Experimental Validation of Transformer Protection Numerical Relay

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Abstract
The importance of testing and validation in power systems guarantees the reliability and the accuracy of the important components like numerical relays. The project focuses on testing and validating the performance of the MiCOM P642 relay, which is part of the important components in a power system protection application. In carrying out practical testing in the assessment of performance under varying fault conditions, the use of advanced tools with capabilities like the computer-Monitored Control (CMC) injection kit and Test Universe software is imperative. The theoretical calculation is used as a benchmark in the determination of real performance, while optimization of setting in the Programmable Scheme Logic tab enhances the overall performance. In developing a comprehensive manual as a learning resource to avail step-by-step procedures and practical guides for relay testing, everyone will be exposed to knowledge and skills on how this can be accomplished. We do this with a view to contribute and support the advancement of electrical protection technology to ensure transformer numerical relay reliability and accuracy, such as MiCOM P642, and to guarantee safe, stable, and reliable operation of the power system for the benefit of the society. The features of this project are to present a demonstration of the importance of proper testing and optimized settings to maintain the safety and reliability of the power system, showing how transformer numerical relays work in general.
Key Words: *Transformers, MiCOM Relay Computer-Monitored Control (CMC) Injection kit, Test Universe, Programmable Scheme Logic.*

1. INTRODUCTION

The protection of a power transformer forms the most important part of an electric power system, ensuring safe and reliable operation. These protection schemes have a wide range of elements aimed at detecting and responding to different fault conditions. These include differential relaying, where the current entering and leaving the transformer winding is checked to note magnitude and phase difference in case of an internal fault; overcurrent relaying is used to monitor the flow of current to protect the systems from overloads and short circuits. The protection schemes have also outlined actions during more complex fault scenarios like over fluxing/overexcitation, and this is managed by restricted earth fault relays in conjunction with protective relays, sensors, and control devices to rapidly detect and limit faults. These transformer protective designs are intended to exclude damage and consequent interruption of service, to ensure the soundness and continuity of power systems (Berg & Fritze, 2015).
One of the solutions in this area is the MiCOM P642 relay which combines digital intelligence and advanced algorithms. It performs essential protection functions such as differential protection, overcurrent protection, over fluxing protection and restricted earth fault protection.
It detects faults quickly and accurately minimizes damage and ensures power system continuity (Electric, 2010).
This research is aimed at testing and confirming the MiCOM P642 relay in the college's switchgear and protection laboratory. This work will test the accuracy and dependability of the relay under real fault conditions simulated from injection kit, evaluate its response versus a few theoretical calculations for the relay to be used in future cases concerning its wide application, and optimize its Programmable Scheme Logic (PSL) settings for improved performance. Additionally, through the completion of the above steps, we will develop a set of comprehensive notes that can be used as a guide for teachers, students, and technicians as they work with modern advanced protection and relay testing methodologies and practical procedures. The student can derive value from these notes in terms of learning how to proceed with effective relay testing and validation methodologies.
This is important for electrical protection systems as we are making transformer numerical relays like MiCOM P642 robust and reliable so we can

have safe and reliable power systems and support the development of protection standards and practices.

2. METHODOLOGY

By following this flow chart, we were able to successfully complete our project without any delays and problems.

3. SYSTEM OVERVIEW

We use the CMC 356 Injection Kit, Test Universe software, and Programmable Scheme Logic (PSL) to inject
parameters, communication medium and to do relay settings respectively. These tools are very important for testing and simulation processes as it offers advanced features and capabilities that ensure accuracy and reliability in various applications.

