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DYNAMIC TESTING OF DISTANCE PROTECTION ACCORDING TO IEC 60255-121 STANDARD

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A b s t r a c t: As a primary protection of high voltage (HV) and extra high voltage (EHV) transmission line, distance protection needs to operate as fast as possible for faults inside its protection zone, whilst it also must be able to discriminate between internal and external faults to prevent unnecessary disconnection of the healthy lines. The operational performances of distance protection during dynamic conditions are specified in the latest IEC 60255-121 standard. The standard describes different tests that need to be performed using a transient network simulator and how the test results to present. In this paper, an implementation of the dynamic testing of distance protection based on the IEC 60255-121 standard will be presented. The network modelling and the simulation of test cases described in the standard are implemented using ATP-EMTP. The test results of two distance relays show that depending on the dynamic conditions, the operational performance of the relay might be affected. In some situations, the operating time of the relays was delayed, while, in other conditions, the accuracy of impedance measurement is affected causing the relay to overreach.

Key words;; ATP-EMTP; IEC 60255-121; distance protection; operating time; transient overreach; dynamic condition

ДИНАМИЧКО ИСПИТУВАЊЕ НА ДИСТАНТНА ЗАШТИТА СПОРЕД СТАНДАРДОТ IEC 60255-121

А п с т р а к т: Како примарна заштита во високонапонските и екстремно високонапонските преносни водови се користи дистантната заштита која треба да проработи колку што е можно побрзо при дефекти во нејзината зона на заштита, а исто така треба успешно да ги разликува грешките кои се јавуваат во штитената зона и надвор од неа, со цел да се спречи непотребното исклучување на здравите водови. Оперативните перформанси на дистантната заштита при динамички услови се наведени во стандардот IEC 60255-121. Стандардот опишува различни тестови што треба да се извршат со помош на мрежен симулатор на транзиенти и како да се претстават резултатите од тестот. Во овој труд е претставена имплементација на динамичкото тестирање на дистантната заштита врз основа на стандардот IEC 60255-121. Моделирањето на мрежата и симулацијата на повеќе тестирани случаи опишани во стандардот се имплементирани со користење на програмата ATP-EMTP. Резултатите од тестот на два дистантни релеи покажуваат дека во зависност од динамичките услови може оперативните перформанси на релеите да бидат засегнати. Во некои ситуации оперативното време на релето е со временска задршка, додека во други услови е засегната точноста на мерењето на импедансата предизвикувајќи пречекорување на штитената област.

Клучни зборови: ATP-EMTP; IEC60255-121; дистантна заштита; време на проработување; транзиентно пречекорување; динамички услови

1. INTRODUCTION

Distance relay is the main protection of high voltage (HV) and extra high voltage (EHV) transmission networks. It detects disturbance (such as short circuit) by measuring the impedance between the faulted point and the relay location using voltage and current at its terminal. As the main protection in the transmission network, distance relay needs to operate as fast as possible for faults inside its protection zone, while it also must be able to discriminate between internal and external faults to prevent unnecessary disconnection of the healthy transmission networks.

The operational performances of distance relay are usually defined in terms of the operating time and the reach accuracy. Operating time is defined as the time interval between the instant when the fault occurs and the instant when the relay operates (trips). Reach accuracy means that distance relay must not have overreach or underreach operation under all fault conditions. Overreach happens when the calculated impedance is *lower* than the actual fault impedance causing the relay to trip for faults located outside of its protection zone. On the other hand, underreach arises when the calculated impedance is *greater* than the actual fault impedance causing the relay failed to trip for internal faults.

The minimum requirements for functional and performance evaluation of distance protection are defined in the latest IEC 60255-121:2014 standard [1]. The standard describes different tests to be performed on distance protection and how to present the test results. Distance protection test according to this standard can be divided into two parts: the accuracy test and the dynamic performance test. Accuracy test aims to measure the accuracy of the characteristic shape under steady state conditions, while the dynamic performance test seeks to evaluate the protection function performance under the simulated transient conditions.

