltage measurement in the two devices is the correct angle relative to each other. Then, the metering command, as mentioned previously, can verify that the other measurements are in the correct relative position versus the established reference voltage.

D. Validation of Higher-Level Systems

In an integrated PCM system, the protective relays serve additional functions over and above detecting and initiating isolation of faults in their protective zone. Additional functions include the following:

- Trip decisions made externally by other protective devices where the relay is acting as a 94 auxiliary tripping relay (e.g., breaker failure trip from an adjacent circuit that is sent via a communications link).
- Manual trip and close controls from a remote operator where the relay is acting as the interposing relay from the SCADA communications link.
- Manual trip and close controls from a local operator via the relay's local control interface.

It may be necessary to isolate the relay from the primary equipment in order to validate and troubleshoot changes to these higher-level systems. Testing these systems often consists of validating tags in a computer HMI database and addresses in a network protocol message. It is necessary to assert a command in a remote system and ensure that the correct bit toggles in the correct PCM device to validate these higher-level systems.

As recommended in Section III.C of this paper, combine all similar functions, such as circuit breaker trips, in programmable logic inside the device and wire only a single contact to the primary equipment as a way to regularly validate this critical circuit [4]. If you use a traditional test switch in series with this output contact, it becomes necessary to take the circuit protection out of service in order to test these higher-level systems.

A better solution is to use a virtual test switch. The virtual test switch can also solve the problem of isolating outputs, such as tripping signals that are sent via communications links. These trip outputs cannot be isolated by placing a test switch in series with a contact because no physical contact is involved.

