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Testing and Evaluation of Transmission Line Relays Using Advanced Tools

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Abstract:

Protective relays are important parts of the power system. The objective of the protection in power systems is to eliminate faults or unacceptable operating conditions for a component and related effects on the network. Fault elimination is usually done by isolation of the affected component. There are various types of faults, a special category are faults on generators (e.g. under excitation). But all other common transmission components are exposed mostly to faults as overvoltage and most of all over current, which is more commonly referred to as short-circuit. To ensure consistent reliability and proper operation, protective relay equipment must be evaluated and tested. The importance of the relay evaluation issue is linked to capability to test the relays and relaying systems using very accurate waveform representation of a fault event. The purpose of testing protective relays is to ensure correct operation of the relay for all possible power system conditions and disturbances. To fulfill this purpose, relay testing in varying network configurations and with different fault types is required. This paper describes a methodology in testing relays by using advanced digital simulator hardware.

Keywords: The importance of the relay evaluation issue is linked to capability to test the relays and relaying systems using very accurate waveform representation of a fault event.

I- INTRODUCTION

Relay testing is a very important issue when applying the protective relays. Vendors need an evaluation tool to validate the design of the relay logic and communication. Utilities need a tool to compare the performance of different relays, calibrate relay settings and perform troubleshooting. [1].

Operating time of numerical relay is a random value. It is necessary to perform a large number of tests, to determine statistical properties of the relay responses to check its selectivity and average tripping time.

There is no methodology defined with theoretical background and explicit recommendations how the transient tests should be conducted to evaluate random behavior of numerical relays. In summary, the new methodology would need to give the answers to the following important questions:

-Why and when the transient tests are needed?

-What procedures should be applied in transient testing?

-How the transient tests should be created and implemented?

Development of a new methodology that will improve transient testing and its implementation is the major focus of this paper.

Several concepts are realized in practice to conduct transient testing. These concepts include application of various hardware and software tools to create test cases and generate transient waveforms. These concepts do not provide comprehensively defined methodology. Theoretical considerations of transient testing and its application with numerical relays are not well understood.

Existing concepts in transient testing are focused on testing tools application with random and intuitive definition of test scenarios. Various types of microprocessor relays are tested and evaluated through the set of scenarios [2]. New methodology that combines different software packages to facilitate particular testing objectives is applied.

In order to analyze the operation of the protection system during induced fault testing in the Croatian power system, a simulation using the computer-aided protection engineering (CAPE) software has been performed. Once the accuracy of the simulation model had been confirmed, a series of simulations were performed in order to obtain the optimal fault location to test the protection system. Results were used to specify the test sequence definitions for the simulation end-to- end relay testing using advanced testing equipment with GPS synchronization for secondary injection in protection schemes based on communication [3].

This paper describes the Pacific Gas and Electric Company (PG&E) design philosophy of the 500 kV transmission line relay systems and the protection challenges of series-compensated transmission lines operating in single-phase tripping and reclosing modes are presented in [4]. In addition, the relay system settings considerations and their validation using a Real Time Digital Simulator (RTDS) is described. The paper demonstrates the analysis of RTDS results and the benefits derived during the engineering and commissioning stages of the

Reference [5] reviews why we tested in the past and what methods were used. It further reviews, future testing needs and strives to bring a resolution to the question of why test at all. A method for improving the quality of tests and the ability to derive meaningful analysis data is discussed.

Power system modeling and test procedure for using modern digital simulators are presented in [6]. Extensive study of five commercial relays comparing the application for 345 kV transmission line is carried out by performing of one-terminal and synchronized two-terminal transient tests.

The results of a project to develop a proof-of-principle working example of automated hardware-in loop testing of protection schemes on an RTDS Technologies real-time simulator is described in [7]. Which paper describes the test system configured to demonstrate automated closed-loop testing of the relays in a simple protection scheme, and presents the results of a typical set of such tests. The development of the script file to automate the tests is also discussed.

Methods and equipment for on-line testing of analog and digital measurement channels of protection relays have been presented in [8]. During the test, all protection functions of the device are active like during the normal work. Moreover no special hardware is installed inside the protection relay. The methods enable to reveal subtle changes in the measurement channel circuitry frequency characteristic caused for instance by an aging capacitor.

