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Transmission Protective Relay System Performance Measuring Methodology IEEE/PSRC Working Group I3

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1.0 Introduction

To varying degrees, different transmission system operators have measured the performance of their protective relay systems; however, general comparisons cannot be made between different transmission systems because no consistent performance measuring criterion has been utilized. This paper presents a simplistic approach to analyzing the performance of a protective relay system that is associated with any transmission system. This simplistic approach asks " When a system event occurs, did everything work correctly, or did something in the protective system misoperate?" If everything operates as designed, it is counted as one correct operation (even though multiple breakers might have operated). If one or more terminals of the protective relay system misoperate, they are categorized as to the type of misoperation. The total number of misoperations can be compared to the total number of events to determine the relative success of the protective relay system. This simplistic approach is broad enough to allow for comparisons between different transmission systems with different design parameters. However, in using this information in a comparative fashion between different transmission systems, it is necessary to consider the differences in design parameters and in the expected performance of the protective relay system.

2.0 Measuring Methodology

The measuring methodology involves identifying all system misoperations, comparing them to the number of events (i.e. opportunities to misoperate), and calculating a percentage of misoperation.

2.1 Definition of Protective System Misoperation

Fundamental to this relay performance measuring methodology is defining a misoperation and grouping them into logical categories. Table 1 is the foundation for defining a misoperation. The misoperation table is structured such that:

a) Dependability, security, and system restoration statistics can be recorded and trended separately or summed into a total misoperation category;
b) Companies can look at only the performance of the relay system, the performance of the circuit breakers, or the performance of the entire protective system;
c) The criterion can be applied for different voltage levels, or as a composite of several voltage levels.

Additionally, this table structure allows for easy comparison between companies.

It should be noted that this definition is intended to measure the protective system as a whole and not the individual relaying components. For instance, if a fault occurs and is isolated from a backup (or redundant) protective system that operates with no intentional time delay, the fact that the primary system did not operate does not constitute a misoperation.

Table 1 MISOPERATION TABLE

	Dependability			Security		System Restoration	Total Misoperations
	Failure to Trip	Failure to Interrupt	Slow Trip	Unnecessary Trip During Fault	Unnecessary Trip for Non-Fault Event	Failure to Reclose	
Relay **(A)** System [i]	1	—	2	3	4	5	Total for Relay System
Circuit **(B)** Breaker [ii]	6	7	8	—	9	10	Total for Circuit Breakers
Protective System [iii] **(A+B)**	1+6	7	2+8	3	4+9	5+10	Total for Protective System

i - Relay System defined as the protective relays, communication system, voltage/current sensing devices, and dc system up to the terminals in the circuit breaker.

ii - Circuit Breaker is a generic term for any fault interrupting device.

iii - Protective System includes both relay system and circuit breakers **(A+B)**.

The numbers in the table refer to the legend where a definition of the category is given.

LEGEND:

(1) Failure To Trip (Relay System)
Any failure of a relay system to initiate a trip to the appropriate terminal when the fault is within the intended zone of protection of the protective device.

(2) Slow Trip (Relay System)
A correct operation of a relay scheme for a fault in the intended zone of protection where the relay scheme initiates the trip slower than the system design intends.

(3) Unnecessary Trip During a Fault (Relay System)
Any undesired relay-initiated operation of a circuit breaker during a fault when the fault is outside the intended zone of protection.

(4) Unnecessary Trip Other Than Fault (Relay System)
The unintentional operation of a protective relay which causes a circuit breaker to trip when no system fault is present; may be due to environmental conditions, vibration, improper settings, heavy load, stable load swings, defective relays, or SCADA system malfunction. Employee action that directly initiates a trip **is not** included in this category. See Clause 3.1 Human Performance.

(5) Failure to Reclose (Relay System)
Any failure of a relay system to automatically reclose following an event if that is the system design intent.

(6) Failure to Trip (Circuit Breaker)
The failure of a circuit breaker to trip during a fault even though the relay system initiated the trip command.

(7) Failure to Interrupt (Circuit Breaker)
The failure of a circuit breaker to successfully interrupt a fault even though the circuit breaker mechanically attempts to open.