2. METHODOLOGY

Dynamic performance of distance protection represents the response of function blocks used in the relay to disturbance conditions such as short circuit fault. The tests are performed by applying steady state pre-fault conditions, followed by fault conditions (transient and steady state conditions) to the protection relay input terminals. It means testing the protection relays under *real* simulated power system conditions.

Figure 1 shows the implementation of dynamic performance tests using an offline test method. First, the benchmark networks defined in the standard are modeled and simulated in ATP-EMTP. Second, the voltages and currents at relay location (secondary value) for all test cases are calculated, stored and then converted into COMTRADE file format. Third, the test libraries based on these COMTRADE data are developed. Finally, the voltage and current signals are injected into distance relays using a secondary injection kit from OMICRON®, and the protection response is recorded.

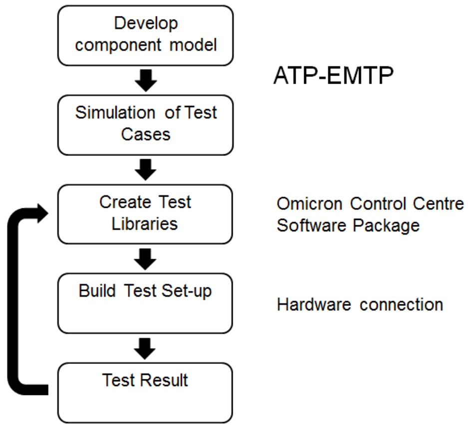


Fig. 1. Dynamic performance tests using an offlie test method

2.1. *Testing and simulations*

The standard defines various network configurations that need to be simulated such as the single in-feed network as shown in Figure 2. Different fault conditions also need to be considered in the simulation, for example, fault location, type, and inception angle. Transient programs like ATP-EMTP is capable of modelling the benchmark networks and to simulate transient conditions as described in the standard.

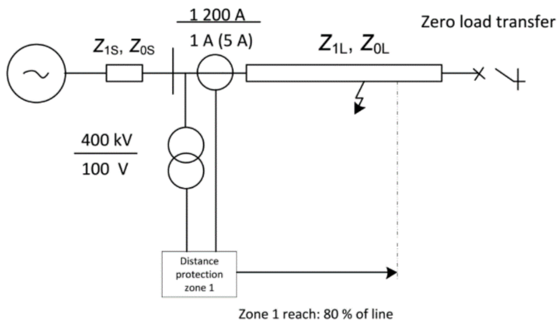


Fig. 2. Single in-feed network [1]

In addition to the benchmark networks, the standard also proposed the equivalent circuit of capacitive voltage transformer (CVT) that can be used to represent voltage transient error caused by CVT during faults. Figure 3a) shows the CVT model developed in the ATP-EMTP, and the transient responses of the model of different fault inception angles are validated as shown in Figure 3b).

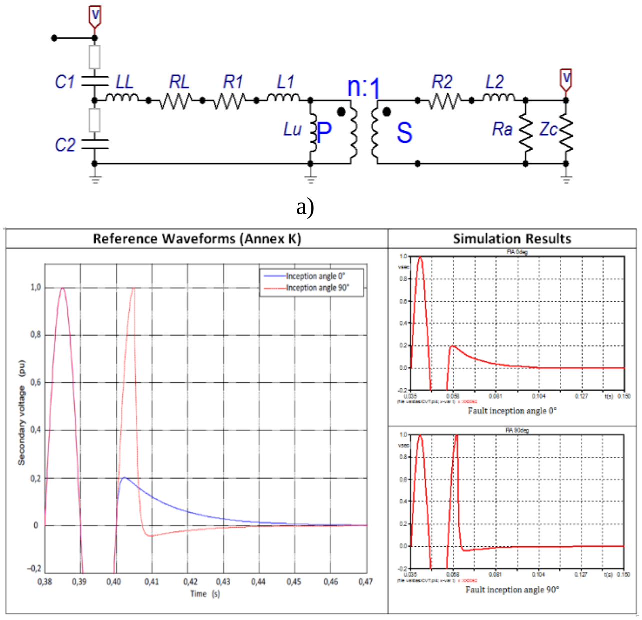


Fig. 3. a) CVT model, **b)** transient response of the CVT model

Figure 4 shows the secondary voltage of VT and CVT when a three-phase fault is initiated in the middle of the transmission line. Comparing the voltage of VT and CVT, it is shown that after the fault initiation at 120 ms the secondary voltages of VT drop rapidly, while in the case of CVT, the voltages contain transient error during the first two cycles.

