COMTRADE-Based Relay Testing: Special Test Cases and Field Data Analysis

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SUMMARY

COMTRADE-based test quantities representing various fault scenarios can be played in protective relays for acceptance testing or commissioning. The basis for COMTRADE files would be the power network model that each electric utility already maintains. The existing network models can generate enhanced test points for relay testing and commission. Exploiting a utility network can significantly enhance the accuracy and efficacy of relay testing since it accounts for the entire network topology. In addition, the process for generating COMTRADE files can be automated to reduce the possibility of human error and facilitate the process's standardization.

Software solutions used by utilities can produce phasor-based quantities that do not contain some of the details required for special test cases. This paper proposes solutions for special testing of certain elements and relay functions and provides a technical and economic analysis of the field data collected via COMTRADE relay testing. The paper indicates how the relay's second harmonic restraining function can be tested and validated without having a time-domain software application to produce second harmonics. The authors use formula-based approaches to produce second harmonic quantities using automated scripting and combine them with the signals' fundamental component. The resultant signal would be a distorted waveform, including a pre-defined magnitude of second harmonic similar to what exists in the transformer inrush current, and thereby can be used to validate the second harmonic restraining function of a transformer differential relay. Notably, while the said waveform does not contain all the components of the transformer inrush current, the field test results show that the waveform is enough for testing purposes since only the second harmonic value is relevant for testing in this case. Besides, the paper proposes a technique for testing the load encroachment function of the relay without having the load information available in the utility software. Such a solution can be highly beneficial to utilities who exercise COMTRADE testing since, in most cases, the load information is unavailable in the network model. Yet, utilities would like to verify the load encroachment feature of their relay.

On another avenue, the paper analyzes the real-world data collected from the field pertaining to the proposed method for COMTRADE relay testing. The cost associated with executing the existing and new COMTRADE-based relay testing solutions is comparatively studied. In addition, the technical quality of the two methods is compared to demonstrate how each method can help capture potential issues in the relay settings. The technical and economic analyses are included to demonstrate how the proposed methods can both enhance the technical efficacy of testing and reduce the test execution costs.

The solutions proposed in this paper have been utilized by a major transmission utility. The proposed techniques have been implemented and validated in the field to ensure that they are feasible and effective. The results demonstrate that the proposed methods and tools can reduce advertent relay tripping while substantially alleviating the test execution cost.

KEYWORDS

Automation, Relay Testing, COMTRADE, Transmission Protection, Modelling and Simulation, Field Test, Commissioning, Process Enhancement, Labour Cost, Relay Setting File

1. COMTRADE-BASED METHOD FOR RELAY TESTING

The COMTRADE-based relay testing method utilizes a short-circuit model's simulated faults to generate current and voltage waveforms for playback using relay testing software and hardware. This testing is done via automated scripts, which allow a user to select a fault location, along with other parameters such as fault type (single-line-to-ground, three-phase, double-line-to-ground, or line-to-line), fault resistance, and voltage angle at fault inception. The scripts then generate waveforms via time-domain calculations to simulate not only the fundamental components but also the decaying DC components of fault currents. This method also allows the injection of harmonic frequencies for use in testing differential relays with harmonic restraint.

This approach has many advantages over traditional testing methods. Since microprocessor relays do not typically require calibration, traditional testing methods such as Maximum Torque Angle (MTA) and reach tests add little value; however, applying faults with currents and voltages consistent with real-world values can help ensure that the relay will perform as expected during faults. Particularly, system-dependent settings for directionality and fault detection are better verified using this approach. Secondly, the COMTRADE-based method is done in the time domain, which allows for the testing of harmonics and fault currents' DC components. Lastly, utilizing automated processes reduces the potential for human error in the generation of test values and provides more independent verification than a manual calculation of test quantities based on the settings themselves. The details of COMTRADE-based relay testing can be obtained from reference [1].

2. HARMONIC RESTRAINT TESTING USING COMTRADE

Generating COMTRADE files using the time domain allows easy injection of non-fundamental frequencies. This approach is useful for testing the harmonic restraint function of transformer differential relays. Harmonic restraint is used to prevent differential relays from operating during the initial inrush current upon energization. Inrush current is rich in 2nd harmonics, unlike internal transformer faults; therefore, differential relays are designed to prevent tripping if the 2nd harmonic is above a specified percentage of the total current waveform. This is simulated in the COMTRADE method of relay testing by simply superimposing the 2nd harmonic (120 Hz) signal onto an internal fault waveform to simulate the inrush current. In the time domain, this is a simple addition of the 60 Hz signal and DC component with a 120 Hz sinusoid. The user specifies the desired percentage of 2nd harmonic for each phase current. This percentage is then calculated from the magnitude of the 60 Hz fault current and used to generate the signal at 120 Hz. Lastly, the two signals are added together to form the signal generated for the COMTRADE test. Figure 1 below shows the process for generating the harmonic restraint tests. Figure 2 shows a sample waveform with the 2nd harmonic.