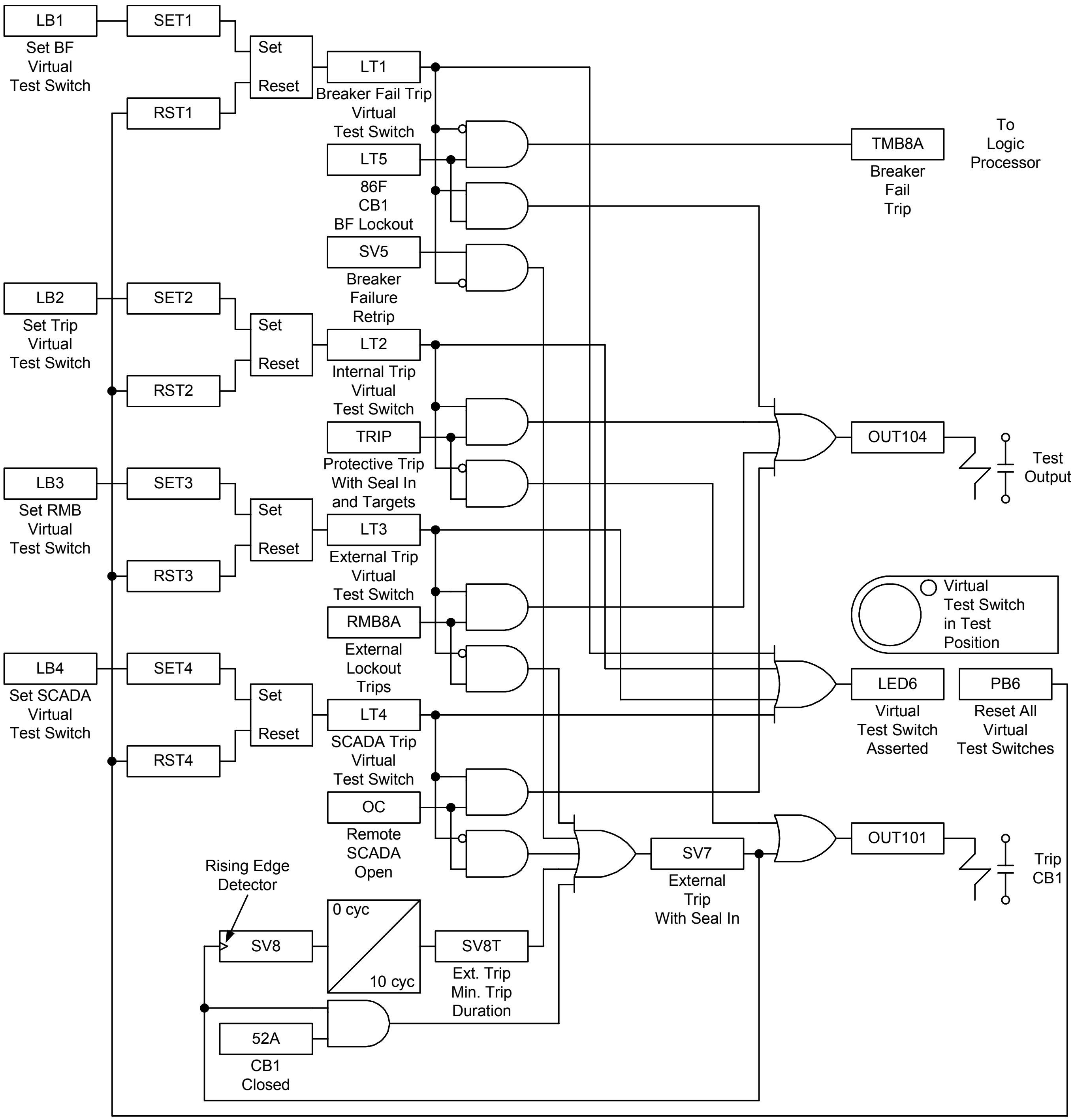

Fig. 3. Virtual Test Switch Logic Example

Virtual test switches can be created in programmable logic to eliminate the need for physical test switches wired to the PCM device. Fig. 3 provides an example. In addition to the zone protection trips, the relay also trips its breaker for manual trip via a SCADA communications link. The relay also trips backup circuit breakers via a communications link in the event that breaker failure tripping is required.

The recommended practice is to use a local control bit to set each virtual test switch. Local control bits are software switches that can be accessed locally from the HMI menu on the PCM device. These software switches can be programmed to emulate on/off switches or momentary pushbutton-type switches. Local bits can only be found by scrolling through the HMI menu. Relay technicians, not operations personnel, typically will access these bits, so the separation of operational divisions is maintained. With a traditional test switch, the operations and maintenance personnel can easily see if a test switch is in an abnormal state by the fact that the test switch cover is off, and a test switch is open. To emulate this, the status of the virtual test switches should be indicated by one of the programmable pushbutton LEDs on the front of the relay so that it is readily apparent if a virtual test switch is in the blocking state. This same pushbutton can be used to deassert the virtual test switches.

In the example system, four virtual test switches, labeled LT1, LT2, LT3, and LT4, are provided to isolate the following functions:

- LT1 – Isolate breaker failure trip transmitted via a protection communications link.
- LT2 – Isolate protected zone trips (internal trip decisions).
- LT3 – Isolate external trips received via a protection communications link (e.g., breaker failure trips from adjacent circuit breakers).
- LT4 – Isolate remote SCADA trips.

When the virtual test switch is asserted, the tripping output for that function is blocked from asserting the trip contact (OUT101 in the example) that is wired to the trip coil of the primary circuit breaker. Instead, the tripping function is redirected to assert a test output (OUT104 in the example) that can be monitored. If any of the virtual test switches are in the test state, an LED (LED6 in the example) is illuminated on the front of the relay to indicate the abnormal condition. Pressing the pushbutton associated with the alarm LED (PB6 in the example) will return all virtual test switches to the normal state.

With this scheme, these higher-level systems can be validated without taking the primary systems out of service. This would not be easy to accomplish using traditional test switches.

V. VALIDATION OF THE COMPLETE SYSTEM

In this section, we discuss testing the system and not just the relay. These tests concentrate available maintenance resources on the items that are most likely to fail. In some cases, we recommend using the PCM devices to help perform tests on the entire system. Isolation of the PCM device using test switches is not required for these types of tests.