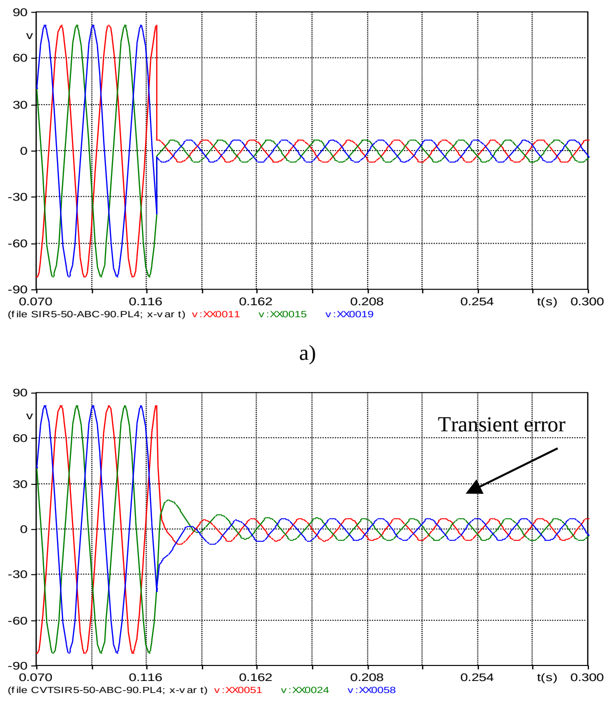


Fig. 4. Secondary voltage of (a) VT and (b) CVT

The other transient condition that needs to be tested is the superimposed harmonics in voltage and current signals. In the simulation, the harmonics are generated through oscillations between the source capacitance and the transmission line inductance during faults [1]. This condition represents the application of underground transmission cable which generates oscillation between the healthy-cable capacitance and the fault impedance when faults occur. Figure 5 shows the voltage and current of a three-phase fault with superimposed harmonics. It can be seen that when the fault is initiated at 120 ms, the voltage and current waveform are highly distorted with harmonics.

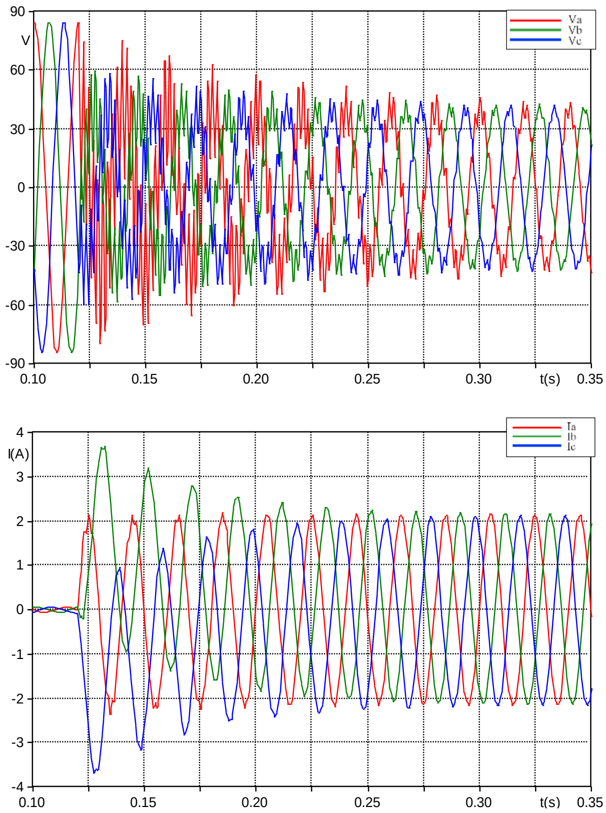


Fig. 5. Voltage and current superimposed by harmonics

2.2. *Test set-up*

The test set-up consists of test libraries and hardware connection between the tested relay and secondary injection kit. A test library consists of embedded functions which contain voltage and current signals at the relay location and a defined fault inception time. Figure 6 shows the test set-up used in this paper. The hardware connection consists of two three-phase analog signals (voltage and current) and two binary signals (trip and pick-up).