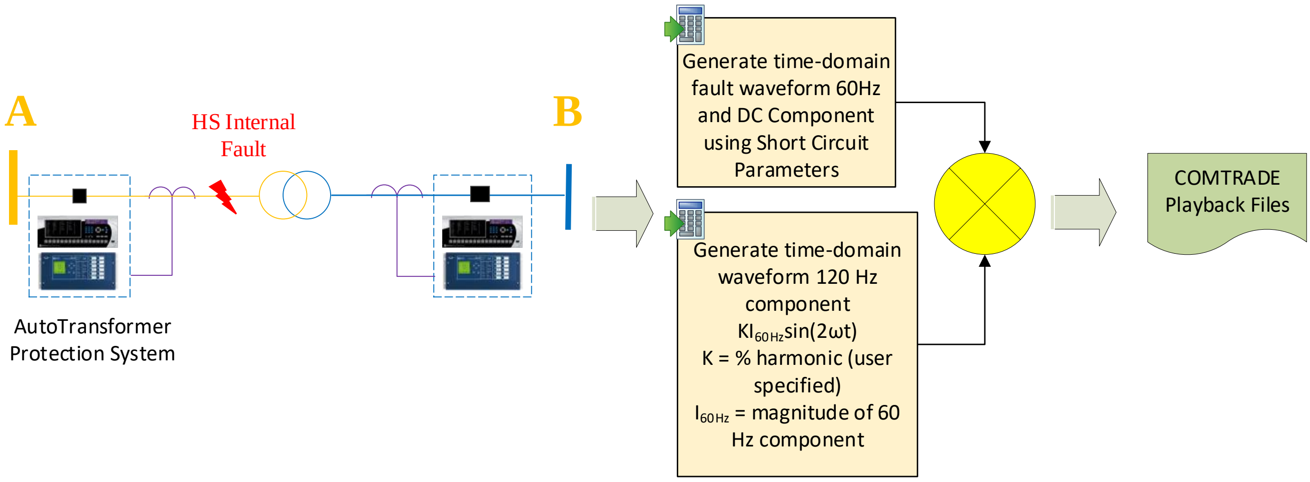


Figure 1 – 2nd Harmonic Testing using COMTRADE

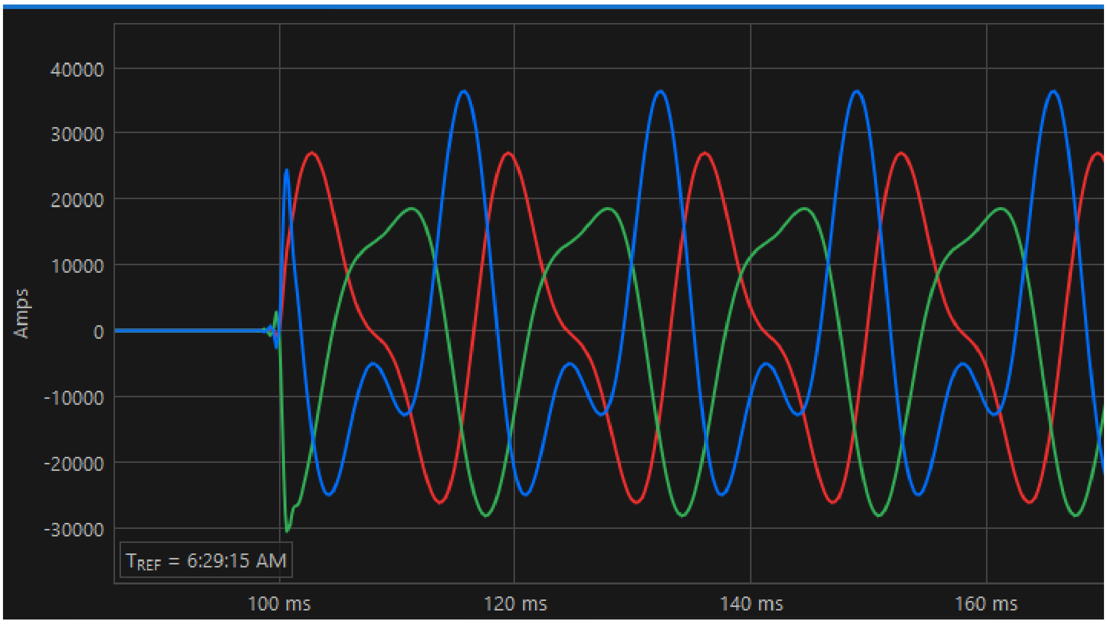
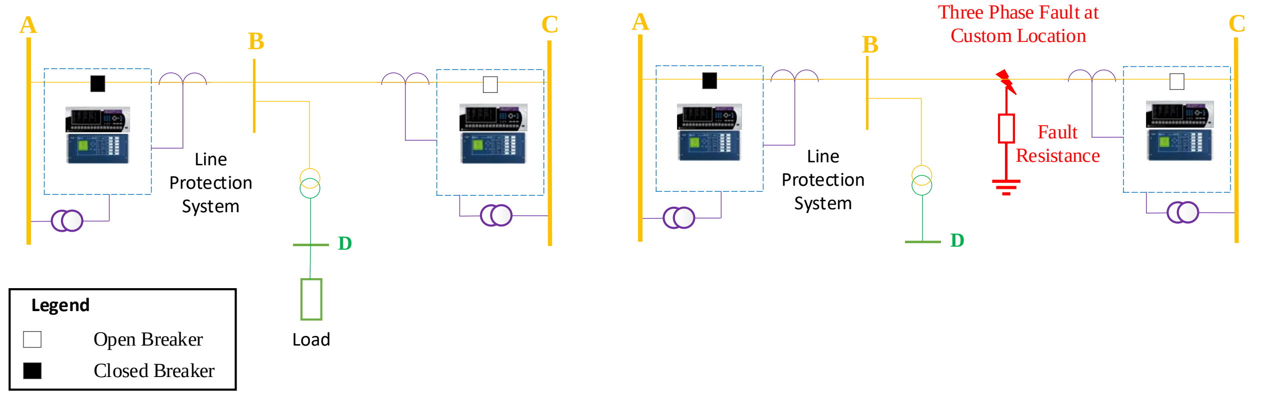


Figure 2 – Sample Output File with 2nd Harmonic

3. LOAD ENCROACHMENT TESTING USING COMTRADE

The COMTRADE method of relay testing can be used to test load encroachment settings in protective relays. Load encroachment for distance relays is designed to prevent relays from operating under load conditions. Load encroachment function is typically achieved by removing a portion of the traditional MHO circle, characteristic of load, so the relay becomes less sensitive at load angles. This testing is performed by placing a balanced three-phase fault at a user-defined location with a specified fault resistance to simulate the load. The resistive fault along with the reactive characteristic of the line represents the load behaviour. The user determines the location and resistance necessary to achieve the load characteristic they wish to study. The load encroachment test can be used to verify the element’s operation and non-operation under various conditions. Figure 3 below shows the model for generating load encroachment tests using COMTRADE.



(a): Power system example with load modelled

(b): COMTRADE-based load encroachment testing approach

Figure 3 – Load Encroachment Testing using COMTRADE

An alternative approach considered for generating these load encroachment tests was to create the time-domain signals based on a load characteristic specified by the user. For instance, the user could simply specify the desired load (in MW and MVAR or current and load angle) for testing, and the waveforms could be generated manually without needing to generate faults. However, the chosen method allows for a more accurate representation of the load-flow solution.

4. FIELD DATA ANALYSIS OF RELAY TESTING USING COMTRADE

A large-scale electric utility utilized the COMTRADE method of relay testing. The utility analyzed the COMTRADE testing method's success using cost savings and overall end-user satisfaction. They also identified multiple successes of the testing method that would not have been possible using traditional testing methods. This section describes the analysis and results of relay testing using COMTRADE and draws from quantitative and qualitative field data.

The utility piloted the COMTRADE-based relay testing approach on the commissioning of six substations with sixteen different protection schemes and three relay manufacturers (SEL, GE, and Siemens). The first way in which the success of COMTRADE-based relay testing was measured was using cost savings. The utility found a significant decrease in technician hours spent on commissioning using the COMTRADE-based approach. Even though the new approach required additional engineering hours to generate the tests, the overall cost saving was significant. For standard designs, the total cost savings was approximately 34%, and for non-standard designs, it was approximately 42%. The results are in Tables 1 and 2 below.