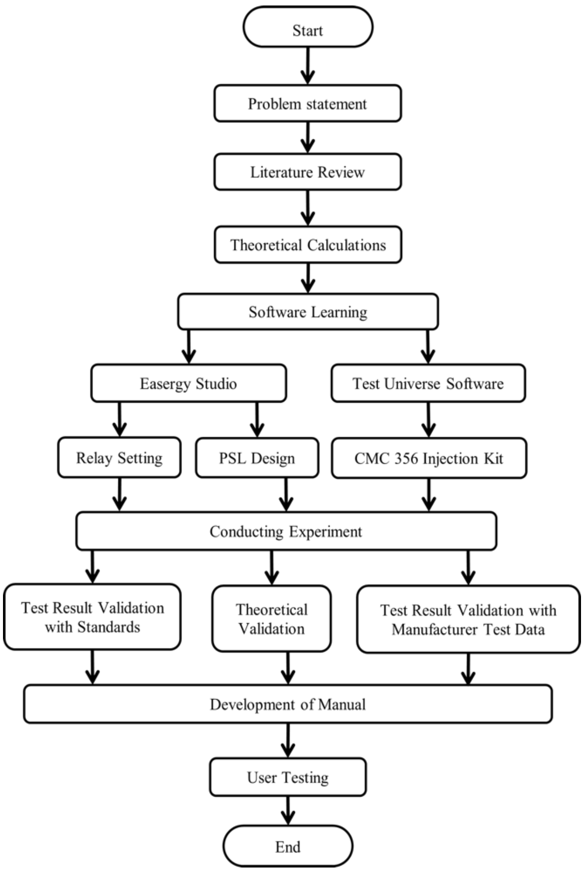

Fig. 1: *Flow Chart*

3.1. CMC 356 injection kit

The CMC 356 Injection Kit is one of the most sophisticated tools in electric testing and simulation, known for its accuracy, reliability, and versatility (OMICRON electronics, 2020). This great system has a main unit that uses a high-performance processor for the management of real-time data processing and complicated test sequences. This central unit is supplied with a stable power supply having overload protection to ensure a constant performance at maximum demands.

The voltage and current amplifiers of the CMC 356 are designed with high precision, ensuring stable outputs under dynamic load conditions. This makes it possible to reproduce the real-life conditions that are very important for assured test results. This capacity allows for the testing of high-burden electromechanical relays and facilitates primary injection tests for current transformers, thereby streamlining the commissioning process.

A USB port and an Ethernet port allow easy connectivity to a PC and even remote operation. Ethernet connectivity means integration within present IT infrastructures is easy, enhancing the usability and flexibility of the device.

The CMC 356 can be operated from a PC with the Test Universe software for a rich and user-friendly interface for test sequences, data collection, and results analysis. In its alternative configuration, the device is controlled through the Control interface, quite important for on-site applications with requirements of quick and simple operation.

3.2. Test Universe

Test Universe is an advanced software that forms the basis of the CMC 356. It offers a user-friendly environment for conducting all kinds of tests from simple manual tests to complex. It offers a library of preconfigured test templates for most available protection relays; this means it is easy to set up the system and uniformity can be ensured.

The QuickCMC module in the Test Universe is designed for fast and effective manual testing. It provides a streamlined interface, making it easy to control all the test signals of the CMC 356, perfect for rapid setup and execution. Users can set test signal parameters such as voltage, current, phase, and frequency by numeric input or graphic tools.

QuickCMC supports static tests, transient condition simulations, and also includes a Fault Calculator for complex test setups. Its advanced functions include Step Mode, which enables making very small adjustments to the test conditions, and the Ramp Mode, which will ramp test signals to observe how a relay responds to changing conditions—useful for testing relays with overlapping characteristics.

3.3. Programmable scheme logic

The Programmable Scheme Logic, or PSL, is one of the features found in numerical relays to carry out a specific kind of protection scheme. Several characteristics of a numerical relay easily facilitate implanting several protective schemes in just one numerical relay. PSL is a logical block and contains a more appropriate DDB (Digital Data Bus) signal. There are many DDBs available in Numerical Relay, and each DDB has its purpose. Therefore, for designing the protection logics, one must understand the function of each DDB.

PSL provides an option where the protection scheme can be programmed into a single control device individually depending on its use. It also uses map functions of the inputs and output contracts, outputs of the protection elements such as protection starts and trips, and outputs of the fixed protection scheme logic. Generally, the logic gates can be programmed to perform a very wide variety of different logic functions and can accept any number of inputs. (Electric, 2020).

4. EXPERIMENTAL SETUP

The communication between the pc and the relay is done through MOXA cable and to that with the injection kit is either ethernet or USB cable as mentioned above. The CMC 356 injection kit is controlled through the Test Universe software where we can simulate the real-world faults and scenarios, then adjust the required parameters to be injected based on the setting calculation. For different protection schemes, we need to configure their respective wiring connections and inject the values. The following figures show the different kinds of wiring connections based on the protection schemes.