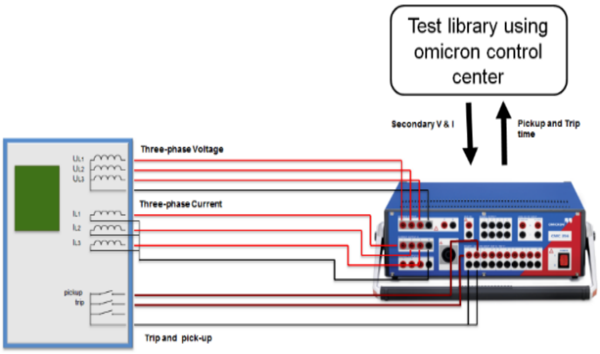


Fig. 6. Test set-up

3. TEST RESULT

3.1. *Average operating time and transient over-reach (SIR diagram)*

According to the standard, the dynamic performance tests shall be reported using SIR (source impedance ratio) diagram. Source impedance ratio is the ratio between the source impedance and the impedance reach setting of the distance relay. SIR diagram shows the operating time of distance relay as a function of the fault position and the source impedance ratio. Minimum, maximum, and average operating time of distance relay need to be documented. In the test result, only the average operating times are presented. For each fault position, the average operating time is calculated from 16 test shots (4 inception angles with 4 repetitions).

The first test aims to analyze the operational characteristic of distance relays with dc-offset in fault current. The magnitude of dc-offset is varied by changing the instant of the fault occurrence (or the fault inception angle). The tests are performed on both short (20 km) and long (100 km) transmission networks. For each test, the total time duration is 300 ms with pre-fault duration around 100 ms.

The instantaneous zone 1 of the relay is set to protect 80% of transmission network with no time delay. Moreover, zone 2 setting is deactivated. Two distance relays from different manufacturers are tested: Relay M and Relay N. Both distance relays are the numerical type relay used for protection of HV and EHV transmission lines. Figures 7–10 show the SIR diagrams for different fault types.

It can be seen that the operating time characteristics of both relays are similar. The relays trip relatively faster for faults located closer to the relay location (0%) than faults at the end of the reach setting (90–95%). Delayed operating times are also observed for higher SIR values.

