11

EVALUATION OF CHARACTERISTICS AND PERFORMANCE OF POWER SYSTEM PROTECTION RELAYS AND PROTECTIVE SYSTEMS

Working Group 04 of Study Committee 34 (Protection)

M. MONSEU (Convener)

January 1986

cigré

EVALUATION OF CHARACTERISTICS AND PERFORMANCE OF POWER SYSTEM PROTECTION RELAYS AND PROTECTIVE SYSTEMS

Working Group 04 of Study Committee 34 (Protection)

M. MONSEU (Belgium), Convener

with the help of the Working Group

L. Barretta (Italy), M. Chamia (Sweden), H. Chorel (France), P. Crossley,
R. Millar (United Kingdom), I. De Mesmaeker (Switzerland), H. Hoel (Norway),
I. Kukovic (Yugoslavia), F.W. Voltman (Netherlands)

THIS DOCUMENT IS A GUIDE AND IS NOT INTENDED TO BE USED AS A STANDARD.

INDEX

	Page
INTRODUCTION	5
CHAPTER 1 - TEST METHODS AND PROCEDURES	
1.1 GENERAL	7
1.2 STEADY-STATE TESTS	9
1.2.1 Object	
1.2.2 Test procedures	
1.2.3 Test programs	
1.3 SINGLE-SOURCE DYNAMIC TESTS	10
1.3.1 Object	
1.3.2 Test procedures	
1.3.3 Test programs	
1.4 DOUBLE-SOURCE DYNAMIC TESTS	11
1.4.1 Object	
1.4.2 Test procedures	
1.4.3 Test programs	
CHAPTER 2 - FUNCTIONAL TESTS FOR DISTANCE RELAYS	
2.1 GENERAL	16
2.2 STEADY-STATE TESTS	17
2.2.1 Object	
2.2.2 Test procedures	
2.2.3 Test programs	
2.3 SINGLE-SOURCE DYNAMIC TESTS	18
2.3.1 Object	
2.3.2 Test procedures	
2.3.3 Test programs	
2.4 DOUBLE-SOURCE DYNAMIC TESTS	20
2.4.1 Object	
2.4.2 Test procedures	
2.4.3 Test programs	
2.5 TESTS WITH AUXILIARY FUNCTIONS	21
LIST OF TABLES	23

Page

CHAPTER 3 - FUNCTIONAL TESTS FOR CURRENT DIFFERENTIAL FEEDER PROTECTION

3.1 GENERAL 37

3.2 STEADY-STATE TESTS 38

3.2.1 Object
3.2.2 Test procedures
3.2.3 Test programs

3.3 SINGLE-SOURCE DYNAMIC TESTS 40

3.3.1 Object
3.3.2 Test procedures
3.3.3 Test programs

3.4 DOUBLE-SOURCE DYNAMIC TESTS 42

3.4.1 Object
3.4.2 Test procedures
3.4.3 Test programs

3.5 TESTS WITH AUXILIARY FUNCTIONS 43

LIST OF TABLES 46

CHAPTER 4 - FUNCTIONAL TESTS FOR CURRENT DIFFERENTIAL BUSBAR PROTECTION

4.1 GENERAL 55

4.2 STEADY-STATE TESTS 56

4.2.1 Object
4.2.2 Test procedures
4.2.3 Test programs

4.3 SINGLE-SOURCE DYNAMIC TESTS 57

4.3.1 Object
4.3.2 Test procedures
4.3.3 Test programs

4.4 DOUBLE-SOURCE DYNAMIC TESTS 59

LIST OF TABLES 64

Page

CHAPTER 5 - FUNCTIONAL TESTS FOR CURRENT DIFFERENTIAL TRANSFORMER PROTECTION

5.1 GENERAL 76

5.2 STEADY-STATE TESTS 77

5.2.1 Object
5.2.2 Test procedures
5.2.3 Test programs

5.3 SINGLE-SOURCE DYNAMIC TESTS 78

5.3.1 Object
5.3.2 Test procedures
5.3.3 Test programs

5.4 DOUBLE-SOURCE DYNAMIC TESTS 79

LIST OF TABLES 83

CONCLUSION 91

APPENDIX A : SYNTHETIC TESTS 92

APPENDIX B : TESTS ON POWER SYSTEM MODELS 95

INTRODUCTION

This report is intended to provide guidance on the tests required to establish the characteristics and performance of power system protection relays and protective systems, leaving the issuing of a standard to IEC. These functional tests are performed as a part of a type test program. The diversity of types of protection relays and protective systems prevents the definition of a universal type test program. However, a general type test program can be defined for a given type of protection equipment.

The basic philosophy of this report is to propose functional type test programs by using generally accepted methods of testing and test conditions as much as possible. However, it is emphasised that this report cannot be viewed as a standard and therefore the tests should be performed in accordance with an agreement between users and manufacturers. It is hoped that IEC can eventually achieve an international agreement on the methods, conditions and requirements of a type test program. Standard methods of testing and test conditions would ensure the reproducibility of the measurements. This allows a comparison between similar relays on a common basis and reduces the cost and duration of the tests.

Chapter 1 gives general recommendations for testing all types of protection relays and protective systems for E.H.V. interconnected power systems. When IEC Publications are available, reference is made to these documents. In other cases, practical suggestions are made.

Chapters 2 to 5 give general recommendations for testing distance relays and current differential relays for feeders, busbars and power transformers respectively. These general recommendations are illustrated from practical examples of application. Rough estimations of the numbers of tests have been made to enable an evaluation of the time required for tests.

Appendix A gives information on modern "synthetic" testing facilities, in order to generate conventional steady-state or dynamic test signals from separate sources.

Appendix B gives information on modern power system models, in order to simulate conventional power system configurations, fault conditions and fault clearance sequences.

Note : this edition of the report is a final version and supersedes all previous editions.

CHAPTER 1

TEST METHODS AND PROCEDURES

1.1 GENERAL

1. Tests for power system protection relays and protective systems can be divided into type tests and individual tests.
   Type tests are normally performed once on a given type of relay.
   Individual tests are performed on individual relays for acceptance, commissioning and routine maintenance.
   Acceptance tests are intended to verify the conformity of the individual relays with the type.
   Commissioning and maintenance tests are intended to verify the correct operation of the relays during their service life.
   This guide is not concerned with individual tests.

2. Type tests can be divided into functional tests and technological tests.
   Functional tests are intended to establish the declared characteristics and performance of the protection.
   Technological tests are intended to check the quality of the relay technology (e.g. : insulation tests, climatic tests, mechanical shocks and vibration tests etc...) This guide is not concerned with technological tests.

3. Functional tests can be divided into steady-state tests and dynamic tests.
   Steady-state tests are intended to measure the accuracy, sensitivity and operating characteristics of the measuring functions of the relay when applying a.c. energizing quantities (without transients). Steady state tests are uncomplicated and appropriate to measure the overall operating characteristics of the measuring functions of the protection.

   Dynamic tests are intended to measure the operating times of the relay when simulating faults within the protected zones and the non-operation (security) of the relay when simulating faults outside the protected zones. Some accuracy and sensitivity measurements are also performed in dynamic conditions to enable a comparison with the steady-state test results. On dynamic tests, the transient phenomena due to fault and fault clearance sequences shall be correctly simulated.

This guide is concerned with both steady-state and dynamic tests. The latter are subdivided into single-source dynamic tests (figure 1-a) and double-source dynamic tests (figure 1-b). Dynamic tests with load current and simulation of fault clearance sequences can be performed in a more realistic way by double source tests rather than by single-source tests.

4. Functional tests are performed in reference conditions and within the ranges of the influencing quantities or factors.

   Table 1.1-a indicates the nominal ranges of general influencing quantities or factors in accordance with IEC Publications. Reference values are given in IEC Publication 255-6 (1978) - Table I.
   Table 1.1-b indicates typical reference conditions and ranges for other influencing quantities or factors. Their inclusion is considered in accordance with the type of relay to be tested and the type of characteristics or performance to be established.

5. Functional test programs in this report are divided into two parts (a and b) :

   Part a : to establish the basic characteristics and performance of the protection for basic types of faults and within the setting ranges. Dynamic tests are repeated for different values of the initial point-on-wave from 0 ... 180° in steps of less than 30°.
   Other influencing quantities or factors are set at their reference values.

   Part b : some of the tests in part a are repeated to investigate the effects of varying the values of the influencing quantities or factors within their ranges. Influencing quantities or factors are normally varied one at a time. Part b tests can be subdivided as follows :
   (b1) : tests to establish the relay's operations at the various extremities of its range of application (parametric tests).

   (b2) : tests to establish the relay's operations for a particular case of application (specific tests).

   Part a tests and part (b1) are basic tests.

   Part (b2) tests should only be performed when required.

6. The block-diagram on page 15 summarizes the general classification of tests and indicates the limited object of this report.

1.2 STEADY-STATE TESTS

1.2.1 Object

1. These tests are intended to measure the operating characteristics of the measuring functions of the relay.
   For single-input measuring functions (e.g. over-current function), the operating and resetting values are measured. For double-input measuring functions (e.g. : impedance functions), the operating characteristics depend on the magnitude (X, Y) and relative phase-angle ( ) of both input energizing quantities, i.e. by vectors $\overline{X}$ and $\overline{Y}$.

   The operating characteristics are generally measured with constant values of one quantity : (X and Y variable), X (and Y variable) or Y (and X variable). For multi-input measuring functions, the operating characteristics are generally measured with constant values of several quantities.