A. System Tests

As high-voltage equipment ages, it is more prone to failure than the modern PCM device. The following are some example failures:

CVT – A shorted series capacitor will cause a gradual change in the output voltage. These units are typically applied as one of the three-phase input devices to the PCM system. The PCM system can be programmed to monitor this change in voltage by using either a V0 or V2 detector set sensitive with an alarm to SCADA. This way the maintenance personnel can take action and schedule repair prior to a catastrophic failure. As described in Section IV.C, synchrophasors are also a useful way to verify that a CVT is not drifting and getting ready to fail. For example, if there are four lines off of the bus with line-side potential sources, you can compare the magnitude and angle of the four A-phase voltage measurements. If the magnitude and angle of one of the CVT secondary voltages is different from the others, that would indicate an incipient failure that can be corrected before catastrophic failure can occur. Of course, this check would also indicate if there is a problem in the A-phase voltage input circuit of the PCM device that has the measurement that is out of tolerance.

CT – The outputs of CTs do not gradually change as they age. The most common failure that can go undetected is a failure of the mounting material. This leads to a low megger (insulation megaohm resistance test) reading. The ability to monitor for this failure cannot be done in service and can only be found by testing. Wiring the CT inputs to the PCM system in such a way that it is easy to remove the single-point ground for testing is all that is required for this type of test. Modern PCM devices should be designed such that they, too, can be meggered along with the rest of the CT circuit.

DC control – The most probable failure of the PCM system is the actual circuit breaker or the control to the breaker. This is discussed further below.

B. Programming System Tests Into the Relay Logic

The most critical mission of a PCM device is to successfully trip its associated circuit breakers. There are many facets of reliable operation of these devices. Most circuit breakers are equipped with two independent trip circuits that can be controlled by two independent PCM systems. To properly determine the electrical integrity of the system, a trip circuit monitor is usually installed in each of the trip circuits. This monitoring can only verify the health of the associated dc supply, the trip coil, and the associated circuitry. It cannot monitor the breaker mechanical system, e.g., mechanical binding or alignment problem. This can be best tested by actually operating the beaker or device while monitoring its parameters. However, with the ability to remotely retrieve and review event reports after a breaker trip operation, it is easy to detect these and many other problems without the need to go on site and physically operate and test the circuit breaker [6].

Though not as critical as the trip circuit, the close circuit is critical in restoring power after an outage. A failure of this circuit will cause an unnecessary delay to restore the system back to normal. Most high-voltage systems rely on reclosing to quickly restore the system for reliability of the power system.

The trip and close systems were tested in the electromechanical relay by physically closing the protective relay contact to initiate a breaker trip. Prior to this test, the circuit under test would have to be isolated from the other in-service equipment to prevent their operation. This simple test would verify the complete breaker trip circuit. Once this test was completed, the isolated circuits were then restored to normal. If a reclosing trip was simulated, then the reclosing circuit could also be tested. With solid-state relays, the trip contacts could not be manually closed, so some devices were equipped with a maintenance-type trip button. If the trip pushbutton was not provided, the relay was forced to trip by an injection test. The ability to exercise the output contacts continues in today's PCM devices. This consists essentially of providing a function for the tester to command a fixed-duration pulse of each output contact.

A better method in testing a modern PCM system is not to program the various outputs to test the device but to program the device to test the surrounding system.