Table 1 – Time and Cost Analysis for Commissioning Standard Protection Designs

	Technician Time (hrs)	Engineering Time (hrs)	Total Testing Time (hrs)	Normalized for Cost/hr
Traditional Testing	37.5	0	37.5	37.5
COMTRADE-Based Testing	15	7.5	22.5	24.83
		%Reduction	40%	33.79%

Table 2 – Time and Cost Analysis for Commissioning Non-Standard Protection Designs

	Technician Time (hrs)	Engineering Time (hrs)	Total Testing Time (hrs)	Normalized for Cost/hr
Traditional Testing	60	0	60	60
COMTRADE-Based Testing	15	15	30	34.66
		%Reduction	50%	42.23%

Additionally, the utility captured four settings errors during commissioning using the COMTRADE-based method. Such errors would not have been captured using the manual injection of testing quantities. This issue is primarily because the manual method generated quantities based on the settings (which in this case were incorrect), whereas the COMTRADE-based method is independent of the settings.

Lastly, the utility surveyed the six commissioning technicians to determine how easy the process was to follow, the technicians' opinion of the thoroughness of the method, the technicians' favorite features, and an overall rating of the experience. Overall, the technicians felt that the COMTRADE-based relay testing method was easier to follow and more comprehensive than their traditional testing methods. The results of the survey are in Figure 4 and Figure 5 below.