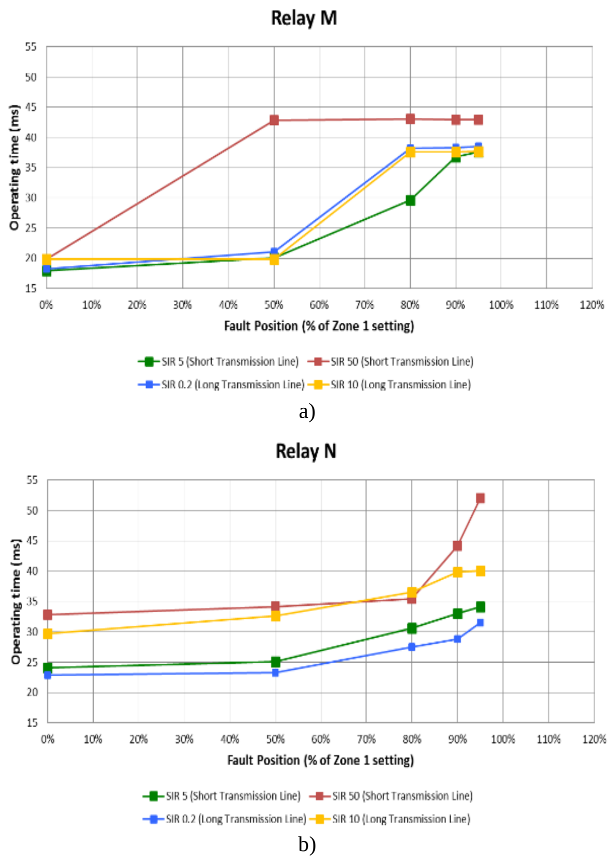


Fig. 7. Average operating time for LN faults

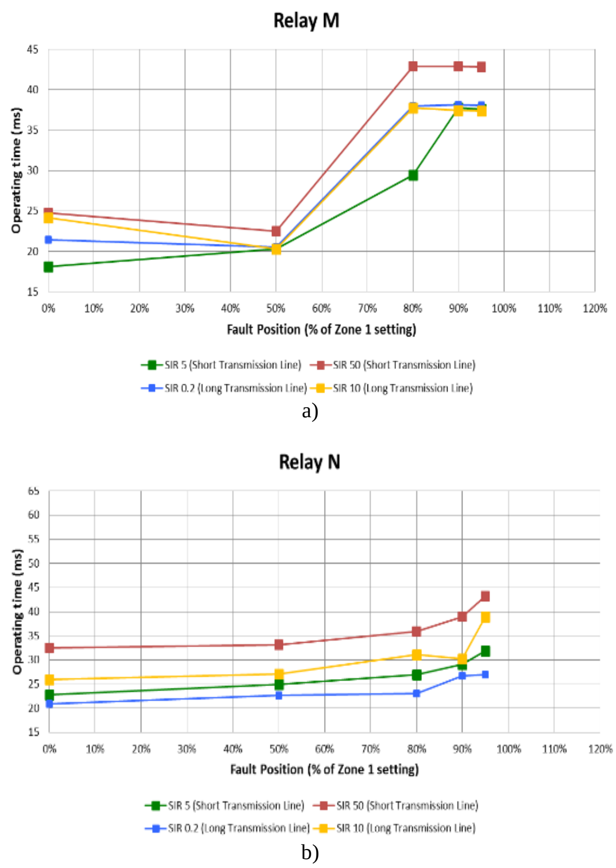
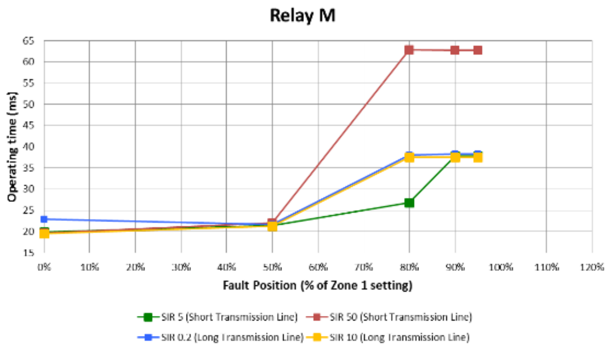
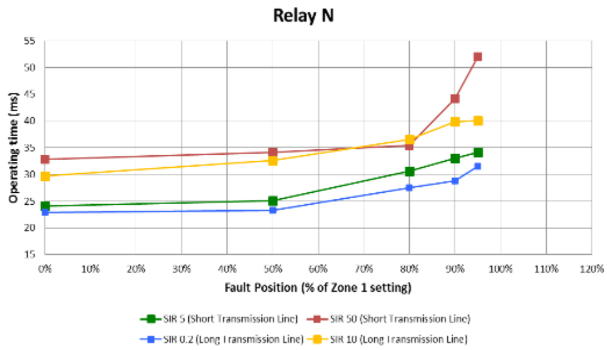


Fig. 8. Average operating time for LL faults

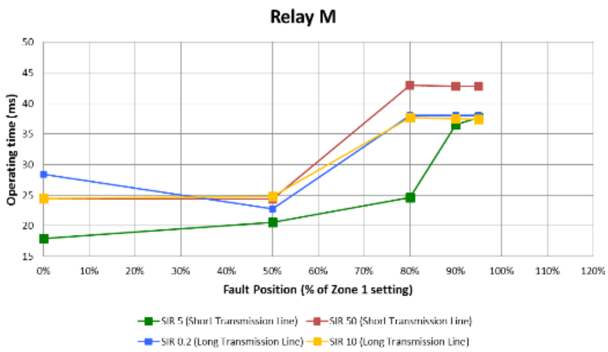


a)