The design of new relay performance testing scheme, especially for complete digital relays is presented in [9]. At first, power system model is established in ATP-EMTP and fault transient data will be obtained by offline simulation. Subsequently, transient data are converted to IEC 61850-9-2 format through the static relay testing instrument. Finally, the complete digital relays directly receive the fault sampled value by process bus and Ethernet switches, and relays will act or not.

Analyzing the factors affecting the performance of generic object oriented substation event (GOOSE) based protection schemes is the primary objective of [10]. The paper then discusses the methodology and advanced hardware and software tools available for performance measurement of IEC 61850 GOOSE.

II- RELAY TESTING

The objective of the protection in power systems is to eliminate faults or unacceptable operating conditions for a component and related effects on the network. Fault elimination is usually done by isolation of the affected component. There are various types of faults, a special category are faults on generators (e.g. under excitation). But all other common transmission components are exposed mostly to faults as overvoltage and most of all over current, which is more commonly referred to as short-circuit.

A short- circuit is an unintentional and undesired conductive connection between two places having a different electrical potential (most common type of a failure is a connection between a phase and ground), which results in an excessive electric current flow. Negative consequences of a short circuit current are mechanical (as a large current induces significant forces) and thermal (losses being dissipated by a short circuit heat up exposed components).

If a short circuit is not eliminated, it may, with a high probability, damage an exposed component. Origins of short circuits are normally very difficult to predict as they may involve natural phenomena (as a lightning strike during a thunderstorm), a human error (e.g. hitting an underground cable during digging works) or aging of the equipment (e.g. isolation material degradation) [3].

A. Relay setting

A relay setting software program residing on the PC communicates with the relay to configure relay settings and an automated relay file retrieval software program residing on the PC communicates to the relay to automatically retrieve relay event reports triggered by certain pre-set conditions. These settings Separate relay time at 3 seconds from the moment the error occurs and current setting 0.7 A. the relay setting is tabulated in table (1).

TABLE I: RELAY SETTING

Potentiometers settings		
I > T_N	Tripping value for the low set element	0.71 A
I > T_H	Hysteresis value for the low set element	o.69 A
Hysteresis value <= trip value		
TI >	Tripping delay time for the low set element	0.000 s
TI >	Tripping delay factors for the low set element	0.00
I >> T_N	Tripping value for the high set element	1.00 A
I >> T_H	Hysteresis value for the high set element	0.97 A

Hysteresis value <= trip value		
TI >>	Trip delay for the high set element	0.000 s

B. Transmission Line Data

In transmission line simulation data [11], the used parameter simulation is tabulated in table (2). These parameters are used when ATP draw generates the ATP input file. Options are sorted in eleven tabs, such as resistance, inductance, and capacitance per length in [Ohm/km].

TABLE 2: TRANSMISSION LINE DATA

Item	Description	Value
R/l+	Resistance per length in [Ohm/km] Pos- sequence.	0.0217
R/l0	Resistance per length in [Ohm/km] Zero- sequence.	0.247
A=L' in [ohm/km] if Xopt =power frequency, ILINE=0		
A+	Inductance per length in [Ohm/km] Pos-sequence.	0.302
A0	Inductance per length in [Ohm/km] Zero- sequence.	0.91
B=C' in [ohm/km] if Copt =power frequency, ILINE=0		
B+	Capacitance per length in [Ohm/km] Pos-sequence.	3.96
B0	Capacitance per length in [Ohm/km] Zero- sequence.	2.94
L	length of line in km	300
ILINE	Takes values from 0 to 2	0
IPUNCH	Distortion less-mode modeling. G'=R'*C'/L'	1

III. TESTING TRANSMISSION LINE PROTECTIVE RELAY (OVER CURRENT) USING (ATP AND MATLAB) PROGRAMS

Alternative Transient Program (ATP) used by the power engineers and researchers for transient simulations. The ATP contains extensive modeling capabilities for transmission lines, cables, breakers, loads, converters, protection devices, non-linear elements, electromagnetic coupling, and major power electronics devices and equipment. The ATP has an enhanced graphical user interface called ATP Draw as a preprocessor, which allows an easy entry of system topology and data. The ATP program used to simulate the studied power system shown in fig [1]. MATLAB program is used to evaluate the fault diagnose algorithm which applied on the data generated from ATP.