2. These tests are also intended to check the correct operation of internal logic (starting, phase selection, tripping, etc...), indications, output contacts etc... The returning values of starting functions, accuracy of timing functions and power consumption of a.c. current, a.c. voltage, and d.c. auxiliary voltage circuits are also measured.

3. The test procedures are uncomplicated and appropriate to the investigation of the effect on the protection of varying the basic influencing quantities or factors such as : ambient temperature, auxiliary voltage, H.F. disturbances, frequency, harmonics, etc...

1.2.2 Test procedures

1. The steady state tests are performed by applying a.c. energizing quantities on the measuring inputs of the protection and varying some of these quantities slowly or in small steps without generating transients.

2. The number of measured points on each operating characteristic may vary in accordance with the type of characteristic to be measured : e.g. 1 point (over-current function), 12 points (impedance characteristic from 0 to 360° in steps of 30°) etc...

3. At least one point is measured several times (e.g. 10 times) to check the reproducibility of the measurements, according to IEC Publication 255-6 (1978 - Appendix B).

4. Information on the test equipment for steady-state tests is given in Appendix A (synthetic tests, including conventional steady-state tests).

1.2.3 Test programs

Examples of test programs are given in the following chapters for particular types of relays.

1.3 SINGLE-SOURCE DYNAMIC TESTS

1.3.1 Object

1. These tests are intended to measure the operating times and dynamic accuracy or sensitivity of the relay whilst simulating basic types of faults on a single-source, three-phase power system scheme as illustrated in figure 1-a.

2. These tests are also intended to verify the correct operation of internal logic (starting, phase selection, tripping etc...), indications, output contacts, etc. The resetting time after fault clearance is also measured.

3. The tests procedures are uncomplicated and are designed to establish the basic performance data of the protection and to investigate the effect of varying the influencing quantities or factors such as initial point on wave, fault type, d.c. time constant etc.

1.3.2 Test procedures

1. The single-source dynamic tests are performed by simulating basic types of faults (R - N ; S - N ; T - N ; R - S ; S - T ; T - R ; R - S - N ; S - T - N ; T - R - N ; R - S - T ; R - S - T - N) at different locations inside and outside the protected zones and measuring the operating times of the protection. The tests are repeated for different values of the initial point-on-wave (e.g. : from 0 to 180° in steps of less than 30°).

2. According to the type of protection to be tested, the dynamic characteristics can be measured with constant values of source impedance (variable line impedance and fault current) or fault current (variable line and source impedance), etc...

3. At least one point is measured several times (e.g. : 10 times) to investigate the reproducibility of the measurements, according to IEC Publication 255-6 (1978 - Appendix B).

4. Information on test equipment for dynamic tests is given in Appendix B. Some dynamic tests can also be performed by using synthetic methods of testing as indicated in Appendix A.

1.3.3 Test programs

Examples of test programs are given in the following chapters for particular types of relays.

1.4 DOUBLE-SOURCE DYNAMIC TESTS

1.4.1 Object

1. These tests are performed by simulating basic fault and fault clearance sequences on a double-source power system scheme as illustrated in figure 1-b, and are designed to establish :

- the operating times and correct operation of the protection when simulating faults and fault clearance sequences on the protected line (e.g. on line L_1).

- the non-operation of the protection when simulating faults and fault clearance sequences on a adjacent line (e.g. on line L_2).

2. These tests are performed on many types of relays and protective systems : especially distance relays, distance relays with autorecloser, line unit protection schemes, etc...

3. Double-source dynamic tests are also performed to check the correct behaviour of distance relays with auxiliary blocking functions such as : power swing blocking, fuse failure unit, etc...

1.4.2 Test procedures

1. These tests are performed without load current and with load current flowing in both directions (from A to B and B to A).

2. The simulated fault clearance sequence operates according to the tripping and reclosing commands from the tested relays in an interactive way (the tripping and reclosing commands from the tested relays actuate the appropriate circuit-breakers in real time during the simulated fault sequence) or in a pseudo-interactive way (the tripping and reclosing commands from the tested relays are only recorded).

1.4.3 Test programs

Examples of test programs are given in the following chapters for given types of relays.

Fig 1-a
Single-source dynamic tests

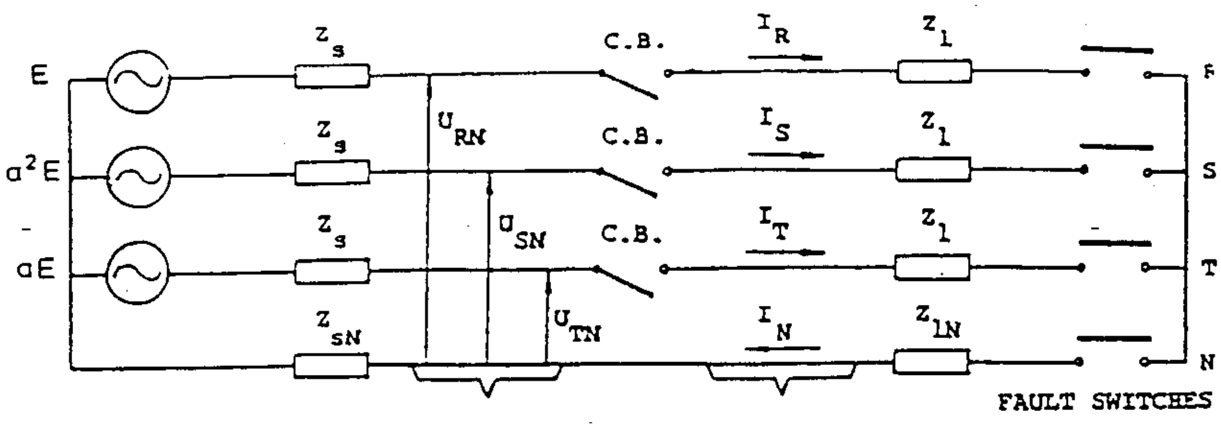


Fig 1-b
Double-source dynamic tests

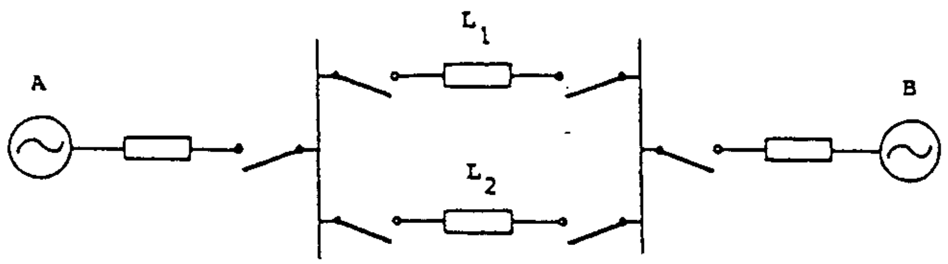


Fig 1-c
Transmission line or cable model

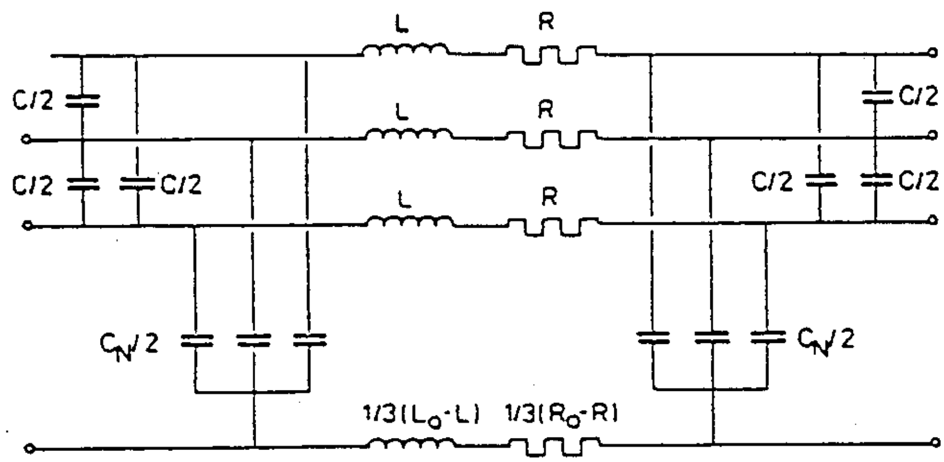


Fig 1-d
CVT and burden models

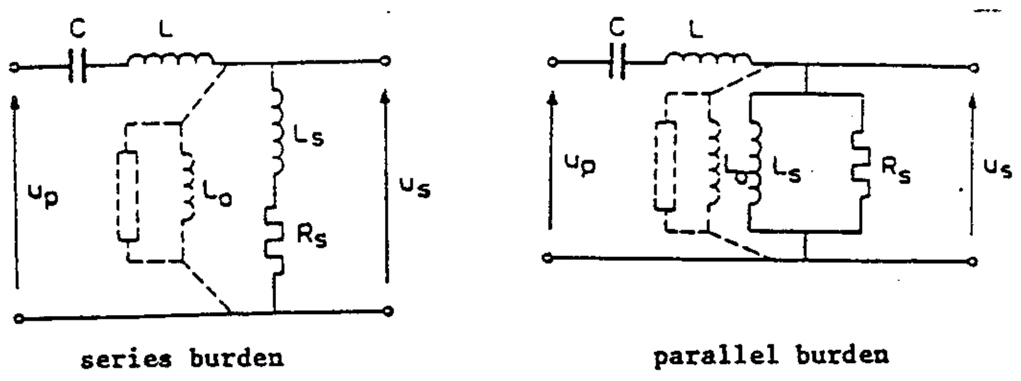
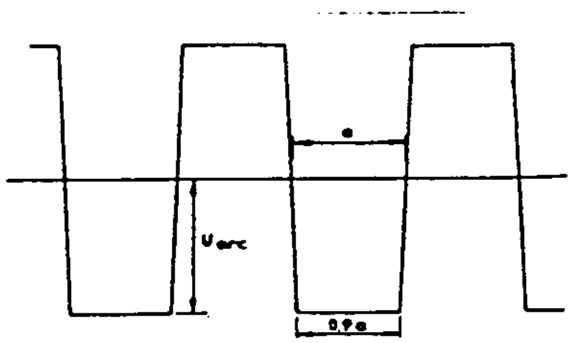