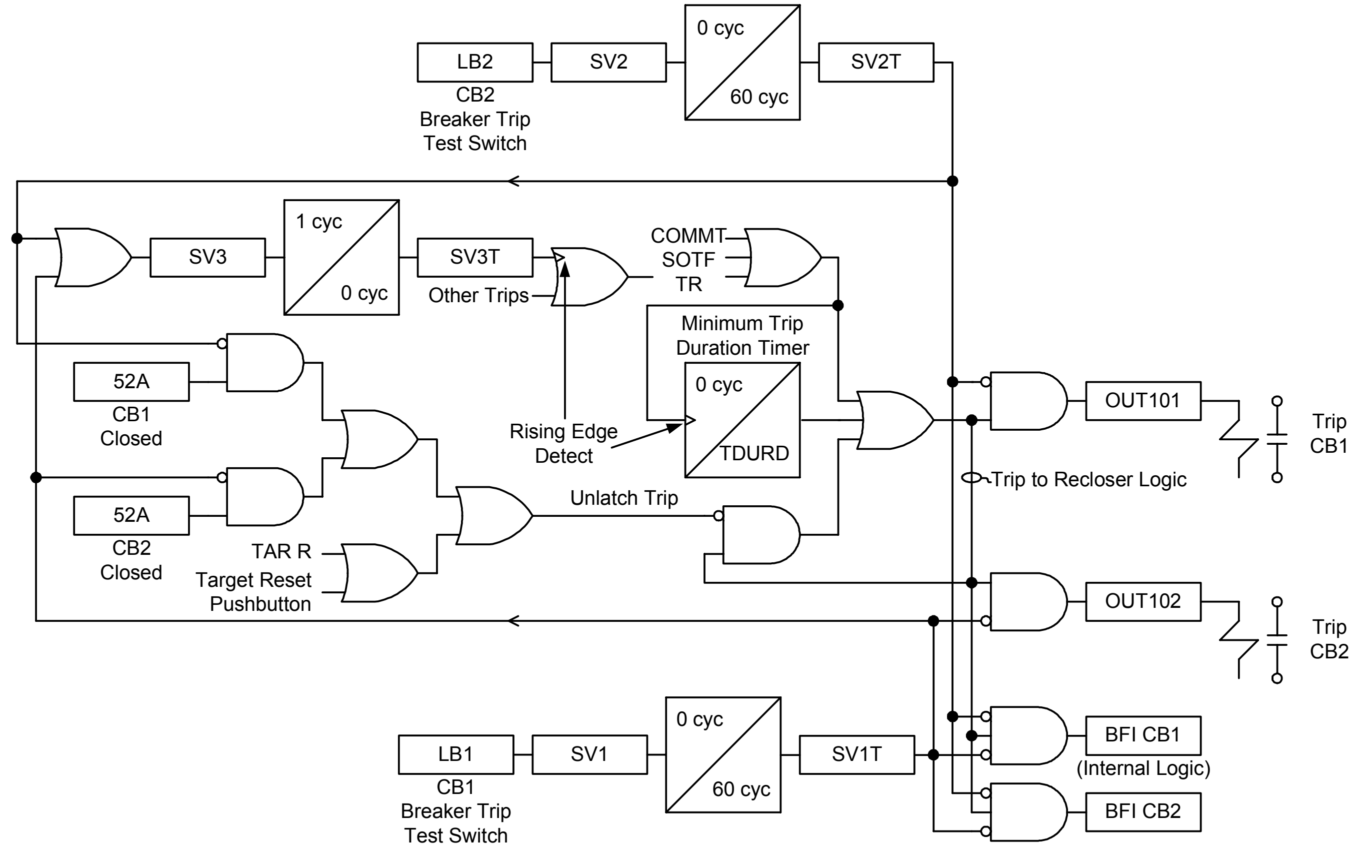

Fig. 4. System Test Logic Example

Consider the following example for a breaker-and-a-half bay on a transmission line. A modern PCM device is configured as the primary protection. This PCM device is backed up by another PCM device with equal protection features. The PCM device is programmed to trip two circuit breakers because of this configuration. It is also possible to exercise each circuit breaker individually without an outage. Fig. 4 shows the trip, close, and breaker failure logic. There are several local control bits that are enabled when the relay is put into test mode. An explanation of the circuit follows.

Local control bit one (LB1) when pulsed will start a one-second timer (SV1). While this timer is active, the protective trip logic to the follow breaker (CB2) will be blocked along with the breaker failure initiate outputs. The follow breaker status will also be removed from the unlatch trip logic, allowing the relay to issue an unconditional reclosing trip one cycle after the test is started via timer SV3, which is ORed with the protective elements in the relay's trip logic. This test, if successful, will cause CB1 to trip and reclose if the recloser is enabled. When the trip is initiated, the PCM device is programmed to initiate an event record to determine trip and reclose time of the breaker and see the contact disparity of each breaker pole. For our case, each breaker has independent CT input to the relay, so triggering an external event recorder is not required. In a similar fashion, the follow breaker (CB2) is tested using local control bit two (LB2). Not only is the output of the relay tested but the complete breaker trip and close system, including any breaker auxiliary switches, is tested. Test switches are not required for these tests because each test automatically isolates those outputs that are not part of the test.