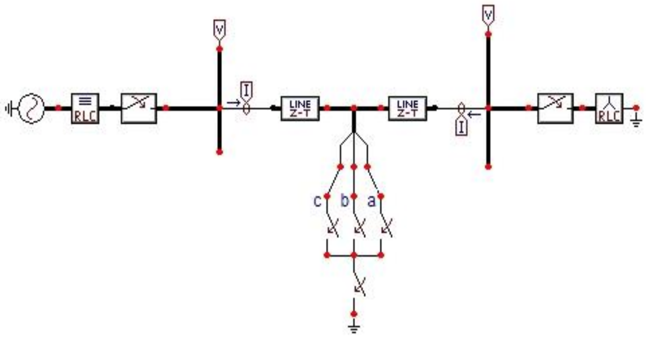


Fig.1 Studied power system model

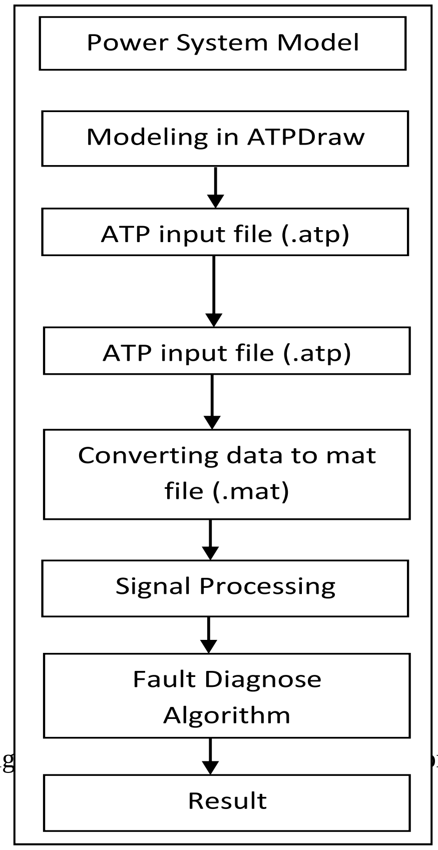


Fig r test

IV –COMPUTER SIMULATION

In order to investigate the applicability of the proposed Testing and Evaluation of Transmission Line Relays fault detection algorithm, extensive simulation studies are done, only ten study cases are presented. These cases compute of various fault conditions at single line to ground fault SLG and Double line to ground faults DLG and three line to ground fault 3LG. The aim of these cases is to check the algorithm accuracy for fault detection. In each case study the voltage wave-forms are presented.

A. Fault Conditions Effect

In the first study case (Case study 1:Three phase voltage signals for a- c- g fault , the fault is done at a distance of 400 kv at DLG The fault occurred on the transmission and distribution line in a time of 22ms . Fig 1 and Fig. 2 shows the voltage wave-form when the fault is done at three phase voltage signals for a-b-c-g fault. The fault occurred on the transmission and distribution line in a time of 20ms.

Cases study 3 and 4 present the effect of fault to show the accuracy of the suggested technique for the high impedance faults where the fault is done at three phase current signals for a-b-c- g fault. Fig.3 and Fig. 4 show the simulation results and technique evaluation for these cases.

Cases study 5 and 6 the fault is done at a distance of 10kA at three phase current and voltage signals for c-b-g fault. The fault occurred on the transmission and distribution line in a time of 20ms as show in Fig. 5 and fig. 6.

The same sequence is done for cases study 7, 8 and 9, where the fault is done at L-L fault as shown in Fig.7. Since the system is unloaded before the occurrence of the fault we have. Fig. 8 and fig. 7 shows the simulation results and technique evaluation for these cases.

In the fig. 10 three phase current signals for a-c fault where it is assumed that the fault has occurred on the transmission and distribution line in a time of 20ms and the fault is done at a distance of 8km.

From those results, it is clear that, the magnitude of the high frequency noise changed from faulted case to another according to fault conditions. It is important to mention that, the fault occurred at 20ms.the results indicate that the detection time is direct proportional with the fault location.

V. TECHNIQUEEVALUATIONUSING EXPERIMENTAL RESULTS

A. Experimental Setup

The hardware implementation is required to demonstrate the ability of the on line implementation of the suggested technique in real time. Fig 11 shows the overall experimental setup. In this figure, the laboratory model consists of digital power system simulator is used to test the over current protective relay and The relay acts to operate the appropriate circuit breakers to prevent damage to personnel and property .and confirm the simulation results obtained from the simulation tools.