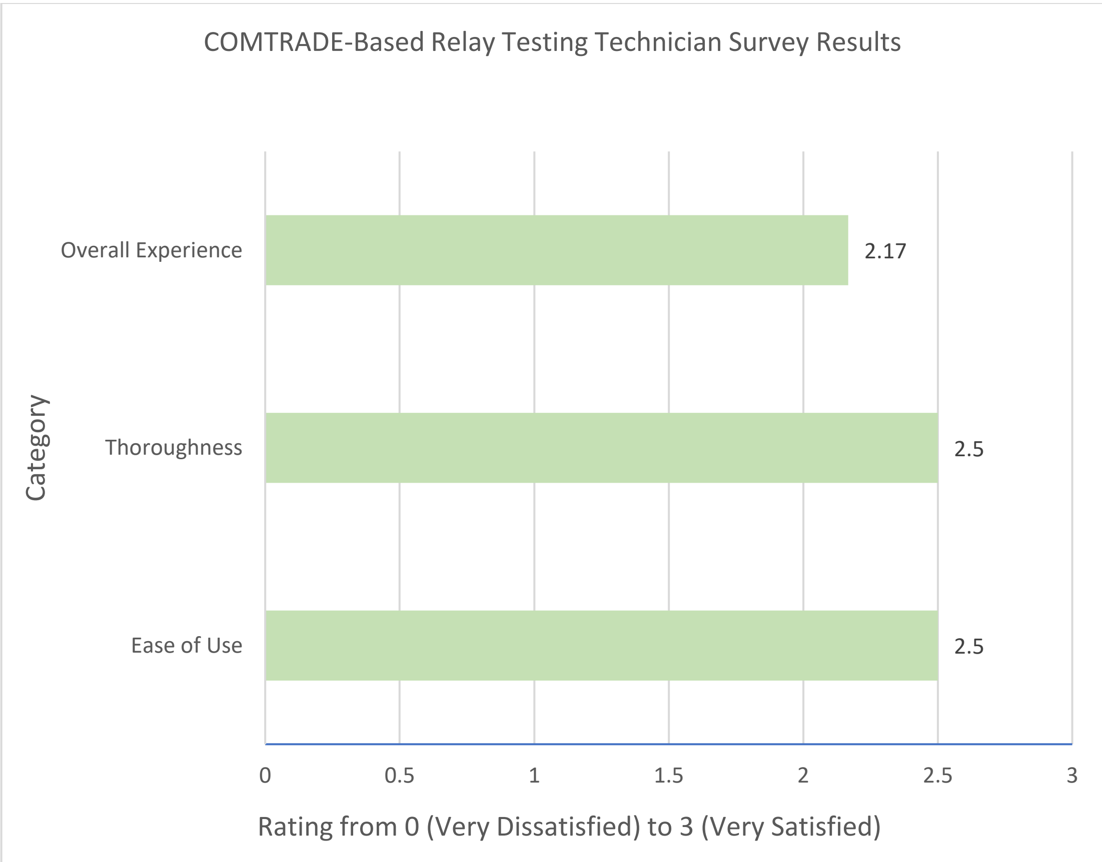


Figure 4 – COMTRADE-Based Relay Testing Technician Survey Results: Satisfaction

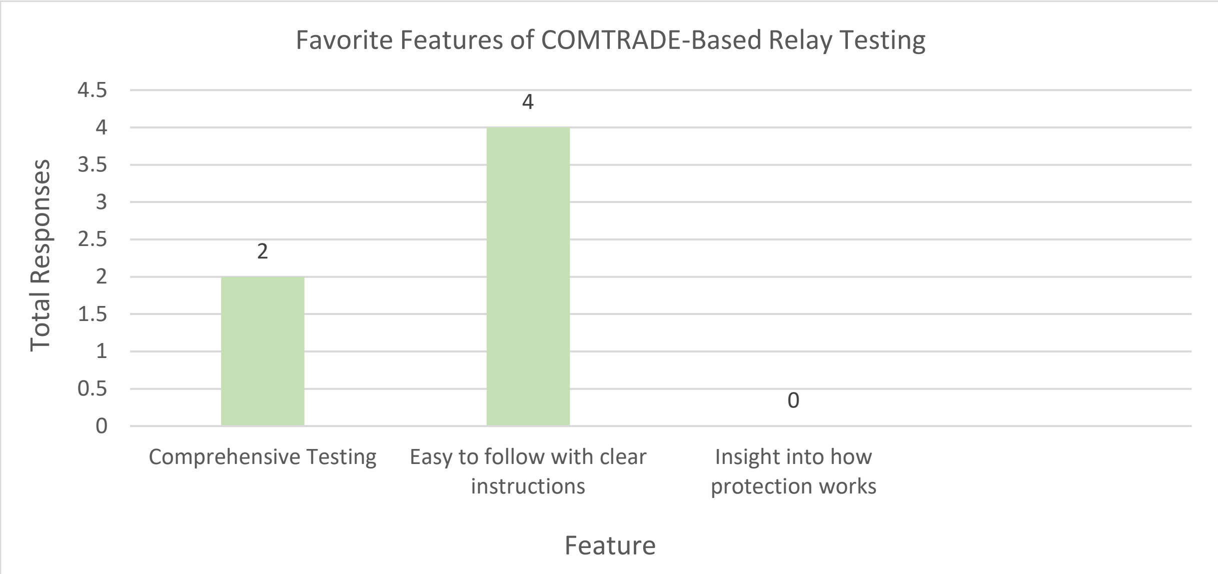


Figure 5 – COMTRADE-Based Relay Testing Technician Survey Results: Features

5. CONCLUSION

This paper expands upon the subject of COMTRADE-based relay testing to explore unique ways of generating test plans for special cases. The proposed approach was used to generate tests for verifying harmonic restraint of transformer differential relays and load encroachment for distance relays. The philosophy used to generate the COMTRADE files was discussed, along with the methods of calculating and generating the testing quantities. It is worth mentioning that the proposed load encroachment testing approach can be further enhanced to ensure that it covers various scenarios in the field. In addition, accurate line parameters are needed for the approach to produce realistic test points.

In addition, a large utility quantitatively and qualitatively analyzed the testing method's success by using field data. The analysis was performed in terms of cost reduction, ease of use, thoroughness, and end-user satisfaction. This analysis showed that the COMTRADE-based relay testing method is more efficient and thorough than the traditional testing methods deployed by the utility under study. It also showed that the technicians were more satisfied with this approach than with traditional testing methods. It is worth noting that the survey data used in this paper is collected from a small population of utility staff that commissioned relays during the pilot stages of the project. As more projects are commissioned, more data becomes available that can be analyzed and used in the future.

In the future, this method can be expanded for additional special test cases, such as communication-based protection schemes via Satellite End-to-End testing. It can also be enhanced to generate test files based on standard-setting philosophies automatically. This use would reduce engineering time in generating the tests and provide settings- and user-independent calculation of testing quantities. Lastly, the success of COMTRADE-based relay testing should be further analyzed against other utilities with different philosophies and approaches to relay commissioning.

BIBLIOGRAPHY

[1] H. Khani et al., "Methodologies and Processes to Enhance the Accuracy, Technical Quality, and Efficacy of Protective Relay Testing using COMTRADE Files," CIGRE Canada, 2021.