VI. Benefits Extend Beyond Panel Costs

Designing test switches out of PCM panels results in many additional benefits. When we use the features of a modern protective relay to cover control, metering, monitoring, etc. in addition to the protection of the circuit, it becomes possible to cover more circuits on each PCM panel. Installing traditional test switches involves a lot of additional wiring and panel space. If test switches can be designed out of the circuit, the number of circuit PCM equipment that can be placed on each panel becomes greater.

If more circuits can be accommodated on each panel, fewer panels are required. If fewer panels are required, a smaller control building can be used. Reducing periodic testing after the system has been placed in service leads to further reduction in space requirements. A smaller control building can be easily assembled in a factory and shipped to the site. Factory fabrication can significantly reduce costs compared to on-site construction. Factory fabrication also allows complete testing of the PCM system before it arrives, which can improve both quality and project schedules. A smaller building typically requires inexpensive pier-type foundations, further reducing installation costs. And finally, a smaller building requires less HVAC operating costs over the entire life of the PCM system. This synergistic affect leads to significant life-cycle cost savings for the electrical substation.

Fig. 5 shows an example of a PCM panel with traditional test switches. A great deal of additional expense and wiring has gone into constructing this panel. The user interface of the relays that are used for local operator indication and control are located well above and below comfortable operator access levels to make room for the test switches that may only be used a few times over the life of the panel.

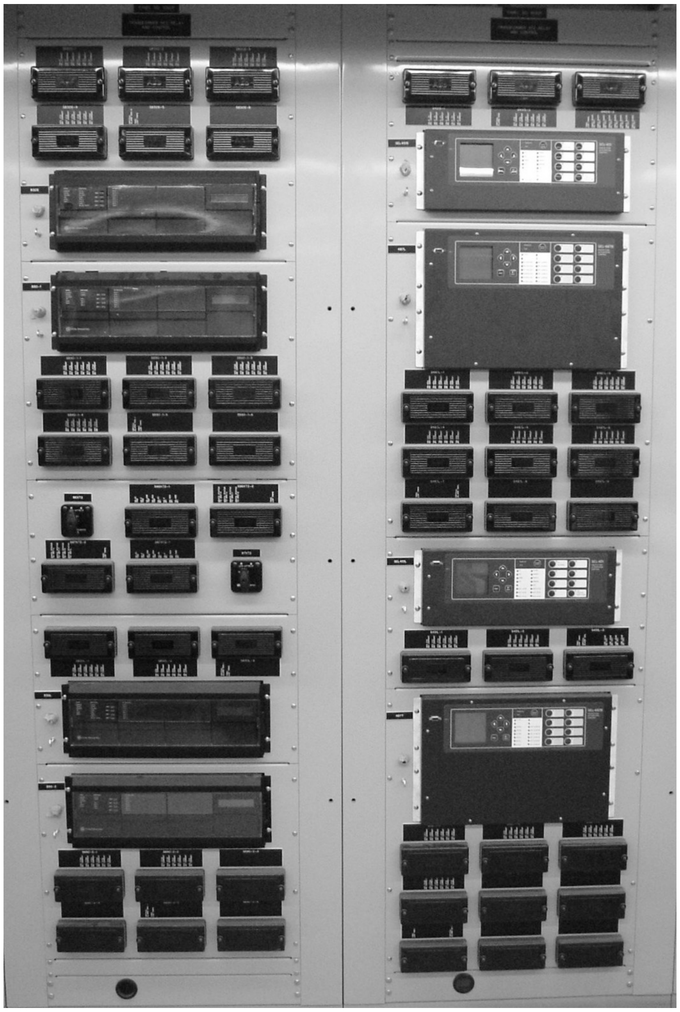

Fig. 5. Panel With Traditional Test Switches

Fig. 6 shows an example of a PCM panel where the test switches have been designed out. The operator interfaces, on the fronts of the relays, are all located between waist and eye level for comfortable operator access. This example includes test switches to short circuit current channels and isolate trips in the bus differential relay. The rest of the relays use quick-disconnect terminal blocks for quick replacement and repair. Isolation of outputs for testing higher-level systems is accomplished by programming virtual test switches.