Double line to ground faults

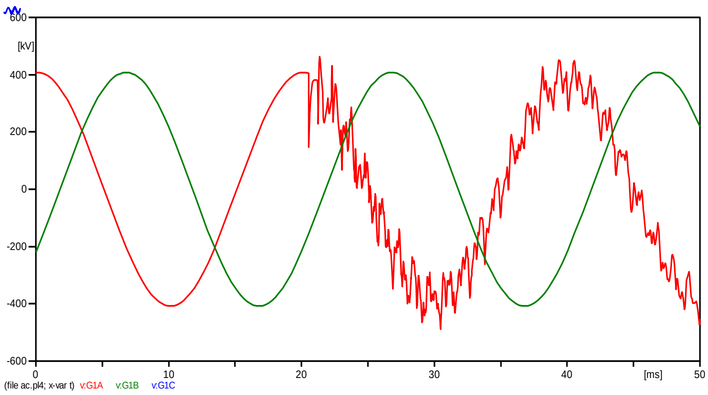


Fig.(1) Three phase voltage signals for a- c- g fault

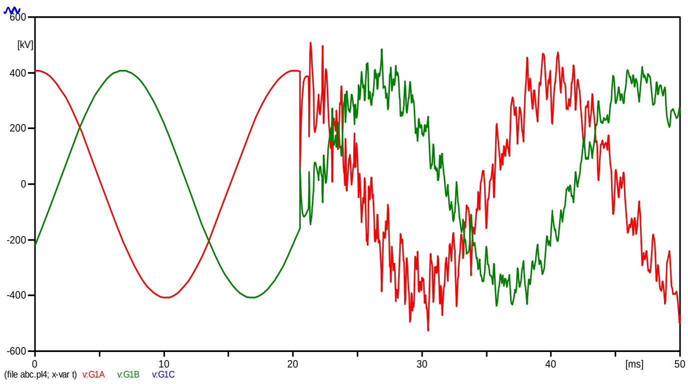


Fig.(2)Three phase voltage signals for a-b-c-g fault

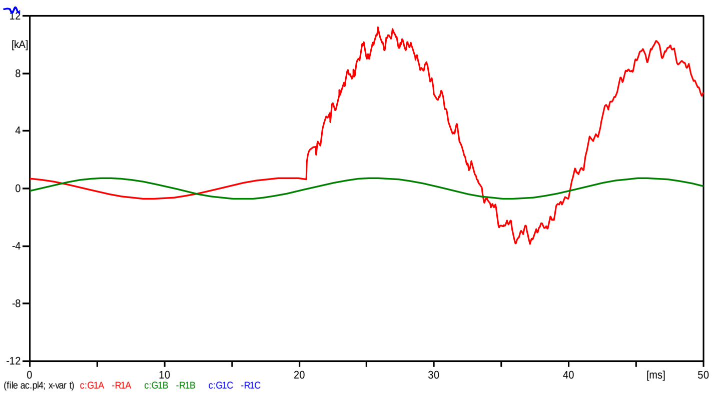


Fig.(3) Three phase current signals for a- c- g fault

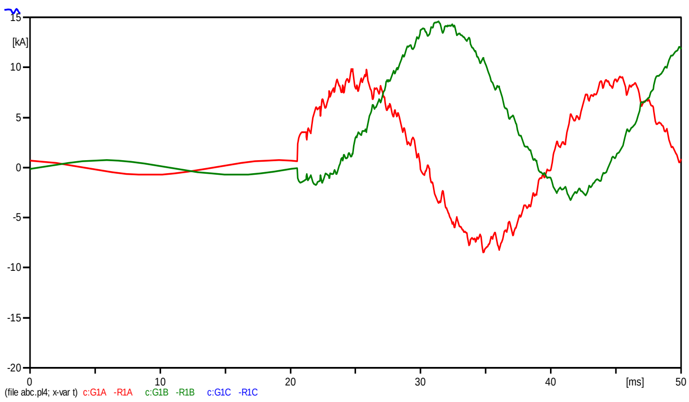


Fig.(4) Three phase current signals for a-b-c- g fault

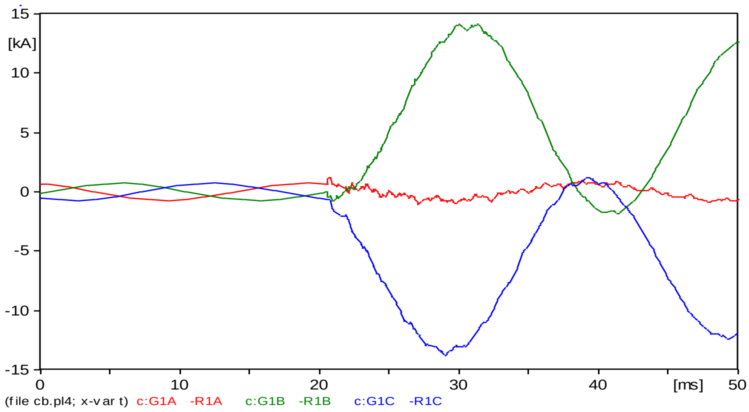


Fig.(5) Three phase voltage signals for c -b - g fault

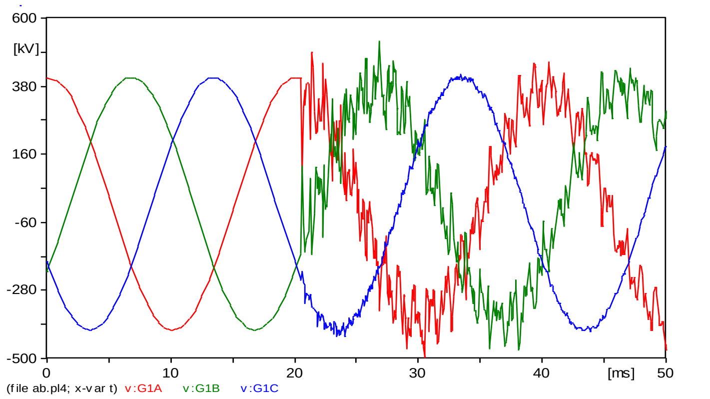


Fig.(6)Three phase voltage signals for a-b- g fault