(8) Slow Trip (Circuit Breaker)
A circuit breaker which operates slower than the design time during a fault following the trip initiation from the relay system.

(9) Unnecessary Trip Other Than Fault (Circuit Breaker)
The tripping of a circuit breaker due to breaker problems such as low gas, low air pressure, etc.

(10) Failure to Reclose (Circuit Breaker)
Any failure of a circuit breaker to successfully reclose following the reclose initiate signal from the relay system.

2.2 Definition of Event

An event is defined as **"the operation of all necessary breakers to isolate an electrical fault including all subsequent automatic or manual recloses (and trips if appropriate) or any set of conditions resulting in an unintentional operation of the protective system"**. For example, if three breakers trip and successfully reclose following a temporary electrical fault, this counts as one event. If the same three breakers trip multiple times for a planned reclose-trip sequence during a permanent fault, this counts as one event.

2.3 Percent Misoperation

For any selected time period, percent misoperation of a relay scheme for a system is defined in Equation 1.

Where:

$$\%\,\text{Misoperation} = \frac{\text{All Misoperations}}{\text{Total \# of Events} + K} \times 100 \qquad (1)$$

"All Misoperations" is the sum of the misoperations (as defined in Table 1) that have occurred over a time period.

"Total # of Events" is the sum of events (as defined in Clause 2.2) that have occurred over the same time period.

"K" is equal to the number of misoperations for any event minus one.

"K" is an add-on term to account for those situations where more than one misoperation occurs during an event. "K" is a cumulative number that will increase as multiple misoperations occur during events within the period under review. For instance, during an event, if two misoperations occur, the value of K would be increased by 1. If three misoperations occurred during an event, the value of K would be increased by 2. Therefore, if during the time period under study, there were no events where more than 1 misoperation occurred, K would equal zero. However, if during this period, three misoperations occurred during one event, K would equal 2.

Using this equation, percent misoperation can be determined for any voltage class, or for a combination of voltage classes. Furthermore, the misoperation of the protective system can be monitored with or without the circuit breakers.

3.0 Application of Measuring Criterion

When this measuring criterion is first applied, several questions will probably arise. This section should address many of them.

3.1 Human Performance

It is the intent of the measuring criterion to measure the performance of the relay system as it interrelates with the electrical system, not as it interrelates to personnel involved with the relay system. With this in mind, if an individual directly initiates an operation, it is not counted as a misoperation (i.e., unintentional operation during tests). On the other hand, if a technician leaves trip test switches or cut-off switches in an inappropriate position and a system fault or condition causes a misoperation, this would be counted as a relay system misoperation.

3.2 Abnormal Electrical System Conditions

In order to keep the measuring criterion simple, it is desirable to virtually eliminate exceptions to what constitutes a misoperation. For that reason, if a system configuration is abnormal and the relay system misoperates, or if simultaneous faults occur on the system and the relay system misoperates, these conditions would count as a misoperation of the relay system.

3.3 Application at Multiple Voltage Levels

In many cases, the application of this measuring criterion will be segregated by various system voltage levels. This is often necessary to effectively measure the performance of the high speed communication-assisted line relay systems used at the higher voltages from the

more basic relay systems often used at lower voltages. When this is done, a fault that occurs at one voltage level on a system may cause a misoperation of the relay system associated with a different voltage level. In this case, the misoperation should be classified as a misoperation of the voltage level where the misoperation occurs. This may or may not be the voltage level where the fault (event) occurred. It is recognized that this could lead to a small statistical error in looking at the percent correct operation of a particular voltage class; however, it is generally insignificant and it will correct itself as the data is rolled up into groups of voltage classes.

3.4 Multiple Misoperations During an Event

Occasionally, during a system event, more than one terminal or one relay system on a system misoperates. When this occurs, **each terminal that misoperates** should be counted as a misoperation. For instance, if a fault occurs and is properly cleared from the system, but a remote terminal to the fault line also trips in error, and the system fails to properly reclose, this would be counted as two misoperations. One misoperation would be classified as an "Unnecessary Trip During Fault" and one would be classified as a "Failure to Reclose". This would be a situation where the K factor shown in equation 1 would be increased by one.

