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Practical Assessment of POTT and DCB Teleprotection Schemes Using Computer Environment

R. N. Meira, R. C. D. de Lima, J. P. Nascimento, N. S. D. Brito, F. V. Lopes and R. L. A. Reis

Abstract - Several tools are used for evaluating teleprotection schemes in transmission lines, however, there is no concern about the cost-benefit ratio of the use of these methodologies. In this paper, six tools applied in these methodologies commonly used for teleprotection evaluation are compared, seeking to achieve the best possible cost-benefit ratio. The most cost-effective tool is used to solve a complex testing problem with realistic relay models from different manufacturers, in order to evaluate the POTT and DCB teleprotection schemes. To do so, CAPE fault simulations were carried out in a 230 kV/60 Hz power system. From the obtained results, the DCB scheme has proved to be more efficient than the POTT for the evaluated scenarios with the use of CAPE software, which in turn presented itself as a reliable alternative to high-cost loop hardware methodologies for the evaluation of teleprotection schemes.

***Keywords*: Distance relays, teleprotection schemes, methodologies.**

I. Introduction

Teleprotection schemes have been widely used in power transmission networks as an alternative to provide unitary line protection. Unlike differential protection schemes, teleprotection is usually independent of local and remote data synchronization, which is a feature that guarantees reliable operation even when Global Positioning System (GPS) or communication channel-based time synchronization solutions fail [1]. Hence, utilities have demonstrated great interest in reliable teleprotection schemes, including developments and studies on new functionalities and testing methodologies capable of allowing realistic assessment and configuration of existing schemes.

Since teleprotection requires a set of logics, different relays usually present different particularities from the point of view of performance and dependability. Moreover, as these schemes require communications, including channel latency delays during testing cases is also important to accomplish realistic tests. As a result, several testing methodologies have been proposed in the literature.

Methodologies based on the use of hardware tools are typically reported in the literature for analysis and evaluation of teleprotection schemes. In [2, 3], for example, tests using the Real-Time Digital Simulator (RTDS) were performed to evaluate the performance of teleprotection schemes aided by debilitated communication channels. The discussion includes, for example, the impact of channel latency. A similar approach is reported in [4], in which the main aspects regarding teleprotection schemes and logical particularities of real numerical relays were analyzed using the RTDS with two communication structures. On the other hand, in [5] it was proposed the use of the modified Direct Transfer Trip (DTT) teleprotection scheme for a closed circuit distribution network, using an OMICRON CMC-356 test box for its validation.

Methodologies based on the use of computational platforms are also commonly reported for analysis and evaluation of teleprotection schemes. In [6], an algorithm was proposed to select the best teleprotection scheme for a Three-Terminal L, by means of the Alternative Transients Program (ATP). In [7], a new teleprotection scheme was proposed and the MATLAB tool was used to validate the new scheme. From another point of view, in [8, 9] a methodology based on the probabilistic approach was used by means of the Monte Carlo simulation to assess the performance analysis methodology and Compare performance four different protection schemes. In the same way, in [10] and [11] methodologies based on ASPEN OneLiner and CAPE, respectively, were used to evaluate the coordination between distance relays assisted by permissive overreaching transfer trip (POTT) and Directional Blocking Comparison (DCB) teleprotection schemes.

Thus, it is noticed that among the relevant aspects considered in the evaluation of teleprotection schemes, the effects of communication channel latency and coordination between relays stand out. However, it is known that communication channel latency is difficult to emulate in physical assemblies. Besides, in many of the reported tools used to assess the teleprotection scheme performances, there are no realistic models with promptly available channel latency, as a consequence, realistic studies on teleprotection schemes may be just guaranteed by the use of real relays or with promptly available realistic relay models in the computational tools. In this context, the seek of cost-effective solutions to provide reliable teleprotection scheme tests are of great interest to protection engineers.

Therefore, the main contributions of this paper are: an

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innovative comparative study on the existing test methodologies to choose a cost-benefit tool to assess teleprotection scheme performances; the chosen cost-benefit commercial testing methodology is used to evaluate the impact of channel latency and teleprotection schemes embedded in multiple relay models in the protection reliability. This type of analysis is of great importance especially when the same relay models cannot be used in the transmission line terminals, such as when these lines connect different utilities. Finally, the results show that the use of computer platforms also enables a reliable assessment of teleprotection performance, providing flexibility over important aspects that are typically challenging for hardware-based test approaches.