Fig 1-e
Arc voltage waveform



Influencing quantities or factors		Typical ranges proposed by WG 04	IEC Publications
Ambient temperature		– 5 °C to + 40 °C (+ 55 °C)	IEC 255-6 (1978) Table II
d.c. auxiliary source	voltage	80 % ... 110 % U_n	IEC 255-6 (1978) Table V
	short interruptions	2 .... 200 ms	IEC 255-11(1979) – § 5
	ripple	max 12 % peak-to-peak	IEC 255-11(1979) Table III
H.F. disturbances on a.c. current, a.c. voltage and d.c. auxiliary voltage circuits (x)		1 MHz – 200 Ω Common mode : 2.5 kV Transverse mode : 1 kV	IEC 255-6 (1978) – Appendix C – Class III
Relay setting		Setting range	IEC 255-6 (1978)

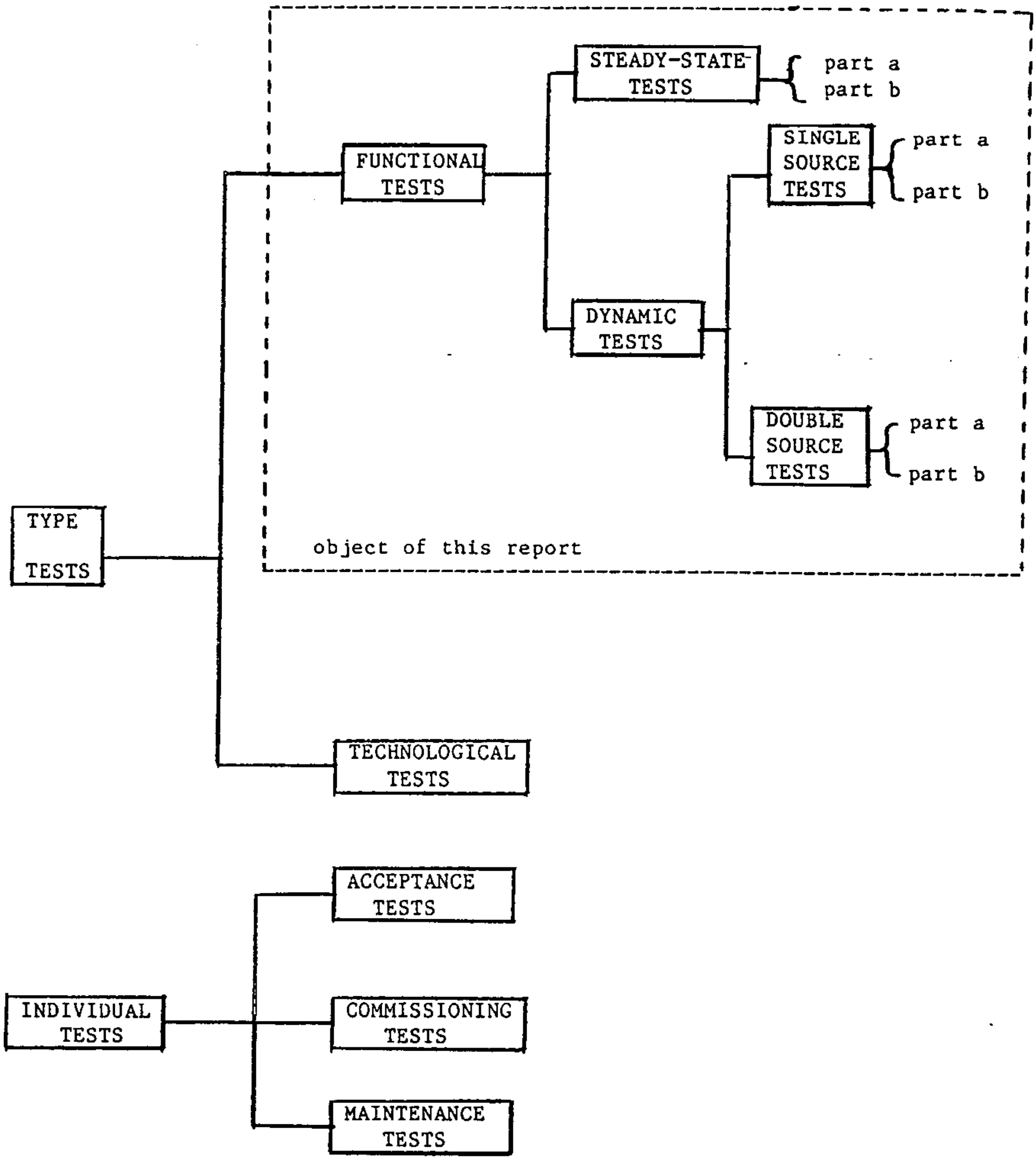
(x) electromagnetic fields as well as fast transients and electrostatic discharges are under consideration by IEC

Table 1.1-a : nominal ranges for general influencing quantities or factors

Influencing quantities or factors		Typical reference conditions proposed by WG 04	Typical ranges proposed by WG 04
Source e.m.f's	frequency	f_N (± 0.5 %)	94 % .... 102 % f_N
	waveform	sinusoïdal (total harmonic distortion ≤ 2 %)	0 ... 5 % harmonics of different orders and phase positions
Source impedance	impedance	reference value	Min ... Max
	time constant	50 ms ± 5 ms	10 ... 500 ms
Line (or cable)	capacitance	Zero	π cells representation (fig 1 -c)
	frequency of line oscillations	no oscillations	Max 1 ... 3 kHz
Current transformers	remanence factor (BR/BS)	Zero	0 ... 0.8 (x)
	knee-point voltage	no transient saturation	5 ... 1200 times internal e.m.f. at rated current
	secondary time constant	≥ 10 sec	unsaturated : 50 ms ... 100 sec fully saturated : 0.2 ... 3 ms
Voltage transformers	remanence factor (BR/BS)	Zero	0 ... 0.8
	knee-point voltage	no transient saturation	U_N ... 2 U_N
	capacitor voltage transformer	not represented	typical CVT model (fig 1 -d)
Faults	impedance	Zero	trapezoïdal representation of arc voltage (fig 1 -e)
	fault types	single-phase-to-ground two-phase two-phase-to-ground three-phase no fault	evolving faults (e.g. R – N → R – S – N) complex faults
Initial conditions	initial voltage	U_N	0 ... U_N
	initial load current	Zero	0 ... I_n
	initial point-on-wave	0	0...180° in steps of less than 30°
Circuit-breaker operation	at closing	simultaneous pole operation	0...10 ms between pole operation
	at tripping	current interruption at natural zero crossings	–
Pilot wires	resistance and capacitance	Zero	0 ... Max
Transmission links	attenuation and time delay	Zero	0 ... Max

(x) consecutive dynamic tests are performed with maximum current offset of the same polarity to obtain a maximum build up of remanence.

Table 1.1-b : typical reference values and ranges for influencing quantities or factors.



STEADY-STATE TESTS
part a
part b
FUNCTIONAL TESTS
SINGLE SOURCE TESTS
part a
part b
DYNAMIC TESTS
DOUBLE SOURCE TESTS
part a
part b
TYPE TESTS
object of this report
TECHNOLOGICAL TESTS
ACCEPTANCE TESTS
INDIVIDUAL TESTS
COMMISSIONING TESTS
MAINTENANCE TESTS

CHAPTER 2

FUNCTIONAL TESTS FOR DISTANCE RELAYS

2.1 GENERAL

See chapter 1, § 1.1

1. The operating principle of a distance relay protection is based on the measurement of the impedance between the fault position and the relay position. When the impedance vector is in a predetermined zone in the R-X-plane, the relay gives a tripping command to the circuit breaker.

   The distance relay may be activated by starting units, which determine if there is a fault in the protected network. The starting units initiate the start of the time unit, which changes the sensitivity of the measuring unit(s) and may also take care of the appropriated phase selection for the measuring unit(s) and the tripping logic. Alternatively in a full scheme distance relay, each measuring element continually monitors the line impedance and a starting unit is not required. The tripping logic combines the decisions of the different units and may give the tripping command.

2. This chapter contains information about test methods for distance relays. Tables with examples of tests are presented, and these may serve as a general guide for a type test program. This chapter does not cover special applications (e.g. lines with series capacitors, shunt reactors, Petersen coil grounding, etc.). The tables also provide an estimation of the number of tests and this allows an assessment of the total effort required. It should be noted that one test may consist of a series of initiations.

3. Reference values and ranges of influencing quantities and factors, valid for the different tests, are shown in table 2.1. Due to the lack of standardized models (e.g. for CT's and CVT's) no numbers of tests are given for some of the influencing factors.