4.1. Differential protection scheme

A differential fault occurs when the current entering the transformer is equal to the current leaving the transformer considering the CT ratios and inrush currents. The secondary injection kit output current terminals are connected to the transformer protection relay through the test block to simulate the real world. The 3 phase currents are injected from two points in the protection panel to simulate the currents leaving and entering the transformer.

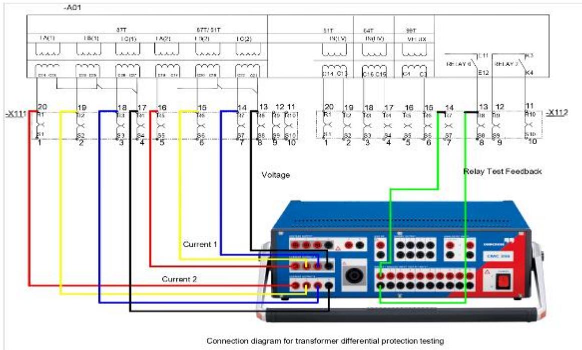

Fig. 2: *SEQ Fig. * ARABIC 2 Differential wiring connection*

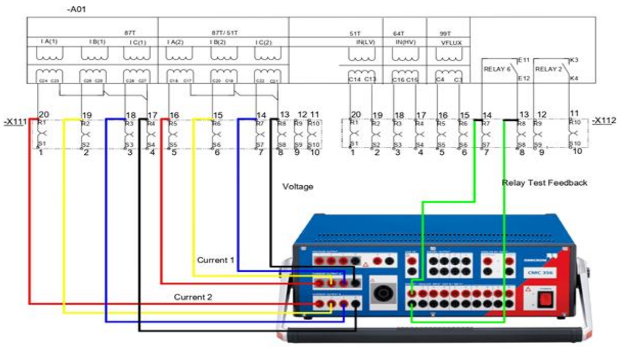

Fig. 3: *Over fluxing protection scheme*

4.2. Over fluxing protection scheme

An over fluxing in the transformer occurs when the voltage to frequency (V / Hz) ratio exceeds its design limits as the transformers are designed to operate at specific V / Hz ratio. The figure below shows the connection between CMC and the transformer protection relay when the tests for overfluxing protection will be done. The tests will be having a total of 5 stages that include an alarm stage and four stages of overfluxing protection set at different values above the rated V / Hz ratio. The connection for this protection is done as shown in Fig.4.

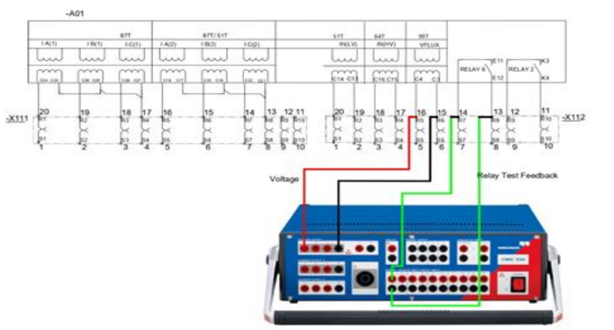

Fig. 4: SEQ Fig. * ARABIC 4 *Overcurrent protection scheme*

4.3. Overcurrent Protection Scheme

Overcurrent testing for transformer protection is

essential to protect transformers and ensure the reliability of power systems. Overcurrent testing involves verifying the settings and functionality of overcurrent protection
relays, typically through primary and secondary injection testing. The goal is to confirm that the relays operate within the specified time limit to isolate faults and prevent transformer damage. Coordination studies are conducted to ensure that protective devices work together effectively, minimizing unnecessary tripping and maintaining service continuity. Testing simulates various fault scenarios, including phase-to-phase and phase-to-ground faults, to ensure comprehensive protection coverage.
By these different configurations for different protection schemes, we can simulate the real-world faults and verify the relay test results with the manufacturer test data taken during their commission.