II. Protection System

A protection system is defined as a set of equipment designed to protect the Electric Power System (EPS) from disturbance events and abnormal conditions [12]. Among the several protection functions used for the transmission line (TL) protection, the distance function is, undoubtedly, one of the most applied elements [13]. These functions typically estimate the apparent impedance between the monitored TL bus and the fault location using the voltage and current measurements provided by instrumentation transformers, whose impedance is directly proportional to the fault location [14].

When there is no communication channel, the line protection relies on gradual functions that may not be able to protect the total TL length. Thus, delayed trips are expected to occur for faults located in a region of approximately 40% of the line length, assuming an instantaneous protection zone of distance elements set to 80% of the TL length. In fact, for a fault taking place within the first 20% of the TL, as illustrated in the EPS shown in Fig. 1, there is a delay to remove the faulted line by means of the relay installed at the B bus, which can initiate an instability process if the TL is not taken out of service as soon as possible [15].

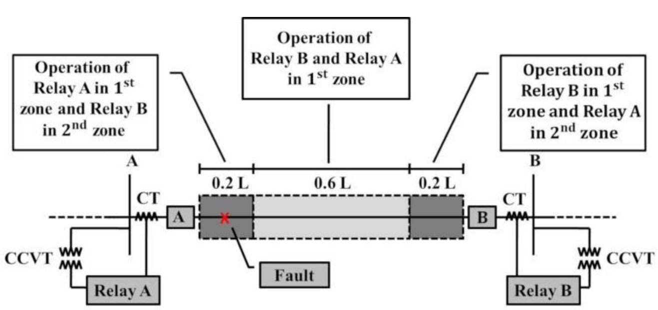

Fig. 1. Interconnection of the acting relay zones in both terminals of a TL.

To improve the aforementioned performance, in cases in which a communication path is available, the teleprotection may be used. Basically, the teleprotection schemes aim to cover all the TL length, enabling the relays on all line terminals compare their responses and determine whether the fault is internal or external to the protected TL. It speeds up the relay's decision-making process, both in blocking operation against external faults, and eliminating disturbances within the protected TL [16].

In practice, each relay manufacturer configures these logics, but with some variations. In the general structure of the teleprotection scheme presented in Fig. 2, three hierarchical levels stand out, which are: protection, teleprotection and telecommunications. Each level is associated with the different equipment and components that interact in the operation of the teleprotection scheme [17].

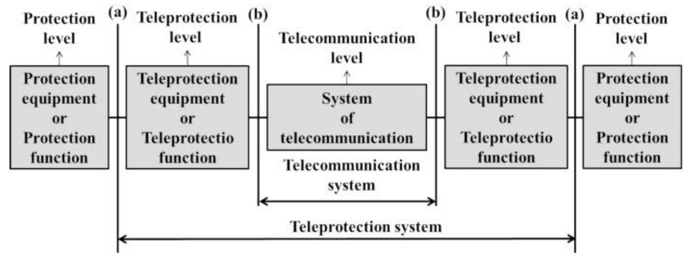

Fig. 2. General architecture of a teleprotection scheme.

From Fig. 2, the interfaces type (a) between the protection and teleprotection levels of both ends of the structure, establish the boundaries of the teleprotection system. Similarly, type (b) interfaces between teleprotection and telecommunication levels from both ends of the structure, establishing the boundaries of the telecommunication system. However, the arrangement of a teleprotection scheme and its different interfaces depends on whether or not the function is embedded into the protective equipment.

In practice, there are six basic teleprotection schemes, defined according to the characteristic of the impedance zone (underreach, limited range only within the protected TL or overreach, extending beyond the protected TL) that will start the signal transmission in the relay, as listed below [18]:

- Direct Underreach Transfer Tripping (DUTT).
- Permissive Underreach Transfer Tripping (PUTT).
- Permissive Overreach Transfer Tripping (POTT).
- Zone Acceleration.
- Directional Comparison Unblocking (DCUB).
- Directional Comparison Blocking (DCB).

Although many utilities use the PUTT scheme, in this paper, the POTT and DCB functions were used, since they are considered quantitatively and statically more efficient when compared to other teleprotection schemes especially considering factors such as probability of erroneous operations, coverage of lack resistance, operating times and complexibility [19].