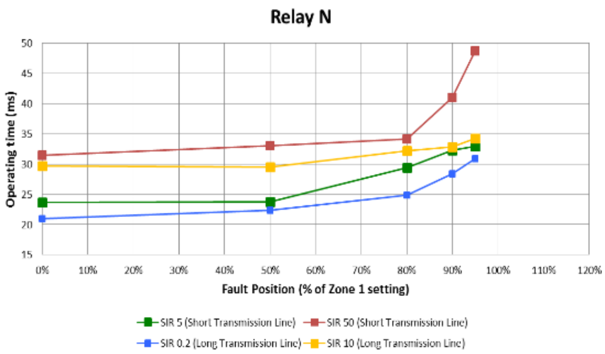


b)

Fig. 9. Average operating time for LLN faults



a)

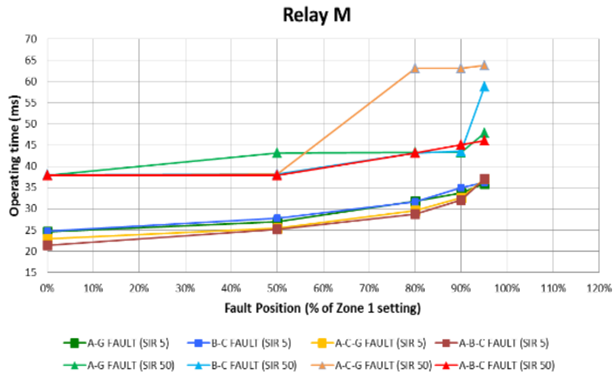


b)

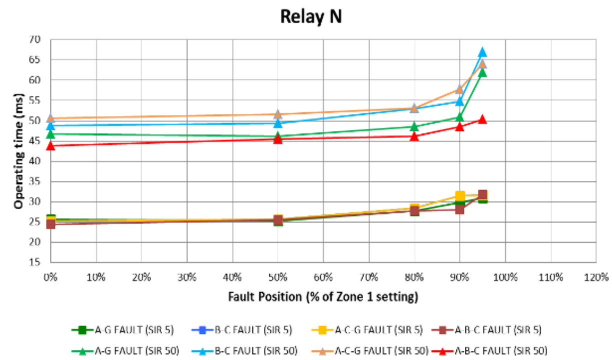
Fig. 10. Average operating time for LLL faults

3.2. *Average operating time and transient over-reach (CVT-SIR diagram)*

Similar with the first test, the second test also aims to analyze the operational characteristic of distance relays with dc-offset in fault current. However, the effect of CVT transient is also taken into account in this case, and only the short transmission network (20 km) is considered. Figure 11 shows the average operating time of both relays with CVT.



a)



b)

Fig. 11. Average operating time with CVT

Comparing the operating time with and without CVT, it can be seen that CVT transient seems to cause significant tripping delays for both distance relays, especially for faults located at the end of the impedance reach setting with high SIR value.

3.3. *Transient oscillation test*

The transient oscillation test aims to verify the distance relay performance when harmonics components are superimposed on voltage and current signals. Two fault types are used: LN and LLL. As explained before, the harmonics are generated through oscillations between the source capacitance and the transmission line inductance during faults. The harmonic orders are varied by changing the source capacitance values. Figure 12 shows the average operating time of relay M with superimposed harmonics.

It can be seen that the accuracy of relay M is not affected by superimposed harmonics as the relay did not trip for faults outside the protection zone 1.

The digital filtering used in relay M seems to be able to extract the fundamental frequency component correctly from the distorted waveforms. However, the filtering process produces a significant operating time delay (one cycle) in the case of AG fault with 7^{th} harmonics.