Line to line faults

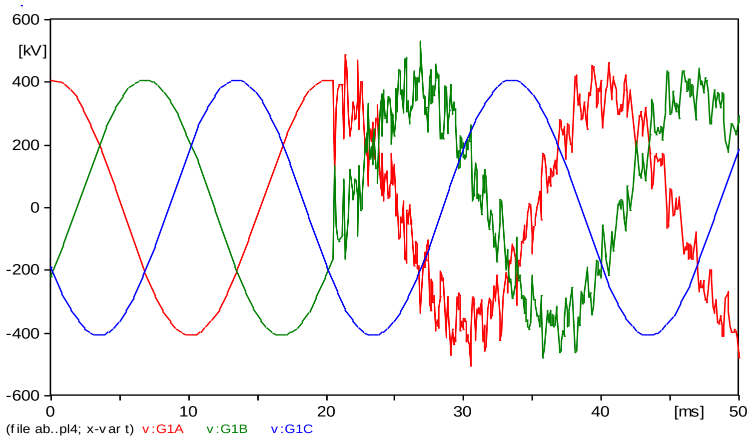


Fig.(7) Three phase Voltage signals for a-b fault

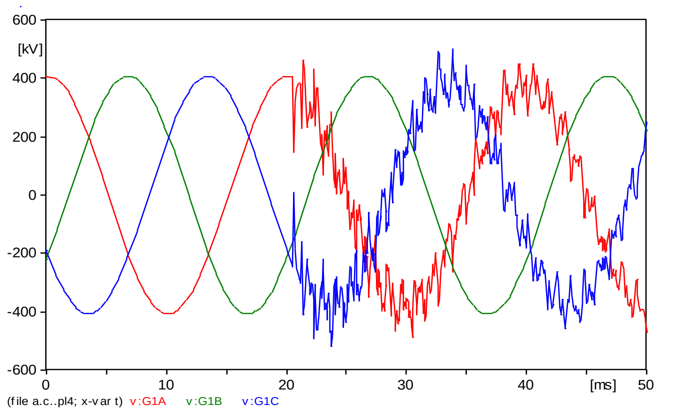
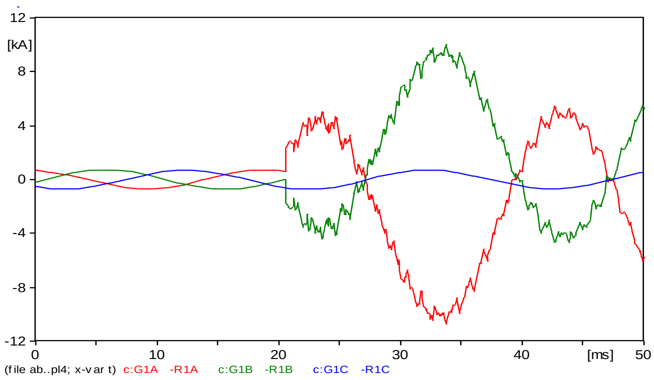
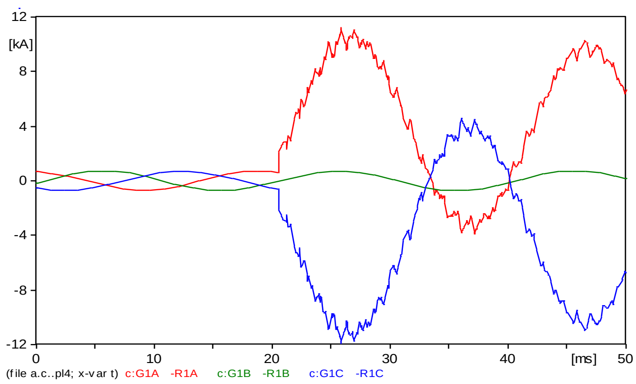


Fig (8)Three phase Current signals for a-b fault





Fig(9) Three phase current signals for A-C fault

Fig(10) Three phase Voltage signals for A-c fault

A digital power system simulator is used to test the over current protective relay and confirm the simulation results obtained from the simulation tools is shown in fig. 11.