A. POTT Scheme

The POTT scheme uses a direct overreach element, represented by the 2nd zone in green in the simplified logic shown in Fig. 3, to send a permissive trip signal to the relay installed at the remote end by means of the transmission communication channel (TX). The relay of the TL remote end issues the opening command to the circuit breaker if it receives the permissive trip signal through the receiver communication channel (RX), and if its second zone overreach element has detected the fault [13].

B. DCB Scheme

In the DCB scheme, a circuit breaker opening is possible by accelerating the actuation of the direct overreach unit, which is represented in Fig. 4 by the 2nd zone (ZA2) in green, using a time delay T lower than the second zone time setting. However, as illustrated in the logic diagram presented in Fig. 4, actuation is only allowed if the relay does not receive a blocking signal of the TL remote end via RX. In addition, in this teleprotection scheme, a blocking signal is sent through TX from one terminal to another in cases in which the reverse relay overreaching unit identifies a fault in the backward direction, as shown in Fig. 4 by the 3rd zone in blue color [13].

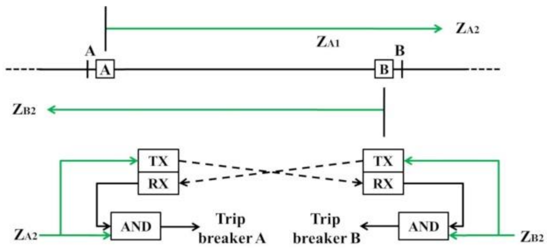

Fig. 3. Logic diagram of the POTT scheme.

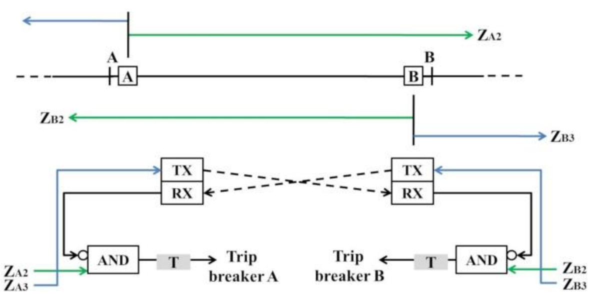

Fig. 4. Logic diagram of the DCB scheme.

III. Materials and Methods

To compare the tools commonly used in the test methodologies for (RTDS, Test boxes, ATP, MATLAB/Simulink, ASPEN/Oneliner and CAPE), the analyses here were subdivided into four indexes to determine the cost-effective tool in providing realistic and reliable teleprotection tests and studies , as shown in Table I, which are as follows:

• Promptly available realistic relay models: used to assess whether the tools have promptly available realistic relay digital models, although we recognize that it is possible to implement models of relays or even to connect physical relays in some of these tools.

• Low cost: To evaluate the overall cost of the structure required to test teleprotection schemes, the analyzed tools were associated to different cost levels, which can be related to license or hardware aspects. Here, we consider low cost amounts below one ten of thousands of U.S. dollars.

• Promptly available channel latency models: used to assess whether tools have promptly available communication channel models, although we recognize that it is possible to implement communication channel models in some of these tools.

• High flexibility: This index is related to the possibility of using different models of channel latency and relays.

Table I
Comparison Between Tools Used in the Test Methodologies for Assessing Teleprotection

Index	Tools used in the test methodologies					
	RTDS	TEST BOXES	ATP	MATLAB	ASPEN	CAPE
Promptly available realistic relay models	-	-	-	-	X	X
Low cost	-	-	X	X	-	X
Promptly available channel latency models	-	-	-	X	X	X
High flexibility	-	-	-	-	X	X

Let us think about the following operation of the system: in transmission line terminals with different relays, it is possible that they are correctly set correctly for a series of scenarios and the performance is therefore reliable. However, it is also possible that in certain cases that have not been tested during the setting process, their performance may be compromised. . In this sense, greater security would be brought to the protection professional if reliable test platforms were used for protection assessment, such as a hardware in the loop scheme with a simulation equipment and the relay that will be installed in the field. But if this infrastructure does not exist, the use of digital models of protective elements available in the literature may not accurately represent what would occur in the field. However, as presented in Table I, CAPE software may be an alternative platform, since it is a tool that promptly provides realistic relay models. In addition to, meeting all the analyzed indexes, it presents itself as a reliable platform that does not require a large investment comparing to the other solutions, even allowing simulated oscillographic records to be loaded and evaluated later on a robust testing platform.