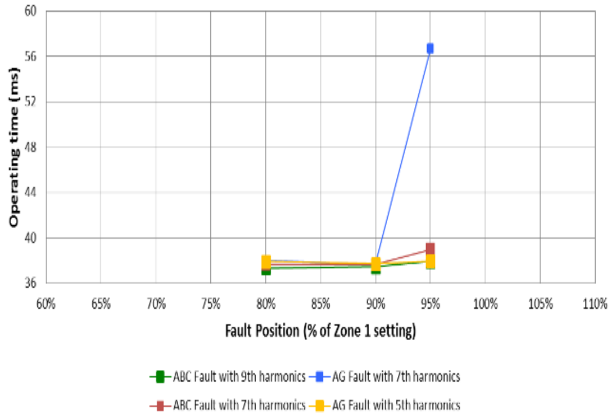


Fig. 12. Average operating time with superimposed harmonics

3.4. *Transient frequency deviation test*

This last test aims to analyze the operational performance of distance relay during power frequency deviation. In the simulation, the frequency of the voltage source is varied to simulate the off-nominal frequency conditions. The frequency of power system is set to the maximum and the minimum allowable frequency of the relay, 51 Hz and 49 Hz (for 50 Hz system), respectively. In this paper, only LN faults are considered. Figure 13 shows the operating time characteristic of relay M under frequency deviation.

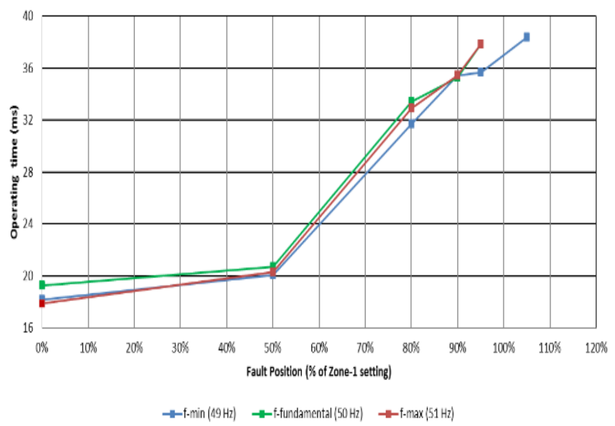


Fig. 13. Average operating time with frequency deviation

The test result shows that frequency variation has negligible effects on the operating time of the relay. However, it effects the impedance measurement accuracy. As shown in the graph, relay M tripped for faults located outside of the protection zone (105% of zone-1 setting).

CONCLUSION

In this paper, an implementation of the dynamic testing of distance protection based on the IEC 60255-121 standard has been presented. The network modelling and the simulation of test cases described in the standard are implemented using ATP-EMTP. The tests have been applied to two distance relays, showing that depending on the dynamic conditions, the operational performance of distance relay might be affected. In some situations, the dynamic conditions cause delayed tripping of the relays, for example in the case of CVT transient and superimposed harmonics. In other situation like frequency deviation, the accuracy of the impedance measurement is affected causing the relay to overreach. Furthermore, the relays show delayed operating characteristic when the faults occur at the of impedance reach setting.