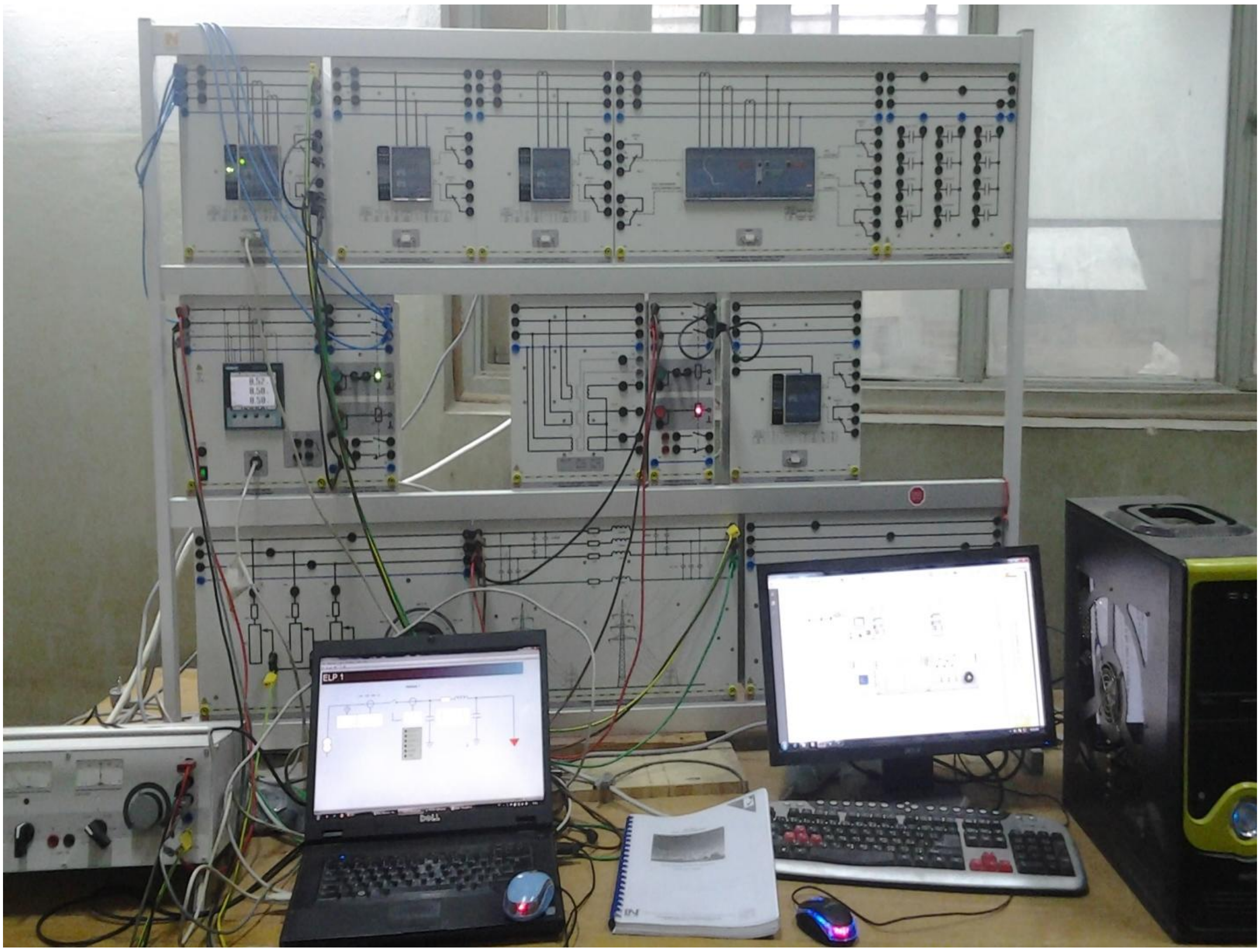


Fig. 11 Lab setup for physical relay test

B. Experimental Evaluation of the test the over current protective relay technique

The experimental results of the laboratory investigation of the fault detection based test the over current protective relay. The laboratory model is used to test real signals during fault occurrence. An extinction series of real time implementation studies has been done using the laboratory model.Figures from [12 to 16] show the front panel of lab-view system and MATLAB program is used to evaluate the fault diagnose algorithm which applied on the data generated from ATP. And a relay setting software program residing on the PC communicates with the relay to configure relay settings and an automated relay file retrieval software program residing on the PC communicates to the relay to automatically retrieve relay event reports triggered by certain pre-set conditions. These settings Separate relay time at 3 seconds from the moment the error occurs and current setting 0.7 A. the relay setting is tabulated in table during fault condition indicating the Digital simulator results The suggested tool succeeds to extract and detect test the over current protective relay components associated with faults. The comparison between the simulation results and experimental results are the identical due of the laboratory model. Moreover, the experimenta results demonstrate the capability of practicalimplementation of suggested tool.