Thus, identifying that CAPE is a cost-effective platform, analyses are carried out to evaluate the application of teleprotection scheme features considering realistic relay models provided from different manufacturers, whose scenario is usually complex to reproduce using real devices. Basically, two different realistic relays models from an X manufacturer, which are named hereafter as relays A and B, and a C relay model from a Y manufacturer were taken into account during the studies. More details about the relays and manufacturers were omitted for confidentiality reasons. The test methodology is presented in the flowchart shown in Fig. 5.

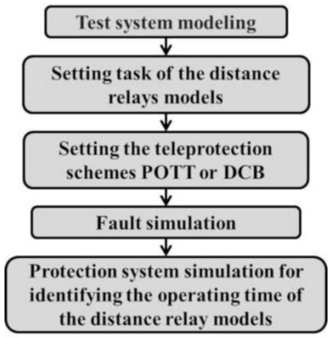

Fig. 5. Adopted methodology.

The step of the proposed methodology consists of:

1. Electrical system modeling: In this paper, the system presented in Fig. 6 was adopted, which is based on the test-system suggested in [20] for TL protection studies. Briefly, it is a 230 kV/60 Hz network with two parallel TL (TL1 and TL2) of 150km length that interconnect buses 1 and 2; a 150 km TL length (TL3) that interconnects buses 2 and 3; two Thévenin equivalents (S1 and S2), which represent the systems interconnected to buses 1 and 3. Although the structure of the modeled system is the same as the system proposed in [20], the electrical parameters were to adapt the structures of the transmission towers to a configuration typically used in national interconnected systems and ensure the use of electrical component models available in CAPE. The electrical parameters used for the TL modeling and the Thévenin equivalents are reported in Tables II and III [21].

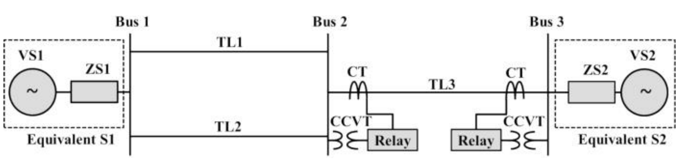

Fig. 6. Adapted test system [21].

TABLE II
PARAMETERS OF TRANSMISSION LINES.

Sequence	Resistance (Ω/km)	Reactance (Ω/km)	Susceptance (µ℧/km)
Zero	0.246349	1.33113	1.80723
Positive	0.0937011	0.677849	2.42979

TABLE III
THÉVENIN EQUIVALENTS PARAMETERS.

Data		**Equivalent**	
Voltage (pu)		**S1(1.00)**	**S2(0.95)**
Impedance (Ω)	**Seq(zero)**	6.1 + j16.7	4.1 + j14.7
	Seq(pos)	2.7 + j8.4	1.7 + j6.4

2. Setting task of the distance relay model: The main purpose of this step is to evaluate the POTT and DCB schemes considering different realistic relay models from the same manufacturer and from distinct manufacturers. In this paper, the relays were inserted at buses 2 (A) and 3 (A, B, or C) of the test-system, in which the relay A was considered as the reference device. The input data are the current and voltage measurements provided by ideal current transformer (CT) and coupling capacitor voltage transformer (CCVT), whose ratios are 400 and 2000, respectively. All the relay calculation settings were based on their respective calculation memories [22, 23].

3. Setting the teleprotection schemes POTT or DCB: Here, the POTT and the DCB schemes were evaluated, whose actuation and time delay are shown in Table IV [23].

TABLE IV
TIME DELAY SETTINGS AND POTT AND DCB PICK-UP SCHEMES.

Teleprotection	time delay in the transmission channel (cycles)	time delay of the channel for *echo* (cycles)	Acting time for coordination (cycles)
POTT	0.5	2	-
DCB	0.5	-	1

4. Simulate faults in the test system: Here, the faults were simulated in TL1 and TL3 of the test system shown in Fig. 6. Basically, single-line, line-to-line and three-phase faults were considered in the simulations.

5. Simulation of the system: to evaluate the performance of the protection system, i.e., the performance of the transmission signals in terms of the distance element or pilot scheme, as well as the operating time.