   Depending on the field of application or of special features of a relay, additional tests may be required, e.g. to establish the correct behaviour of the relay with arc voltages, saturated CT's, etc.

4. As the basic distance relay is often equipped with units for auxiliary functions, examples of tests for the combination of distance relay and auxiliary equipment are given. These examples show the kind of tests that are required to verify correct operation.

2.2 STEADY-STATE TESTS

2.2.1 Object

See chapter 1, § 1.2.1.

1. These tests are intended to measure :

   - the operating characteristics and accuracy of the starting units (if required).
   - the operating characteristics and accuracy of the measuring unit(s)
   - the accuracy of the timing unit

2. These tests are also intended to check the correct operation of internal logic (e.g. phase selection, tripping, etc.) optical indicators, output signals, etc. The power consumption of the a.c. current, a.c. voltage and d.c. auxiliary circuits is also measured.

2.2.2 Test procedures

See chapter 1, § 1.2.2.

1. The operating characteristics of the starting and measuring functions of the distance relay are measured with a constant value of current (constant current characteristics) or with a constant value of source impedance (constant source impedance characteristics, e.g. for cross-polarized measuring functions). In the latter case, basic types of faults are simulated under steady-state conditions using the three-phase scheme of figure 1-a. The line impedance is varied slowly or in small steps to determine the operating levels of the starting and measuring functions.

The above test procedure can also be used to determine the operating characteristic of the directional function. The minimum fault voltage for correct directional discrimination (sensitivity) has to be measured.

2. For the tests under reference conditions, which form the base with which to compare the parametric tests, the number of measuring points must allow an accurate representation of the characteristics (e.g. at least three points for each straight line, 12 points from 0° to 360° for an impedance characteristic).

3. To investigate the influence of the different influencing quantities or factors, the number of measured points can be reduced to a selection of representative points. Examples of selected measuring points are given in figure 2-a.

2.2.3 Test programs

Examples of test programs are presented in tables 2.2 parts a and b.

2.3 SINGLE-SOURCE DYNAMIC TESTS

2.3.1 Object

See chapter 1, § 1.3.1

1. These tests are intended to investigate :

- the behaviour of the distance relay (accuracy, tripping times, etc.) with a limited number of general influencing quantities or factors.

2. With appropriate models the following tests can also be defined :

- the effect on the dynamic characteristics of typical or particular models of instrument transformers,
- the effect on the dynamic characteristics of more accurate models of lines, faults, etc.

2.3.2 Test procedures

See chapter 1, § 1.3.2

1. The dynamic accuracy of the starting and measuring functions can be measured in the first and in the third quadrant. Two accuracy error limits may be determined in the following way :
   - upper limit : 0 operations out of N tests, when varying the initial point-on-wave, from 0 to 180°

   - lower limit : N operation out of N tests.

   In the tables with examples of tests, each of these limits is counted as one test result.

2. The directional sensitivity is measured in a similar way, the limits are :
   - fault in the forward direction, minimum residual voltage for correct operation.

   - fault in the reverse direction, minimum residual voltage for no maloperation.

   The effect of a voltage memory must be taken into account : the directional sensitivity is to be measured with and without rated voltage before initiation of the fault.

3. The operating times of the relay must also be investigated by varying the point-on-wave from 0° to 180°.

   In the tables with examples of tests, this variation of the point-on-wave is indicated as one test result.

4. Examples of presentation of dynamic characteristics are given in figure 2-c

2.3.3 Test programs

Examples of test programs are presented in table 2.3., parts a and b.

1 For the dynamic tests it is in general not necessary to investigate the effect of all the influencing quantities or factors, listed in table 2.1. However, the effect of harmonics and travelling waves should be considered as specific tests, defining the models according to the actual power systems. Dynamic tests with H.F. disturbances are often limited to a few points. Examples of tests for the commonly used influencing parameters are given in table 2.3 part b.

2. Similar tests could be made to investigate the effects of CT-models, CVT-models, source and busbar and line models on the dynamic characteristics and performance of the relay. In order to obtain comparable test results it would be necessary to define standard models. In any case, the type of model or the simulated line component should be specified in the test report.

2.4 DOUBLE-SOURCE DYNAMIC TESTS

2.4.1 Object

See chapter 1, § 2.4.1

These tests are intended to investigate :
- the effect of load current on the behaviour of the relay,
- the stability of the relay during external faults and fault clearance sequences.

2.4.2 Test procedures

See chapter 1, § 1.4.2

The accuracy and operating times are measured as described in 2.3.2.

2.4.3 Test programs

1. The test scheme is one of the double-source configurations as shown in figure 2-b. The same models of sources, lines, faults and instrument transformers can be used as for the single-source tests. The mutual impedance between parallel lines may have to be taken into account.

2. The impedance values of the lines and sources are chosen in such a way, that a phaseshift of 30° or 60° between the two sources causes a load current of 1 In in each line.

3. Measurements are made without load current and with load current in both directions.

4. The tests are made with a limited number of influencing factors, which may have a particular influence due to the presence of the second source (and a load current).
   Examples of tests are given in table 2.4., parts a and b.

2.5 TESTS WITH AUXILIARY FUNCTIONS

1. Tables 2.5a to 2.5d give examples of dynamic tests for the distance relay in combination with one or more of the following auxiliary functions :
   - autoreclosing equipment
   - power swing blocking unit
   - fuse failure unit
   - communication equipment (directional comparison or blocking scheme).