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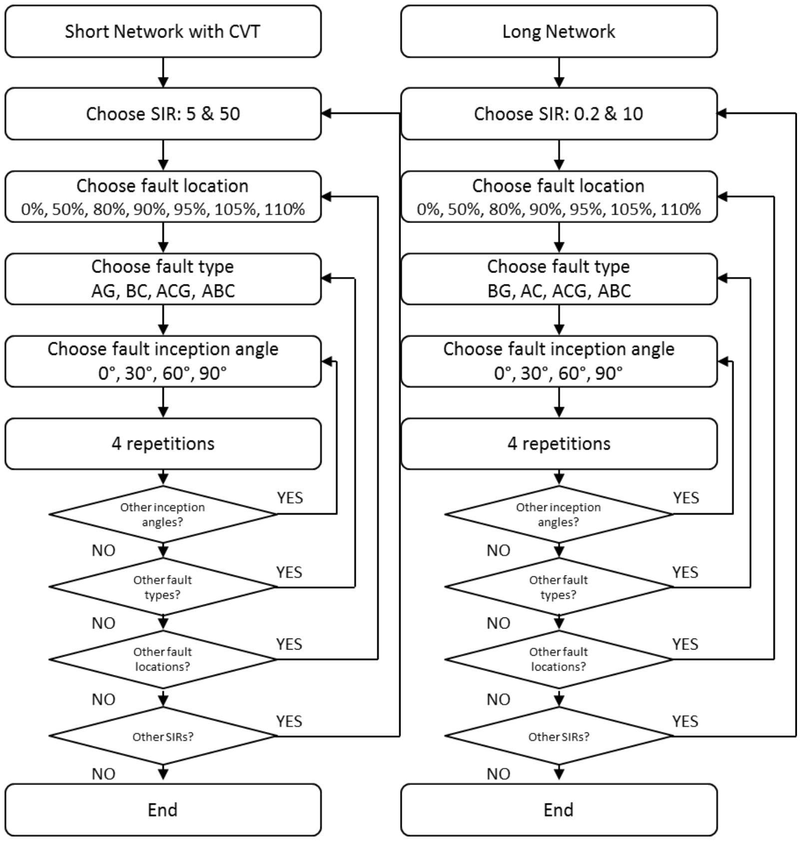
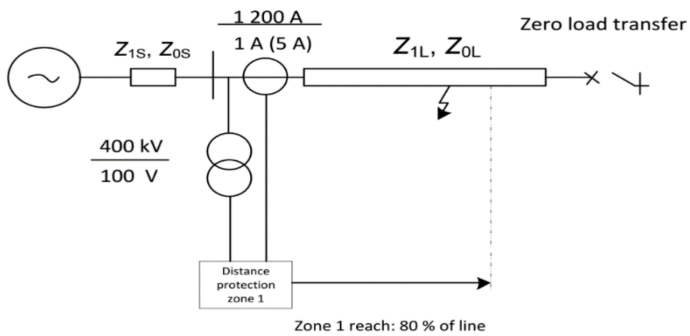
A P P E N D I X

Test sequences of SIR diagram (long line) and CVT-SIR diagram



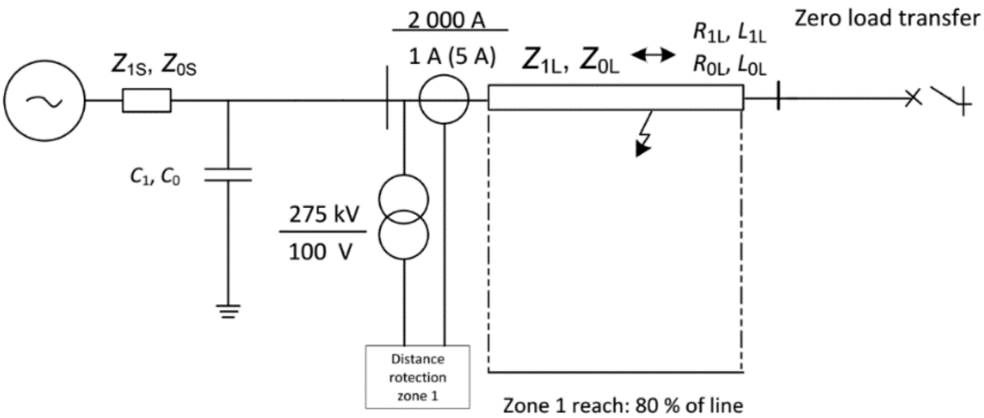
SIR diagram network parameters



Type	SIR	Source impedance*				Reach impedance setting* (80% of line length)			
		X1s	X0s	R1s	R0s	X1set	X0set	R1set	R0set
Short line	5	29.09	116.42	2.55	10.19	5.82	23.28	0.51	2.04
	50	290.88	1164.16	25.47	101.92	5.82	23.28	0.51	2.04
Long line	0.2	5.82	23.38	0.51	2.04	29.09	116.42	2.55	10.19
	10	290.88	1164.16	25.47	101.92	29.09	116.42	2.55	10.19

* Primary side values

Transient oscillation network parameters



Source*	$R1_S$	1.9 Ω
	$L1_S$	86 mH
	$R0_S$	8 Ω
	$L0_S$	350 mH
Transmission line*	$R1_L$	2.4 Ω
	$L1_L$	107.5 mH
	$C1_L$	1.6 μF
	$R0_L$	10 Ω
	$L0_L$	437.5 mH
	$C0_L$	1.1 μF
Source capacitance*	C1 = C0	4.31 & 8.93 μF

*Primary side values