IV. CASE STUDIES

Even though a great variety of fault simulations have been carried out, the scenarios presented in Table V were selected due to space limitations. Basically, the faults were applied in TL1 and TL3 of the test system, considering scenarios with and without teleprotection to allow comparative analyses. In this context, only solid faults were taken into account, as the fault resistance is a cause for concern during the distance relay operation, whose subject is outside the scope of this paper.

Although we recognize that the analysis of the reliability of teleprotection schemes under failure of the communication channel failure is a very important topic, in this work the main goal is evaluating the operating time of teleprotection schemes. As a consequence, in all cases that were evaluated, we consider the communication channel active and correctly functioning.

The obtained results are presented in Table VI. In the carried out studies, the following parameters were adopted: time in seconds represented by T(s); three phase zones of the relays represented by Z1P, Z2P and Z3P, respectively; the three ground zones were represented by Z1G, Z2G and Z3G, respectively. The relays have the following features and operating principles:

1) Relays A and B:

- Employ positive-sequence memory-polarized phase mho distance elements.
- Use impedance to make directional decision and has no minimum current and voltage requirements.
- The mho and quadrilateral earth elements can be activated.

2) Relay C:

- Employ positive-sequence memory-polarized phase mho distance elements.

- Directional elements determine the direction of a fault using a torque unit, which require a minimal stress of imbalance and current to make a directional decision.
- The mho and quadrilateral earth elements can be activated.

TABLE V
THE ANALYZED FAULT SIMULATIONS

Cases	Type of Fault	TL	Fault Location
1a	AG	TL3	25 km from bus 2
1b	AG	TL1	100 km from bus 1
2a	AB	TL 3	125 km from bus 3
2b	AB	TL 1	75 km from bus 1
3a	ABG	TL 3	125 km from bus 2
3b	ABG	TL 1	10 km from bus 2
4a	ABC	TL 3	50 km from bus 3
4b	ABC	TL 1	150 km from bus 1

TABELA VI
THE OBTAINED RESULTS OF THE PROTECTION PERFORMANCE

Cases	Relays (Buses 2 and 3)	Without Teleprotection				POTT				DCB			
		Bus 2		Bus 3		Bus 2		Bus 3		Bus 2		Bus 3	
		T(s)	Zone	T(s)	Zone	T(s)	Zone	T(s)	Zone	T(s)	Zone	T(s)	Zone
1a	A e A	0.024	Z1G	0.424	Z2G	0.024	Z1G	0.032	POTT	0.024	Z1G	0.024	DCB
	A e B	0.024	Z1G	0.424	Z2G	0.024	Z1G	0.032	POTT	0.024	Z1G	0.024	DCB
	A e C	0.024	Z1G	0.417	Z2G	0.024	Z1G	0.032	POTT	0.024	Z1G	0.024	DCB
1b	A e A	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G
	A e B	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G	1.024	Z3G
	A e C	1.024	Z3G	1.017	Z3G	1.024	Z3G	1.017	Z3G	1.024	Z3G	1.017	Z3G
2a	A e A	0.021	Z1P	0.421	Z2P	0.021	Z1P	0.029	POTT	0.021	Z1P	0.024	DCB
	A e B	0.021	Z1P	0.421	Z2P	0.021	Z1P	0.029	POTT	0.021	Z1P	0.024	DCB
	A e C	0.021	Z1P	0.417	Z2P	0.021	Z1P	0.029	POTT	0.021	Z1P	0.024	DCB
2b	A e A	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P
	A e B	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P	1.021	Z3P
	A e C	1.021	Z3P	1.017	Z3P	1.021	Z3P	1.017	Z3P	1.021	Z3P	1.017	Z3P
3a	A e A	0.421	Z2P	0.021	Z1P	0.029	POTT	0.021	Z1P	0.024	DCB	0.021	Z1P
	A e B	0.421	Z2P	0.021	Z1P	0.028	POTT	0.020	Z1P	0.024	DCB	0.021	Z1P
	A e C	0.421	Z2P	0.017	Z1P	0.025	POTT	0.017	Z1P	0.024	DCB	0.017	Z1P
3b	A e A	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P
	A e B	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P
	A e C	1.021	Z3P	0.417	Z2P	1.021	Z3P	0.417	Z2P	1.021	Z3P	0.417	Z2P
4a	A e A	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P
	A e B	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P	0.021	Z1P
	A e C	0.021	Z1P	0.017	Z1P	0.021	Z1P	0.017	Z1P	0.021	Z1P	0.017	Z1P
4b	A e A	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P
	A e B	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P	1.021	Z3P	0.421	Z2P
	A e C	1.021	Z3P	0.417	Z2P	1.021	Z3P	0.417	Z2P	1.021	Z3P	0.417	Z2P