2. It is supposed that the performance of the auxiliary equipment is tested before.

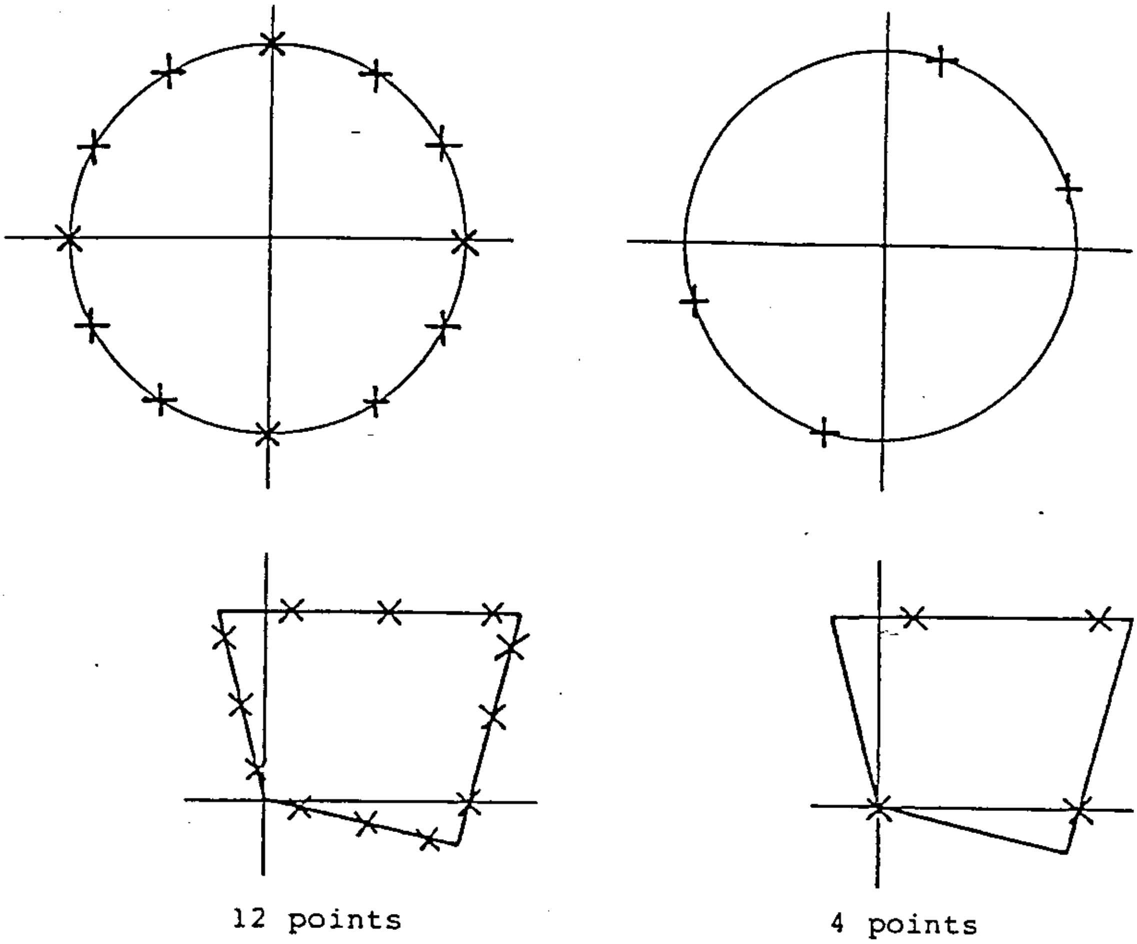


Figure 2-a Examples of selected measuring points

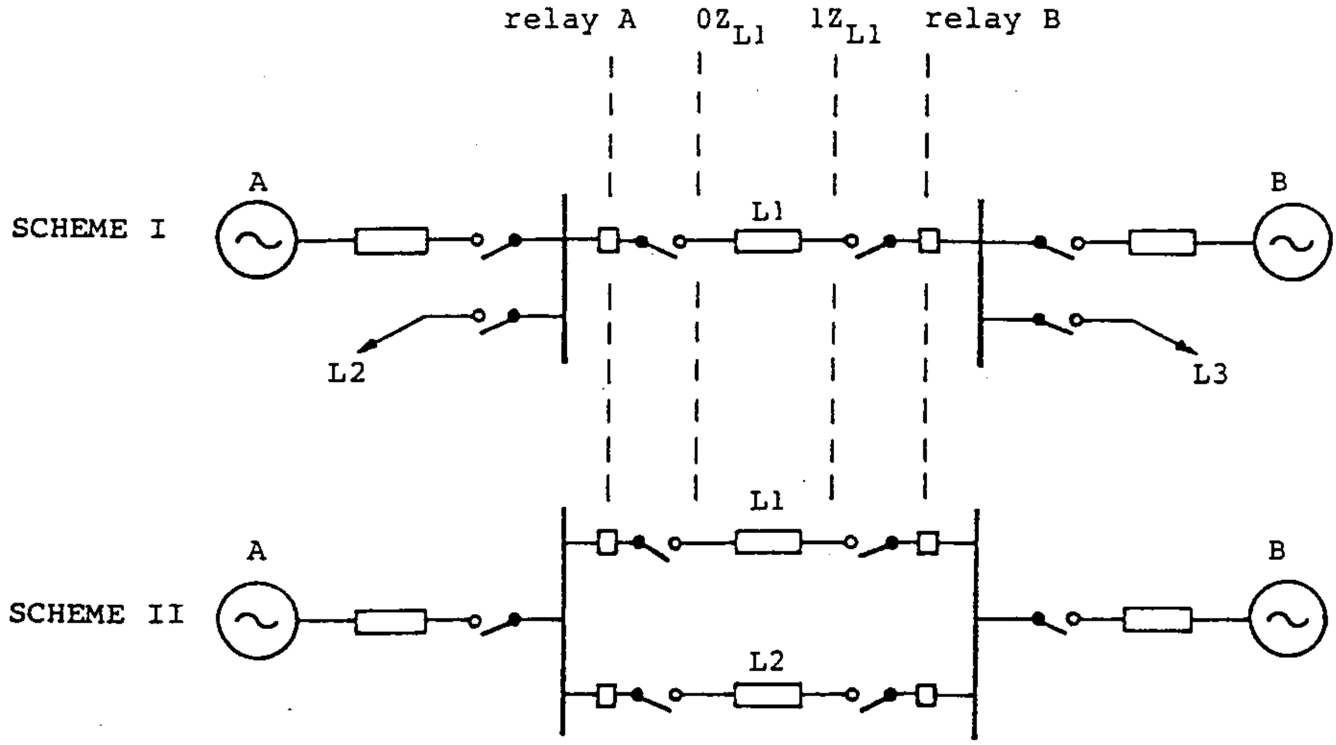
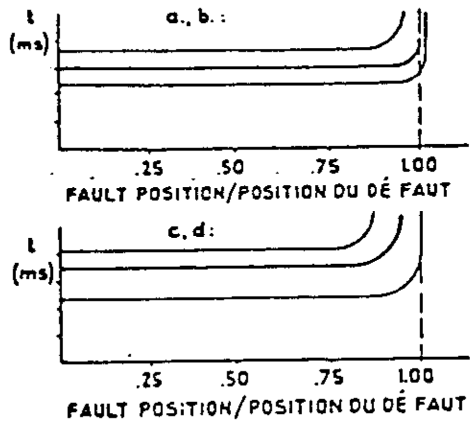
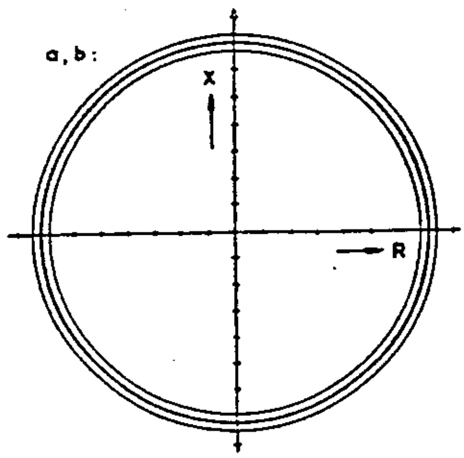
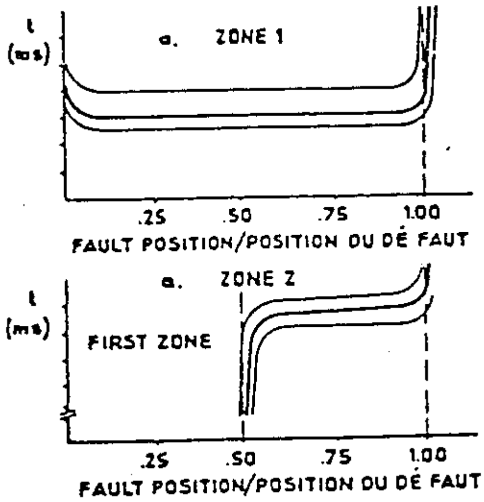
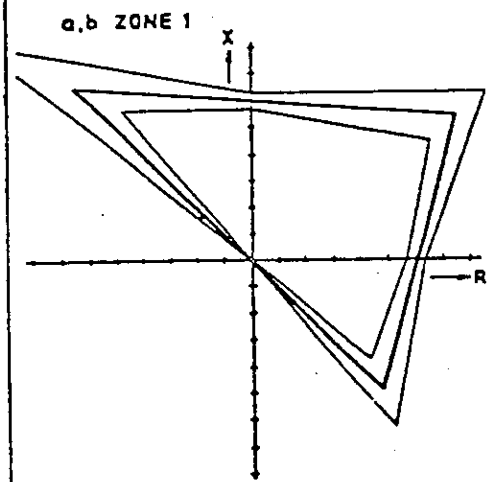
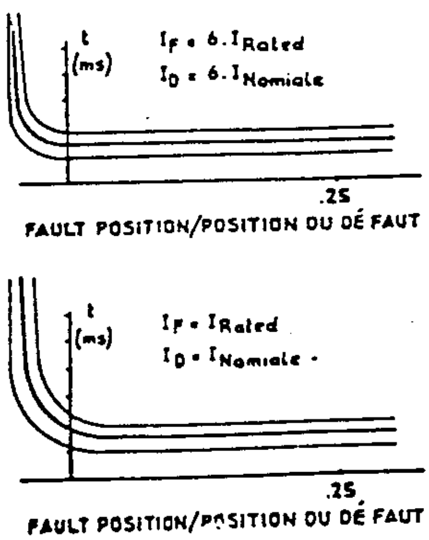
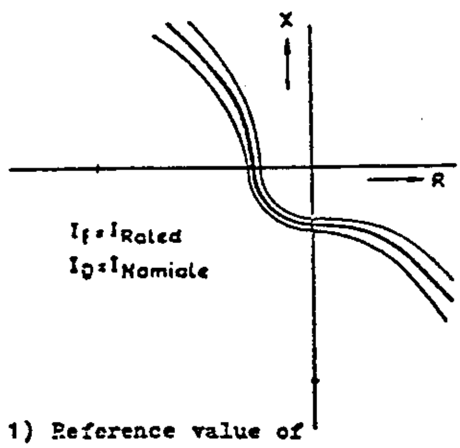


Figure 2-b Test schemes for double-source tests

Figure 2-C Examples of presentation

Unit and kind of fault (a .. d)	Charateristics and limiting errors [1] Operating times	 Reach
Start unit(s) a. phase - phase b. three phase c. phase - ground d. simultaneous ground faults	Examples: 	Examples: 
Measuring unit(s) a. phase - phase b. three phase c. phase - ground d. simultaneous ground faults		
Measuring unit(s) Directional sensitivity a. $I_{Fault} = I_{rated}$ b. $= 6.I_{rated}$		 1) Reference value of fault incidence angle (deg) Test tolerances +,-(deg)

Type tests for distance relays

List of tables

Influencing quantities or factors	2.1	
Tests in steady-state conditions	2.2-a	2.2-b
Tests in dynamic conditions		
- single-source dynamic tests	2.3-a	2.3-b
- double-source dynamic tests	2.4-a	2.4-b
Tests with auxiliary equipment		
- auto-recloser	2.5-a	
- power swing blocking unit	2.5-b	
- fuse failure unit	2.5-c	
- communication equipment (two distance relays)	2.5-d	
Estimated number of tests	2.6	

Comments:

n Estimated number of tests.

x Observation during tests.

ж Number of tests not indicated; no teststandards available.

In the tables 2.4 and 2.5 Z_L indicates the line impedance. The first zone setting is supposed to be 0.85 Z_L. The fault position is indicated as a part of Z_L (e.g. 0.8 Z_{L1} fault at 80% of line 1). The relay under test is placed in line 1 at station A.

1) Max. harmonic distortion of currents in inductive circuits: 5% divided by the rank of harmonic. With synthetic tests current and voltage sources cannot be independent. Alternatively tests can be made with frequencies slightly different from harmonic frequencies (e.g. 2.01, 2.99... times f_N) and with frequencies between multiples of the fundamental frequency (e.g. 2.5, 3.5, .. times f_N)

2) Fault current and source impedance are not independent of each other.

3) Measurements are only necessary if the internal D.C. voltages are not independent of the stated variations of the input auxiliary voltage. In the number of tests, they are not taken into account.

4) Two different types: short circuited and open circuited. Duration of interruptions: refer to manufacturers specification.