5. RESULT

5.1. Differential Protection

Differential protection is one of the leading schemes of protection against internal failures of a transformer, which promptly segregates the defective zone so that the entire system does not get affected by a breakdown. For the differential protection, we concluded with a number of results obtained with different types of testing such as trip tests and stability tests. The results obtained are also verified with the manufacturer test data from Bhutan Automation Engineering Ltd.

Table 1: *HV Measurement test*

HV measurement test					
Phase	Injected (A)	Primary Current Reading (A)			
		1A (1)	IB (1)	IC (1)	IN-HV derived
R	1.0	150.3	0	0	150.3
Y	1.0	0	150.2	0	150.2
B	1.0	0	0	150.2	150.2
RYB	1.0	150.2	150.2	150.3	0
LV measurement test					
Phase	Injected (A)	Primary Current Reading (A)			
		1A (2)	IB (2)	IC (2)	IN-LV derived
R	1.0	399.5	0	0	399.5
Y	1.0	0	400.4	0	400.4
B	1.0	0	0	400.5	400.5
RYB	1.0	399.2	401	400.8	0

Table 2: *Differential Pickup test mmmmmmmmmmmm*

Low Set Element Current Sensitivity (Is1)		
Phase	**Pick-up Value (A)**	**Time delay (ms)**
R	0.105	31
Y	0.105	29.5
B	0.105	31.2
RYB	0.105	29.4

Table 3: *Through fault stability test*

Experimental test result						
Injected Current(A)		Expected Values (PU)		Measured Values (PU)		Remarks
HV	LV	ID	IR	ID	IR	
0.524 ∠0	0.656 ∠180	0	1	0.003	1	No trip
0.524 ∠-120	0.656 ∠60	0	1	0.001	0.999	
0.524 ∠120	0.656 ∠300	0	1	0.002	1.001	

Table 4: *Through fault stability test data*

Manufacture test result						
Injected Current(A)		Expected Values (PU)		Measured Values (PU)		Remarks
HV	LV	ID	IR	ID	IR	
0.524 ∠0	0.656 ∠180	0	1	0	1	No trip
0.524 ∠-120	0.656 ∠60	0	1	0	1	
0.524∠ 120	0.656 ∠300	0	1	0	1	

Table 5: *In-zone stability*

Experimental test result						
Injected Current(A)		Expected Values (PU)		Measured Values (PU)		Remarks
HV	LV	ID	IR	ID	IR	
0.524 ∠0	0.656 ∠0	2	1	2.001	1	Is1 Trip
0.524 ∠-120	0.656 ∠-120	2	1	1.999	1.001	
0.524 ∠120	0.656 ∠120	2	1	2	1.001	
Manufacture test result						
Injected Current(A)		Expected Values (PU)		Measured Values (PU)		Remarks
HV	LV	ID	IR	ID	IR	
0.524	0.656	2	1	2	1	

∠0	∠0					Is1 Trip
0.524 ∠-120	0.656 ∠-120	2	1	2	1	
0.524 ∠120	0.656 ∠120	2	1	2	1	

Table 6: *Low set differential stability test (operating region)*

Experimental test result					
Phase	HV	LV	ID (PU)	IR (PU)	Trip status
R	0.268 ∠0	0.190 ∠180	0.222	0.399	Is1 Trip
Y	0.268 ∠-120	0.190 ∠60	0.221	0.4	
B	0.268 ∠120	0.190 ∠300	0.221	0.399	
Manufacture test data					
Phase	HV	LV	ID (PU)	IR (PU)	Trip status
R	0.268 ∠0	0.190 ∠180	0.222	0.402	Is1 Trip
Y	0.268 ∠-120	0.190 ∠60	0.222	0.402	
B	0.268 ∠120	0.190 ∠300	0.222	0.402	

Table 7: *Low set differential stability test (non-operating region)*

Experimental test result					
Phase	HV	LV	ID (PU)	IR (PU)	Trip status
R	0.257 ∠0	0.203 ∠180	0.181	0.398	No Trip
Y	0.257 ∠-120	0.203 ∠60	0.181	0.399	
B	0.257 ∠120	0.203 ∠300	0.180	0.399	
Manufacture test data					
Phase	HV	LV	ID(PU)	IR(PU)	Trip status
R	0.257 ∠0	0.203 ∠180	0.181	0.401	No Trip
Y	0.257 ∠-120	0.203 ∠60	0.181	0.401	
B	0.257 ∠120	0.203 ∠300	0.181	0.401	