From the obtained results presented in Table VI, the following discussions have arisen:

1) Faults located on the adjacent TL (TL 1): the performance of the systems with and without teleprotection was similar. In the cases 1b, 2b, 3b and 4b, it is attested that:
   - Relays from same manufacturer (A and B): The operating times of the relays are the same, since their operational characteristics and principles are identical.
   - Relays from distinct manufacturers (A and C): The operating time of the relay C is 0.007 seconds smaller than the relay A. This is due to the different operational characteristics and principles of the relays. However, as this operating time difference is too small, the coordination of the relays is not affected.
2) Faults located in the protected TL (TL3): outside the intercession area of the first relay zones located at buses 2 and 3. In cases 1a, 2a and 3a, it is noticed that:
   - Relays from same manufacturer (A and B): The operating times of the relays are similar, as their operational characteristics and principles are identical.
   - Relays from distinct manufacturers (A and C) and system without teleprotection: For cases 1a and 2a, the operating time of relay C is 0.007 seconds smaller than that of relay A. As for case 3a, the operating time of relay C is 0.004 seconds smaller than that of relay A. This is due to the different characteristics and operational principles, whose differences are not enough to affect the coordination of protection.
   - With the use of the POTT scheme: the time delay from full fault extinction has been reduced to 0.008 s for same manufacturer or for relays from different manufacturers, which is due to the sent echo signal and channel latency.
   - With the use of the DCB scheme: the time delay of the relay furthest from the fault is 0.024 s, which corresponds to the sum of the coordination time (T) and the latency of the channel.
3) Faults located on the protected TL (TL3): within the intercession area of the first two zones of buses B and C.
   - Relays from same manufacturer (A and B): The operating times of the relays are similar, as their operational characteristics and principles are identical.
   - Relays from distinct manufacturers (A and C): The

operating time of the relay C is 0.004 seconds smaller than the relay A. This is due to the different operational characteristics and principles, although such difference does not affect the coordination of the protection.

Thus, it is clearly perceived the importance of the studies performed, since the reproduction of scenarios of this type is difficult both in low-cost applications and in applications with equipment and real relays, in which some cases may go unnoticed during the process of adjusting functions.

V. Conclusions

Teleprotection schemes have been widely used in power transmission networks as an alternative to provide unitary protection. Thus, studies on increasingly realistic test methodologies are being developed to allow the evaluation of existing teleprotection schemes. However, in most of these studies, the cost-benefit of using these methodologies is not evaluated. Therefore, in this paper, six tools commonly used in methodologies were compared for readily available realistic network models, low cost, readily available channel latency models and high flexibility. Such resources were taken into account to determine the most cost-effective methodology to enable a reliable testing of teleprotection schemes. As a result, CAPE software has proven to be more efficient than other compared tools.

Thus, when identifying such a platform, tests were performed with different realistic relay models, whose scenarios are difficult to reproduce using typical hardware-in-the-loop schemes due to the associated high-cost equipment.

From the high-cost equipment, in all the evaluated cases, coordination between the relays was achieved. The operating times obtained with the use of different relay manufacturer were very close to or equal to those presented by the same relay manufacturer. Therefore, the relays could be replaced without compromising the protection system in the evaluated cases. The use of POTT and DCB teleprotection schemes enabled the total elimination of faults with minor delays, providing efficient performance for the protection system. In about 75% of the fault cases located in the protected TL, the DCB scheme was faster than the POTT, providing total elimination of faults with minor delays or with equal elimination time for the both buses. The remaining 25% refer to case 4a, in which the fault was located in the 1st zone of both relays, eliminating the fault in both TL terminals, with the same time delay in systems with or without teleprotection. Therefore, the DCB scheme was more efficient than the POTT in the evaluated scenarios.

Finally, the results attest that the use of CAPE software allowed the analysis of several scenarios providing flexible, reliable and realistic testing cases. Hence, it presented itself to be a reliable alternative for teleprotection evaluation when high-cost closed-loop real-time hardware-based methodologies are not feasible.

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