However, if a fault occurs, the system recloses multiple times into the fault, and a remote terminal to the line section trips during the various reclosures, this would only count as one misoperation. This is because the original fault and all subsequent closures into the fault are counted as the same event.

4.0 How to use the Information

This information can be used in a variety of ways, either for a transmission system to compare itself to itself over various time periods, or to compare itself to other transmission systems. When making comparisons between different systems, care must be taken to consider differences in the design expectations, design type, and maintenance practices. For instance, some systems do not require communication-assisted tripping schemes for quick clearing of transmission line faults. The protective relay performance of these particular relay systems is typically better than that of the high-speed communication-assisted relay systems.

4.1 Use of Misoperation Table

The misoperation table can be used as a stand-alone reporting format. This allows for logical grouping of various failures of the protective relay system and the associated circuit breakers. Used in this fashion, a transmission system operator can track trends in the system performance over time or compare among different transmission systems.

4.2 Calculating Percent Misoperation

By calculating a percent misoperation, the measuring criterion normalizes itself to the opportunity for misoperation. This is important for internal comparisons over time where the number of faults may be substantially different from one period to the next. It is also important for any comparisons among companies because by normalizing to the number of events, it allows for comparison of transmission systems, regardless of size of the system or number of fault events on the system.

5.0 Example Use of Measuring Criterion

For purpose of example, this measuring criterion is applied to a utility's 345 kV and 138 kV protective system performance for the year 1997. For that particular year, there were 43 relay system misoperations, 5 circuit breaker misoperations, and 553 events.

5.1 Use of the Misoperation Table

Table 2 is a summary of the results of the utility's annual protective system performance. In that particular year, there were 7 slow trips due to the relay system and one due to problems with a circuit breaker operating mechanism. For this utility, a slow trip is any transmission system fault where the total clearing time for the fault is in

excess of 8 cycles. These slow trips ranged from 9.5 cycles to 38 cycles.

There were a total of 31 occurrences of unnecessary trips during a fault. Most were the result of problems with powerline carrier systems and with the relaying associated with the communication-assisted relay schemes. There were 2 cases of circuit breakers tripping due to problems with the circuit breaker. In both of these cases, there were problems with gas compressors causing the breaker to be automatically removed from service.

There were 7 cases where automatic reclosing did not occur as designed. Five cases were the result of problems in the relay scheme. Two cases were due to problems with the circuit breakers.

5.2 Use of Percent Misoperation Formula

There were 553 events during the year. The majority of these events were due to transmission line faults. Following most of these faults, the system was successfully restored through automatic reclosing. About 5% of these events resulted in facilities automatically reclosing into the faults and eventually "locking out" the faulted circuit.

Out of the 553 events, there were three events where relay systems misoperated on more than one terminal. On one event, three separate terminals tripped unnecessarily. This adds 2 to the K factor in equation 2. On another event, both a slow trip and a failure to reclose occurred. This adds 1 to the K factor. On a third event, both a slow trip and an extra trip occurred. This also adds 1 to the K factor.

$$\%\,\text{Misoperation} = \frac{43}{\{553 + (2+1+1)\}} X100 = 7.7\% \quad (2)$$

Solving for equation 2, the total percent misoperation for this example, is 7.7%.

The bottom three rows of Table 2 indicate the percent misoperation by the various categories. These percentages could also be applied for each category in the table and segregated by voltage class if the user desired.

Table 2
MISOPERATION TABLE
For Example Utility

	Dependability			Security		System Restoration	Total Misoperations
	Failure to Trip	Failure to Interrupt	Slow Trip	Unnecessary Trip During Fault	Unnecessary Trip Other Than Fault	Failure to Reclose	
Relay System	0	—	7	31	0	5	43
Circuit Breaker	0	0	1	—	2	2	5
Total Protective System	0	0	8	31	2	7	48
Percent Incorrect Operation Relay System	0%	0%	1.3%	5.6%	0%	0.9%	7.7%
Percent Incorrect Operation Circuit Breaker	0%	0%	0.2%	0%	0.4%	0.4%	0.9%
Percent Incorrect Operation Protective System	0%	0%	1.4%	5.6%	0.4%	1.3%	8.6%

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