Table 8: *Differential slope K1 stability test for operating region*

Experimental test result						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.493 ∠0	0.440 ∠180	0.271	0.804	Is1 Trip	33
Y	0.493 ∠-120	0.440 ∠60	0.269	0.805		
B	0.493 ∠120	0.440 ∠300	0.270	0.804		
Manufacture test data						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.493 ∠0	0.440 ∠180	0.271	0.812	Is1 Trip	33
Y	0.493 ∠-120	0.440 ∠60	0.271	0.812		
B	0.493 ∠120	0.440 ∠300	0.271	0.812		

Table 9: *Differential slope K1 stability test result for non-operating region*

Experimental test result						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.478 ∠0	0.453 ∠180	0.222	0.80	No Trip	27
Y	0.478 ∠-120	0.453 ∠60	0.221	0.801		
B	0.478 ∠120	0.453 ∠300	0.221	0.80		
Manufacture test data						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.478 ∠0	0.453 ∠180	0.221	0.806	No Trip	27
Y	0.478 ∠-120	0.453 ∠60	0.221	0.806		
B	0.478 ∠120	0.453 ∠300	0.221	0.806		

Table 10: *Differential K2 stability test result operating region*

Experimental test result						
Phase	HV	LV	ID (PU)	IR (PU)	Trip status	Slope (%

						)
R	0.992 ∠0	0.735 ∠180	0.774	1.506	Is1 Trip	93
Y	0.992 ∠-120	0.735 ∠60	0.772	1.507		
B	0.992 ∠120	0.735 ∠300	0.773	1.508		
Manufacture test result						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.992 ∠0	0.735 ∠180	0.776	1.517	Is1 Trip	92
Y	0.992 ∠-120	0.735 ∠60	0.776	1.517		
B	0.992 ∠120	0.735 ∠300	0.776	1.517		

Table 11: *Differential slope K2 stability test result for non- operating region*

Experimental test result						
Phase	HV	LV	ID (PU)	IR(PU)	Trip status	Slope (%)
R	0.955 ∠0	0.781 ∠180	0.633	1.506	No Trip	66
Y	0.955 ∠-120	0.781 ∠60	0.631	1.507		
B	0.955 ∠120	0.781 ∠300	0.632	1.506		
Manufacture test result						
Phase	HV	LV	ID(PU)	IR(PU)	Trip status	Slope (%)
R	0.955 ∠0	0.781 ∠180	0.635	1.517	No Trip	65
Y	0.955 ∠-120	0.781 ∠60	0.635	1.517		
B	0.955 ∠120	0.781 ∠300	0.635	1.517		

5.2. Over fluxing protection

The test verifies that the relay signals properly at input over-flux levels that could cause overheating and, eventually, cause damage to the transformer. Time response testing is performed to ensure that the relay lies within operating limits imposed on it and it is vital in order not to damage the transformer.

Table 12: *Over fluxing test results*

Over fluxing Alarm Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected Voltage (V)	Pickup Value	Measured (V/Hz)	Measured Delay (ms)	Fault Record
66.68	2.31	2.32	37.8	V/Hz Alarm
Over fluxing Trip Stage 1 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected Voltage (V)	Pickup Value	Measured (V/H)	Measured Delay(s)	Fault Record
69.85	2.42	2.44	5.044	V/Hz >1 Trip
Over fluxing Trip Stage 2 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected Voltage (V)	Pickup Value	Measured (V/H)	Measured Delay(s)	Fault Record
73	2.529	2.54	3.039	V/Hz >2 Trip
Over fluxing Trip Stage 3 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected Voltage (V)	Pickup Value	Measured (V/Hz)	Measured Delay(s)	Fault Record
76.18	2.639	2.65	2.042	V/Hz >3 Trip
Over fluxing Trip Stage 4 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected Voltage (V)	Pickup Value	Measured (V/Hz)	Measured Delay(s)	Fault Record
79.35	2.749	2.76	1.048	V/Hz >4 Trip
The pickup values and time delays measured were within tolerance				

5.3. Overcurrent protection

Overcurrent testing for transformer protection is essential to protect transformers and ensure the reliability of power systems. Overcurrent testing involves verifying the settings and functionality of overcurrent protection relays, typically through primary and secondary injection testing. The goal is to confirm that the relays operate within specified time limits to isolate faults and prevent transformer damage.