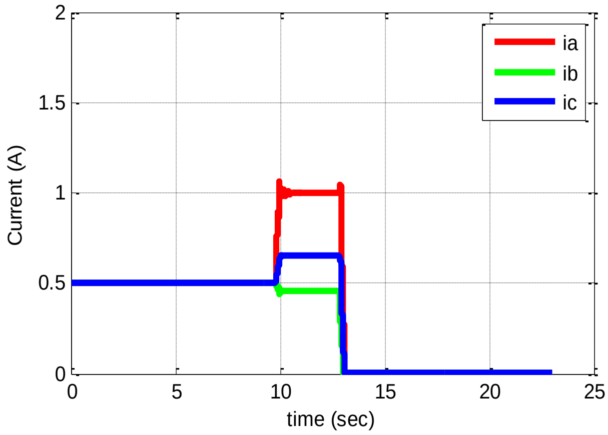


Fig. 12 Simulation results for SLG fault on phase a

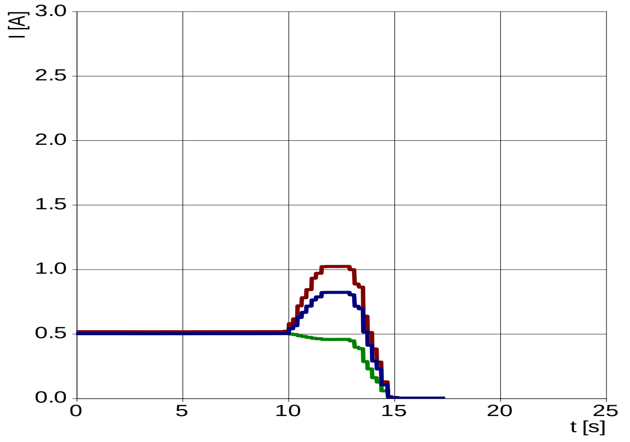


Fig.13 Digital simulator results for SLG fault on phase b

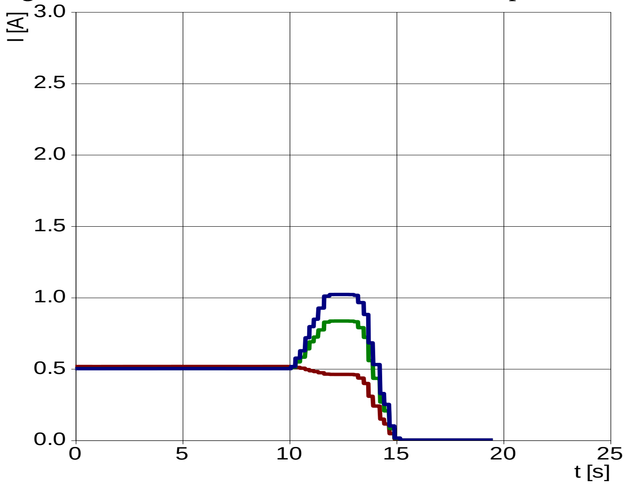


Fig.14 Digital simulator results for SLG fault on phase C

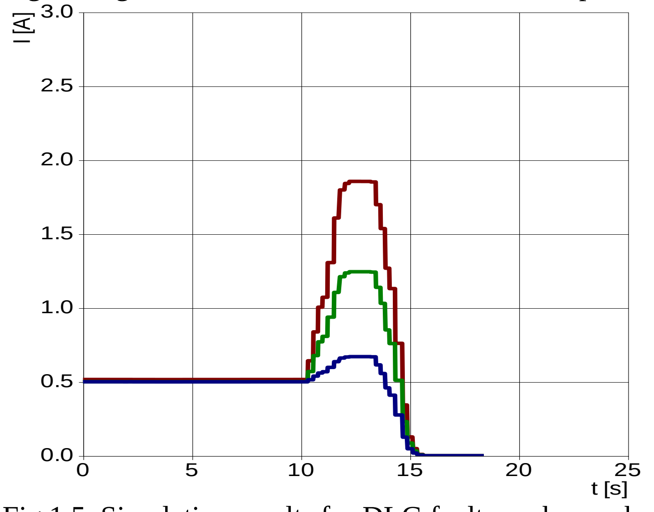


Fig.1 5 Simulation results for DLG fault on phase a-b

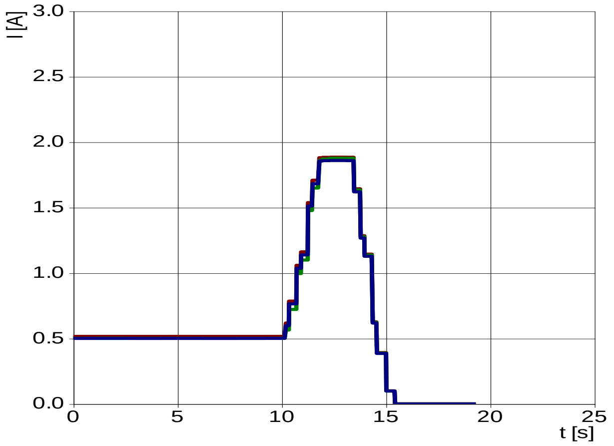


Fig.16 Simulation results for 3 phase fault a-b-c

VI- CONCLUSION

In today's practice of relay testing, there is no methodology defined for transient testing of

Numerical relays. The main contribution of this thesis is that a new methodology is established. By defining and applying the new methodology, the following contributions were achieved:

- Defining purpose of transient testing: It was shown theoretically why the transient tests are necessary and when the transient tests are needed.
- Defining test procedures: It was proposed how the transient tests should be defined and conducted to check selectivity and average tripping time of transmission line protective relays.
- Using different test equipment hardware: It was proven that advanced testing could be conducted with digital simulators of high output power in the laboratory, as well as with compact test sets suitable for field application.
- Using different modeling and simulation tools: By applying modeling and simulation tools in relay testing, it was shown how the advantages of different software tools can be utilized to achieve best possible conditions for testing applications.
- Extensive utilization of the modeling and simulation technology

The relay evaluation and testing in the future may be made more detailed and precise allowing for further improvements in the performance and reliability of protective relays and relaying systems.

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