Fig. 6. Panels With Test Switches Designed Out

VII. SUMMARY AND CONCLUSIONS

In this paper, we have examined the purposes that test switches serve in a PCM panel. In most cases, these purposes are no longer valid in modern PCM system design. When presented with the option of eliminating test switches from the panel, the response is often, “I cannot eliminate them because my procedures require me to perform this test that uses these test switches.” This paper attempts to provoke thought as to whether existing testing procedures remain valid and contribute to improvements in reliability of the power system as a whole.

The following anecdote helps to illustrate the point. A test technician once made a comment about how he enjoyed testing microprocessor PCM devices because he never found them out of tolerance and needing adjustment. Testing for testing sake is counterproductive. A calibration or characteristic test of each protection element within the relay tends to test the ability of the tester to correctly test the element rather than actually find a relay failure.

Including test switches in the design as a convenient location for injecting simulated power system signals into relays provides very little added value during commissioning and after the system is in service. Using the metering features of the PCM device to examine normal in-service power system readings is superior in that it tests not only the relay analog input circuits but also the entire system, including the instrument transformers. In nearly all cases, it is possible to get independent readings from other devices measuring the same power system quantities, e.g., comparing the readings of the System A relay and the System B relay on a circuit breaker. One caution when using this method is that the two devices being compared must use similar measuring techniques. It would not be correct to compare a revenue class true RMS metering device to a protective relay that filters out everything except the fundamental component. Another justification for injection testing is to validate that set points are correctly entered. This can be more easily accomplished by other procedures.

Isolating the PCM device for repair or replacement is actually poorly served by test switches. There are so many connections to a modern PCM device that it is rare that the designer will isolate every wire to the PCM device through a test switch (attempting to emulate the drawout case functionality). Using relays equipped with quick-disconnect terminal blocks or multifunction terminal blocks better serve this requirement. The special case of short circuiting CTs prior to disconnecting wires is usually already covered by special terminal blocks with CT-shorting provisions before they get to the relay. The CT-shorting test switch then becomes redundant to that other device.

Test switches are also particularly inadequate for isolating output signals in integrated systems where various tripping and closing signals travel by communications networks. Designing virtual test switches into the device logic is a better, more functional way to allow isolation of these signals.

In our quest to reduce costs and improve reliability, eliminating unnecessary components and unnecessary maintenance procedures allows us to put available resources towards activities that actually improve the reliability of the power system. Reducing the cost of new PCM systems can also allow us to catch up with vital infrastructure renewal in our aging electric power system.

To summarize, most of the requirements for test switches in the ac sensing and dc logic circuits are no longer valid or can be addressed by other means. Eliminating the extra components and wiring in the circuit can improve the cost and reliability of PCM systems.

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IX. BIOGRAPHIES

Samuel H. Fulford earned an associate degree in electrical engineering technology from Southern Technical Institute, Marietta, Georgia; a BSEE with honors from Florida Atlantic University, Boca Raton, Florida; and an MSEE (power emphasis) from the University of South Florida, Tampa, Florida. He began his career in 1967 at Florida Power and Light Company, Juno Beach, Florida, as a relay technician in System Relay Operations. He then held various other positions at FPL, including system protection field supervisor, assistant area system protection manager with the Eastern Division System Protection Group, relay design principal engineer in Power System Engineering, engineering supervisor, and principal engineer in Transmission Operations. Sam joined Schweitzer Engineering Laboratories, Inc. in 2001. He is a registered professional engineer in Florida, Washington, and Alberta, Canada.

Michael J. Thompson received his BS, magna cum laude, from Bradley University in 1981 and an MBA from Eastern Illinois University in 1991. He has broad experience in the field of power system operations and protection. Upon graduating, he served nearly 15 years at Central Illinois Public Service (now AMEREN) where he worked in distribution and substation field engineering before taking over responsibility for system protection engineering. Prior to joining Schweitzer Engineering Laboratories, Inc. in 2001, he was involved in the development of a number of numerical protective relays. He is a senior member of the IEEE and a main committee member of the IEEE PES Power System Relaying Committee. Michael is a registered professional engineer in the State of Washington and holds a patent for integrated protection and control system architecture.

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