Table 13: *LV Overcurrent test results*

LV Overcurrent stage 1 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (mA)	Pickup Value (mA)	Measured (mA)	Measured Delay (s)	Fault Record
800	790	800	3.053	POC 2 >1 Trip
LV Overcurrent stage 2 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (A)	Pickup Value (mA)	Measured(A)	Measured Delay(s)	Fault Record
1	980	1	2.051	POC2 >2 Trip
LV Overcurrent stage 3 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (A)	Pickup Value (A)	Measured(A)	Measured Delay(s)	Fault Record
1.2	1.18	1.2	1.046	POC2 >3 Trip

Table 14: *HV Overcurrent test result*

HV Overcurrent stage 1 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (mA)	Pickup Value (mA)	Measured (mA)	Measured delay(s)	Fault Record
650	630	650	3.05	POC 1>1 Trip
HV Overcurrent stage 2 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (mA)	Pickup Value (mA)	Measured(mA)	Measured delay(s)	Fault Record
800	790	800	2.047	POC1 >2 Trip
HV Overcurrent stage 3 Tolerance: I: ± 5% of set value; Td: ± 2% or 50ms whichever is greater				
Injected current (mA)	Pickup Value (mA)	Measured(mA)	Measured Delay(s)	Fault Record
950	940	950	1.039	POC1 >3 Trip

6. CONCLUSION

The research was aimed to experimentally validate the transformer protection numerical relay. Different types of protection schemes were looked into depending on the importance to the transformer. The transformer protection relay, MiCOM P642, executed protection schemes such as differential protection, overcurrent protection, over fluxing protection, and restricted earth fault protection. PSL (programmable scheme logic) design, being the brain behind the decision-making of the relay, was also looked into.

The CMC injection kit and Test Universe software were used in testing and validation. The CMC injection kit offered a simulated environment for fault conditions to see the response of the relay. Data analysis and comparison with the manufacturer's specifications and industry standards were provided through the Test Universe software.

A comprehensive manual was specially designed to educate students about testing and validating relay. This manual is an invaluable tool in the education of testing transformer numerical relays, as it provides detailed procedures, theoretical insights, and practical guidelines. We, therefore, empower the next cohort of engineers and technicians with knowledge and tools necessary for the effective testing of relays and to enforce the highest standards of safety and reliability within power systems.

7. RECOMMENDATION AND FUTURE SCOPE

The research covers the testing and validation of some protection schemes, but there are some areas to explore and improve the effectiveness and reliability of the relay. The following are some of the areas that can be explored.

There lies the scope to further extend research with other crucial protection schemes which could be covered in future studies to ensure complete fault coverage and system reliability.

Though the current testing was done under controlled laboratory conditions, which are usually favorable, it would be worthwhile to test the relay under different environmental conditions. This will help attain a better understanding of relay performance under stressful conditions, such as extreme temperatures, high humidity, and the influence of electromagnetic interference.

The laboratory has extra protection panels such as line protection, busbar protection, and generator protection panels. The next projects should consider the verification, testing, and validation of these panels.

By increasing the scope of the protection schemes mentioned, we will have covered complete approaches toward the protection of power systems. All these efforts are for better understanding and preparedness for different fault conditions and operational challenges.

For the improvement in effectiveness and reliability of transformer protection relay and relay testing practices, following recommendations can be proposed.

There is a need to have a structured program for continuous monitoring and maintenance of transformer relays embracing regular testing, calibration, and updating of the software to meet probable issues and give the best performance over time.

Comprehensive training programs on the CMC injection kit and Test Universe software should be created for students, technicians, and for engineers to enhance understanding and proficiency in relay testing and validation.

It is suggested that there be a collaboration with corporation like DGPC and BPC, the relay manufacturers such as Bhutan Automation Engineering Ltd, and the regulatory bodies to stay current with the latest advancements and best practices in relay technology and testing methodologies.

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