5) Upper and lower operating limits in longitudinal mode (class III - 2.5 kV) for each independent circuit (current, voltage, D.C. voltage, input circuit, auxiliary and tripping circuits) and between independent circuits. Upper and lower operating limits in transverse mode (class III - 1 kV) between terminals of the same circuit. IEC 255-6 Appendix C. Identical circuits (e.g. current inputs) are not systematically tested, but connected at random.

6) Reference settings (tables 2.2 and 2.3) may be indicated by the manufacturer. Otherwise an appropriate value is chosen, e.g. geometric middle of the setting range. An example for the settings is given below.

Influencing quantities or factors		Typical reference conditions	Typical ranges (values proposed by WG 34-04)
Ambient temperature		20° C (± 2°C)	- 5° C... + 40° C (+ 55°C)
Relative humidity		45 % to 75 %	-
d.c. auxiliary voltage	voltage	U_N (± 2 %)	80 % U_N ... 110 % U_N
	ripple	zero (3 % peak value)	0 ... 12 % peak-to-peak
	short interruptions	uninterrupted	2 ms ... 200 ms 4)
H.F. disturbances 5)		no disturbances	1 kV/2.5 kV - 1 MHz - 200 Ω serie/common mode current/D.C.circuit
Electromagnetic field susceptibility		no disturbances	under consideration (IEC)
Relay setting 6)		reference setting (*)	setting range (*)
Source e.m.f's	frequency	f_N (± 0.5 %)	94 % .... 102 % f_N
	waveform	sinusoidal (total harmonic distortion ≤ 2 % 1)	5 % 3rd and 5th harm. 3 phase positions
Source impedance or current 2)	impedance	reference value	Min ... Max
	time constant	50 ms (± 5 ms)	10 ... 150 ms
Line	capacitance	Zero	π-cells representation (fig 1-c)
	frequency of line oscillations	no oscillations	Max 1 ... 3 kHz
Current transformers	remanence factor	Zero	0 ... 0.8
	knee-point voltage	no transient saturation	5 ... 1, 200 times internal e.m.f. at rated current
	secondary time constant	> 10 sec	unsaturated : 50 ms ... 100 sec fully saturated : 0.2 ... 3 ms
Voltage transformers	remanence factor	Zero	0 ... 0.8
	knee-point voltage	no transient saturation	U_N ... 2 U_N
	capacitor voltage transformer	not represented	typical CVT model (fig 1-d)
Faults	impedance	Zero	- 0...max. - trapezoidal representation of arc voltage (fig 1-e)
	fault types	single-phase-to-ground two-phase two-phase-to-ground three-phase no fault	evolving faults (e.g. R - N → R - S - N) complex faults
Initial conditions	initial voltage	U_N	0 ... U_N
	initial load current	Zero for single-source dynamic tests	0 ... I_N/line (double source tests)
	initial point-on-wave	0	0 ... 180° in steps of 10...30°
Circuit-breaker operation	at closing	simultaneous pole operation	0...10 ms between pole operation
	at tripping	current interruption at natural zero crossings	-

Table 2.1 Reference conditions and range of influencing quantities and factors

Distance relay

(*) See also page 24 a

Example of conditions and settings (1 A relay)

	Typical Reference conditions		Typical range	
Settings for the 1st zone (Z1)	2 ohm/ph	20 ohm/ph	minimum e.g. 0.2 ohm/ph	maximum e.g. 60 ohm/ph
Setting for the				
- acceleration zone	1.5 Z1			
- second zone	2 Z1			
- third zone	>2 Z1			
- starting elements	>10 Z1	>2 Z1		
Current range	1...10 I_N	0.25..1 I_N	0.25...40 I_N	
Source impedance (time constant)	50 ms		10...150 ms	
Line impedance (time constant)	35 ms		10...60 ms	
Zero sequence impedance				
- line	4 times the positive seq. imp.		2...10 times the positive seq.imp.	
- source	1 times the positive seq. imp.		0.5...4 times the positive seq.imp.	
- time constant	same as the positive seq. imp.		1...40 ms	
R/X ratio	1		minimum	maximum

Notes: 1 For the reference tests with ca. 2 I_N the setting Z1 = 2 ohm/ph is necessary; 0.5 I_N for Z1 = 20 ohm/ph.

2 For tests under reference conditions some additional tests may be done with other settings of Z .

3 If the ratio R/X can be adjusted, some tests should be made with other settings. This applies only for tests with fault resistance.

OBJECT OF TESTS	TEST CONDITIONS	n
Operating characteristics of starting units (impedance starting units)	reference characteristic (most appropriate fault at reference setting and $I = 2\ I_N$): 12 points from 0 to 360° in steps of 30°	12
	other characteristics: 3 settings (max, min, ref) and 6 types of faults: 2 points (phase position)	36
Returning values of starting units	per type of unit, 3 setting values	3
Operating characteristics of measuring units	Zone I: similar tests as for starting units	48
	other zones (with similar measuring principle)	8
Accuracy of timing units	3 timing units at 3 setting values	9
Relay logic (starting, phase selection, etc.)	verification during other tests	-
Indications and output contacts	verification during other tests	-
Power consumption a-c current/a-c voltage/d-c auxiliary circuits	at rated a-c currents and voltages: no fault, R-N fault, R-S fault, R-S-T fault, R-S-N fault	5
	at 2 I_N: R-N fault, R-S fault, R-S-T fault, R-S-N fault	4
		125

Table 2.2-a Tests in steady-state conditions

Distance relay

Object of tests	Ambient temperature 5°C/+40°C	n	D.C. auxiliary voltage 80/110% U_N	n	ripple 12%	n	short interruptions (2 durations) 4)	n	Fault current 0,25-0,5-1-5 - 10 I_N 2)	n	Measuring frequency 94/102% f_N	n	Harmonic components 3rd 5% 5th 5%	n	H.F. Disturbance tests 1MHz, 200Ω 5)	n	Electromagnetic field (susceptibility)	n
Characteristics of starting units - reference setting	12 points	24	3)	-	3)	-	2 points	8	4 points	20	12 points	24	6 points 3 harmonic phase pos.	36	2 points upper/lower, limit	108	*	-
Characteristics of measuring units - reference setting	12 points	24	3)	-	3)	-	2 points	8	4 points	20	12 points	24	idem	36	idem	108	*	-
- min setting	12 points	24						-		-		-		-		-		
Time units - reference setting	1 point	2	3)	-	3)	-	1 point	4	-	-	-	-	-	-	x	-	-	-
- max setting	1 point	2	3)	-	3)	-	-	-	-	-	-	-	-	-	-	-	-	-
Returning value - reference setting	1 point	2	3)	-	3)	-	1 point	4	1 point	5	1 point	2	3 harmonic phase pos.	6	x	-	*	-
Relay logic	x	-	3)	-	3)	-	x	-	x	-	-	-	-	-	x	-	x	-
Indications and output contacts	x	-	3)	-	3)	-	x	-	x	-	x	-	x	-	x	-	x	-
Power consumption: D.C.	RN, RS, RSN, RST, no fault	10	RN, RS, RSN, RST no fault	10	3)	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of tests		88		10		0		24		45		50		78		216		-
																		511

Table 2.2-b Tests in steady-state conditions
Distance relay

OBJECT OF TESTS	TEST CONDITIONS	n
Dynamic accuracy of starting units	6 points in first/third quadrants 3 settings (ref, max, min) 2 limits (e.g. 95%-105% of setting)	72
Dynamic accuracy of measuring units	6 points in first quadrant 3 settings, 2 limits	36
Directional sensitivity	Determination of minimum residual voltage at which the relay gives or does not give a tripping command. 3 settings, 2 fault positions, 2 limits	12
Operating times of starting units	3 settings, 3 fault positions for each type of unit (e.g. 0%, 50% and 80% of claimed starting unit reach)	9
Operating times of distance relays	Zone 1: - 3 settings, 4 fault types, 3 fault positions (e.g. 0, 50, 80% of zone 1 reach)	36
	Zone 2: - 1 setting, 1 fault type, 1 fault position (e.g. 80% of zone 2 reach)	1
	Zone 3: - 1 setting, 1 fault type, 1 fault position (e.g. 80% of zone 3 reach)	1
Resetting times	3 settings, 3 fault types, starting units and trip commands	18
Relay logic	Verification during other tests	-
Indications and output contacts	Verification during other tests	-
		185

Table 2.3-a Single-source dynamic tests
Distance relay

Object of tests	Ambient temperature -5°C/+40°C	n	D.C. auxiliary voltage: 80/110% U_N	n	ripple 12%	n	short interruptions (2 dur.) 4)	n	AC Source: Source impedance (SI)	n	time constant 10/150 ms	n	frequency 94%/102% f_N	n
Dynamic accuracy of starting units - reference setting	-	-	3)	-	3)	-	-	-	2 SI values, 2 phase pos., 2 limits of operation, 3 fault types	24	2 phase pos., 3 fault types 2 limits	24	-	-
- min setting	-	-	3)	-	3)	-	-	-	idem	24	-	-	-	-
Dynamic accuracy of measuring unit - reference setting	-	-	3)	-	3)	-	-	-	idem with 3 SI values	36	-	-	-	-
- min. setting	-	-	3)	-	3)	-	-	-	idem with 3 SI values	36	2 phase pos. 3 fault types 2 limits	24	-	-
Directional sensitivity - reference setting	2 fault pos. 3 fault types	6	3)	-	3)	-	-	-	2 SI values, 2 fault pos., 3 fault types	12	2 fault pos. 3 fault types	12	2 fault pos. 3 fault types	12
- min. settings	idem	6	3)	-	3)	-	-	-	idem	12	idem	12	idem	12

Table 2.3 - b Single-source dynamic tests

Distance relay

Object of tests	Ambient temperature -5°C/+40°C	n	D.C. auxiliary voltage: 80/110% U_N	n	ripple 12%	n	interruptions (2 dur.) 4)	n	AC Source: Source impedance (SI)	n	time constant 10/150 ms	n	frequency 94%/102% f_N	n
Operating times of starting units - reference setting	2 fault pos. 3 fault typ.	6	3)	-	3)	-	2 fault pos.	8	-	-	-	-	1 fault pos	2
- min/max settings	idem	6	3)	-	3)	-	-	-	2 SI values, 2 fault pos., 3 fault types	24	-	-	-	-
Tripping times - reference setting	2 fault pos. 3 fault typ.	6	3)	-	3)	-	2 fault pos.	8	3 SI values, 4 fault pos., 3 fault types, 1 line angle	36	2 fault pos. 3 fault typ.	12	1 fault pos	2
- min/max settings	idem with min setting	6	3)	-	3)	-	-	-	idem	36	-	-	-	-
Resetting times - reference setting	1 fault pos. 3 fault typ.	6	3)	-.	3)	-	1 fault pos.	4	2 SI values, 3 fault types, 1 fault pos.	6	3 fault types	6	-	-
Relay logic Indications and output contacts	x x	- -	3) 3)	- -	3) 3)	- -	x x	- -	x x	- -	x x	- -	- -	
Number of tests		42		0		0		20		246		90		28
														426

Table 2.3 - b (continued)

Object of tests	Trapezoïdal arc representation (Fig. 1-e)	n	Evolving faults (2 time delays)	n	Initial conditions (voltage)	n	CT-transients	n	VT/CVT-transients	n	Line-transients	n	Circuit breaker operation	n
Dynamic accuracy of starting units - reference setting	-		-		*		*		*		*		*	
- min setting	-		-		-		-		-		-		-	
Dynamic accuracy of measuring unit - reference setting	*		*		*		*		*		*		-	
- min setting	-		-		-		*		*		-		-	
Directional sensitivity - reference setting	*		*		*		*		*		*		-	
- min settings	-		-		-		*		*		-		-	

Table 2.3 - b (continued)

Object of tests	Trapezoïdal arc representation (Fig. 1-e)	n	Evolving faults (2 time delays)	n	Initial conditions (voltage)	n	CT-transients	n	VT/CVT-transients	n	Line-transients	n	Circuit breaker operation	n
Operation times of starting units - reference setting	-		-		*		*		*		*		-	
- min/max settings	-		-		-		*		*		-		-	
Tripping times - reference setting	*		*		*		*		*		*		*	
- min/max settings	-		-		-						-		-	
Resetting times - reference setting	-		-		-		-		*		*		*	
Relay logic Indications and output contacts	x x		x x		x x		x x		x x		x x		x x	

Table 2.3 - b (continued)

Object of tests	Scheme (Fig.2-b)	Fault position	Test conditions	n
Correct operation with internal fault:			4 fault types, 3 loads (0, both directions)	
- tripping time	I	0; 0.68 Z_{L1}	2 fault positions	24
- accuracy	I	0.8; 0.9 Z_{L1}	2 fault positions	24
Correct operation with external fault (stability)	I	0 Z_{L2}	4 fault types, 2 load directions, 1 fault position	8
Fault clearance sequence on parallel line	II	0 Z_{L2}; 1 Z_{L2}	4 fault types, 2 load directions, 2 fault positions on the parallel line.. Different breaker times on the parallel line (breaker A/B: 100-40 ms resp. 40-100 ms)	32
Fault with change of S.I.R.	II	0.4 Z_{L1}; 1 Z_{L1}	breaker in B-L_1 opens 40...100 ms after fault inception 1 fault type, 2 load directions, 2 fault positions	4
				92

Table 2.4-a Double-source dynamic tests

Object of tests	Scheme (Fig.2-b)	Fault position	Test conditions	n
Influence of the fault resistance:				
- limit of fault resistance	I	0.1; 0.68; 0.85 Z_{L1}	4 fault types, 3 loads, 3 fault positions, 2 limits of operation	72
- directional sensitivity	I	0 Z_{L1}; 0 Z_{L2}	4 fault types, 3 loads, 2 fault positions, 2 limits of operation (residual impedance to be measured)	48
Correct behaviour with evolving fault	I	0.4 Z_{L1}; 0 Z_{L2}	single phase fault evolving to two phase to earth fault, 2 time values, 2 fault positions, 2 load directions	8
Different times of breaker poles	I	0.4 Z_{L1}; without faults	switching on (three phases) with 2 different pole times (0...10 ms) 2 fault positions, 2 load directions	8
				136

Table 2.4-b Double-source dynamic tests
Distance relay

Object of the tests	Scheme (Fig.2-b)	Fault position	Fault condition	n
Correct operation	I	0,4 Z_{L1}	4 fault types, 2 load directions, with and without resistance, 1 fault position	16
Directional sensitivity	I	0...0,1 Z_{L2};	Auto-reclosing on L_1 4 fault types, 2 load directions, with and without resistance, fault positions Residual voltage or fault impedance to be measured	16
Stability test	II	0 Z_{L2}; 1 Z_{L2}	Auto-reclosing on L_2 4 fault types, 2 load directions, 2 fault positions, with and without resistance	32
Faults during single phase auto-reclosing dead time	I	0...0,1 Z_{L1}; 0,4 Z_{L1}	Auto-reclosing on L_1 Faults on other phases on L_1 4 fault types, 2 load directions, 2 fault positions, with and without resistance	32
Faults during auto-reclosing dead time	II	0,4 Z_{L1}	Auto-reclosing on L_2 (fault on L_2, fault clearance, L_2 auto-reclosure dead time, fault on L_1, L_1 auto-reclosure dead time, L_2 reclosure, L_1 reclosure) 4 fault types, 2 load directions, 1 fault position, without resistance	8
				104

Table 2.5-a Tests with auto-recloser

Object of Tests	Scheme (Fig.2-b)	Fault position	Fault condition	n
Pole slipping test	I		Electrical centre in the middle of the first zone. The range of the power swing frequencies is to be determined where the power-swing-blocking-relay works correctly and where the operation of the relay is limited 3 frequencies	3
Pole slipping due to a fault	I	on L_2	RN (including auto-reclosing sequence, permanent fault or not), RS, ST, TR. RSN, STN, TRN, RST	9
	II	on L_2	RN, RS, ST, TR, RSN, STN, TRN	7
				19

Table 2.5-b Tests with power swing blocking unit
Distance relay

Object of the tests	n
- Short circuit or interruption on one or on three phases (included behaviour of the auxiliary equipment at short circuit in the wiring) n: short ciruit / interruption 2 one phase / three phase 2 with and without load current 3 (both directions)	12
- Behaviour of the equipment with short-circuit in the network: 4 type of faults, 3 fault positions (0; 0.4; 0.85 Z_{L1} Scheme I)	12
- Behaviour at auto-reclosing - one phase auto-reclosing, with load current (both directions) permanent or not permanent fault	4
- short-circuit during the dead time (short circuit in the network or in the wiring) 4 fault types/short circuit or interruption in the wiring	8
	36

Table 2.5-c Tests with fuse failure unit
Distance relay

Object of the tests	Scheme (Fig.2.2)	Fault position	Fault condition	n
Functional control	I	0,4 Z_{L1} 1 Z_{L1}	4 fault types, 2 fault positions, 2 load directions, communication link (2 times and out of service), without fault resistance	48
Stability tests (Fault with change of energy direction)	II	1 Z_{L2}	Breaker in B-L_2 opens 40...100 ms after fault inception 2 different times, 3 load conditions (no load; A → B, B → A)	6
Functional control with auto-reclosing	I	0...0,1 Z_{L1} on L_2	Auto-reclosing on L_1 Auto-reclosing on L_2 4 fault types, 2 fault positions, 2 load directions, with and without fault resistance	32
Faults during auto-reclosing dead time	I	0,1-0,4 Z_{L1}	Auto-reclosing on L_1 fault on other phases on L_1 4 fault types, 2 fault positions, 2 load directions, without resistance	16
Faults during auto-reclosing dead time	II	0,4 Z_{L1}	Auto-reclosing on L_2 4 fault types, 2 load directions	8
				110

Table 2.5-d Tests for two distance relays with communication equipment (comparison or blocking schemes)

	n	Σn
Steady-state test		
Table 2.2-a	125	
Table 2.2-b		
- Temperature 88		
- D.C. auxiliary voltage 34		
- Fault current 45		
- Frequency 50		
- Harmonics 78		
- H.F. disturbance tests 216	511	636
Single-source dynamic tests		
Table 2.3-a	185	
Table 2.3-b		
- Temperature 42		
- D.C. auxiliary voltage 20		
- A.C. source 364	426	611
Double-source dynamic tests		
Table 2.4-a	92	
Table 2.4-b	136	228
Tests with auxiliary equipment		
Table 2.5-a (auto-recloser)	104	
Table 2.5-b (power swing blocking unit)	19	
Table 2.5.c (fuse failure unit)	36	
Table 2.5-d (communication equipment)	110	269
		1744

Table 2.6 Estimated number of tests

Distance relay

CHAPTER 3

FUNCTIONAL TESTS FOR CURRENT DIFFERENTIAL FEEDER PROTECTION

3.1 GENERAL

See chapter 1, § 1.1

1. The operating principle of a current differential feeder protection is based on the calculation of the differential current, i.e. the sum of the instantaneous current values as measured at each end of the protected feeder. To stabilise the protection and avoid unwanted tripping during external faults, when the CT's may be saturated, a low impedance biased differential operating principle is generally used. The stability is maintained for external faults by biasing the operating differential current with the through fault or load current. Figure 3.1.b shows the protection operating characteristic and the effect of the through current in restraining operation. The biased differential calculation can be performed on a single phase basis or alternatively use a combination value obtained by mixing the single phase quantities. If auxiliary CT's are incorporated into the protection for balancing the main CT ratio, these CT's must be included within the protection scheme.

2. This chapter describes the procedure and suggested programme for type testing current differential protection schemes for two terminal overhead lines or underground cables. It does not cover special applications e.g. shunt or series compensated lines. The steady state tests described in section 3.2 are designed to measure the accuracy, sensitivity and stability of the protection when energised with steady-state a.c. currents. The dynamic tests in section 3.3 and 3.4 are designed to measure the operating performance and stability when simulating internal and external faults on single and double source power system models. The dynamic tests in section 3.5 investigate the performance of the protection when used in conjunction with auxiliary equipment. Tables with examples of tests are presented and these may serve as a general guide for a type test programme.

3. Reference values and ranges of influencing quantities or factors, valid for the different tests, are given in table 3.1

4. The performance of the starting and measuring units in the protection relay must be checked individually. When however, the equipment contains one starting and/or measuring unit per phase, the complete tests need only to be performed on one of these units. The performance of the other units are verified during selected "typical" tests. If the three phase currents are combined in one measuring unit all types of faults (one phase-to-earth; two-phase with and without earth, three-phase) have to be simulated. The estimation of the number of tests suggested for the type test programme are based on a protection relay with a polyphase measuring unit.

3.2 STEADY STATE TESTS

3.2.1 Object

See chapter 1 § 1.2.1

1. These tests are intended to measure :

   - the operating characteristics and accuracy of the starting functions
   - the operating characteristics of the measuring units for internal faults with and without load current (sensitivity)
   - the operating characteristics of the measuring units with through fault current - external faults (stability characteristics)
   - the polar operating characteristics of the measuring units for internal faults with phase shifted load current (sensitivity)
   - the returning values of the starting functions

2. When the protection relay is equipped with optical indicators and/or an (automatic) test system, the correct behaviour of these facilities must be observed. The power consumption on a.c. current and d.c. auxiliary circuits are also measured.

3.2.2 Test procedures

See chapter 1, § 1.2.2

1. The operating and returning values of the starting units can be measured at 3 setting values (ref, min, max) by simulating the fault current and applying this to one end of the protection scheme whilst maintaining the other end open or unenergised. The test simulation is shown in figure 3-a, the load current $I_2 = 0$. The test is performed by applying the a.c. current (fault current) and varying the current slowly or in small steps without generating transients.

2. The sensitivity of the measuring unit with zero load current can be measured at 3 setting values (ref, min, max) and for 4 types of faults (single phase, phase-phase, phase-phase-ground, 3 phase). The test is performed as previously using the test simulation in figure 3-a and with the load current $I_2 = 0$.
   To select the faulted phase or phases to be involved in the test programme this test is initially performed at the reference setting for all 10 fault types. Based on the respective operating current values the winding configuration of the summation transformer can be determined.
   Polyphase Measuring Unit : subsequent tests are designed to involve the least sensitive winding for internal faults and the most sensitive winding for external faults.

3. The sensitivity of a measuring unit with load current can be measured by applying the fault and load current to one end of the protection and the load current to the other end. The test is performed as previously using the test simulation in figure 3-a with the load current I_2 in phase with the fault current. Figure 3-b shows a typical operating characteristic of a measuring unit in a low impedance, biased differential protection.

4. The stability characteristics of the measuring units can be measured by simulating the through "fault" current and applying this to both ends of the protection scheme. The test is performed as previously using the test simulation in figure 3-a.

5. The polar operating characteristics (sensitivity) can be measured by applying the fault current and the phase shifted load current to one end of the protection and the phase shifted load current to the other end. The test is performed as previously using the test simulation in figure 3-c with the fault current Id phase shifted with respect to the load current I_2. Figure 3-d shows a typical polar operating characteristics. The vector drawn from the point 1.0 on the horizontal axis to the boundary of the characteristic represents the ratio of fault to load ampere-turns on the summation transformer at an angle $\theta°$.

3.2.3 Test programme

An example of a steady state test programme is presented in table 3.1, parts a and b.

3.3 SINGLE SOURCE DYNAMIC TESTS

3.3.1 Object

See chapter 1 § 1.3.1

1. These tests are designed to investigate :

   - the dynamic accuracy of the starting units,
   - the sensitivity and operating time of the measuring units for an internal fault,
   - the stability of the measuring units for an external fault

   against a limited number of general influencing quantities or factors.

2. With appropriate models the following tests can also be defined :

   - the effect on the dynamical response of actual or simulated (typical or particular models) current Transformers (Appendix B.3.4),
   - the effect on the dynamic response of improved models of lines, faults etc.

3. The correct operation of internal logic (starting, phase selection, tripping etc.), indications output contacts, etc. are verified. The resetting time after fault clearance is measured.

3.3.2 Test procedures

See chapter 1, § 1.3.2

1. The dynamic accuracy of the current starting units can be measured at 3 setting values (ref, min, max). Two accuracy limits may be determined in the following way : - correct operation on an internal fault - no operation on an external fault

   when varying the initial point-on-wave from 0 to 180 degrees in steps of 10 degree. In table 3.3 (Single source dynamic tests) each of these limits is counted as one test result.

2. The sensitivity and operating times of the measuring units for an internal fault are measured in a similar way. The operating times are measured at 5 fault current values with no load current, inphase load current and phase shifted load current.

3. The stability of the measuring unit for an external fault is measured as previous with 4 through fault current values.

4. To test a line differential protection it is essential to consider the effect on the protection of saturation in the main and auxiliary CT's. This requires the correct reproduction of the saturated current as measured at the secondary of the auxiliary CT. To comply with this condition all dynamic tests must be performed with real auxiliary CT's or alternatively, when the protection is fed by amplifiers, realistic CT models may be used. These CT models must adequately represent the behaviour during saturation including the effect of remanence.

3.3.3 Test programme

An example of a single source dynamic test programme is presented in table 3.3. In general the dynamic test programme does not require a complete investigation into the effect of variations in all the influencing quantities or factors.
Dynamic tests with H.F. disturbances are often limited to a few points.
The effects of the harmonics and travelling waves should be examined as specific tests according to the actual power system.

3.4 DOUBLE-SOURCE DYNAMIC TESTS

3.4.1 Object

See chapter 1, § 1.4.1

Double source dynamic tests are not normally necessary, nevertheless in some applications these tests may be required. These tests are designed to investigate the effect of load current, evolving faults and changes in the source impedance on the sensitivity of the protection. The stability of the measuring units are also monitored during external faults on a parallel line, external faults with changes in the source impedance and fault clearance sequences. Double source dynamic tests may be valuable in determing the effect on the protection of the division of the line or cable capacitive current between ends of the protected feeder.

3.4.2 Test procedures

See chapter 1, § 1.4.2

The dynamic accuracy of the starting units and the sensitivity and stability of the measuring units are measured in the same manner as described in § 3.3.2.

3.4.3 Test programme

1. The tests are performed using one of the double source power system models shown in figure 2-b. Scheme I represents a single circuit line and scheme II represents a double circuit line with no mutual coupling between circuits. The same models of sources, lines, faults and current transformers can be used as for single source tests. The impedance values of the lines and sources are selected so that a phase shift of 30 degrees or 60 degrees between sources results in a load current of $1 \cdot I_n$ per line. Measurements are performed without load current and with load current flowing in both directions. Particular examples of tests are given in table 3.4.

2. The tests are performed with a limited number of influencing factors that have a particular incluence on the performance.

3.5 TESTS WITH AUXILIARY FUNCTIONS

Table 3.5 provides an example of a dynamic test programme for a feeder differential protection with auto-reclosing equipment.

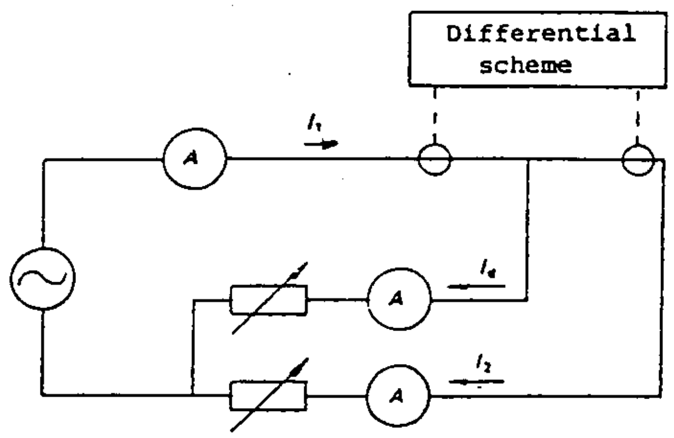


Figure 3 — a. Test simulation to measure operating characteristic and stability characteristics.

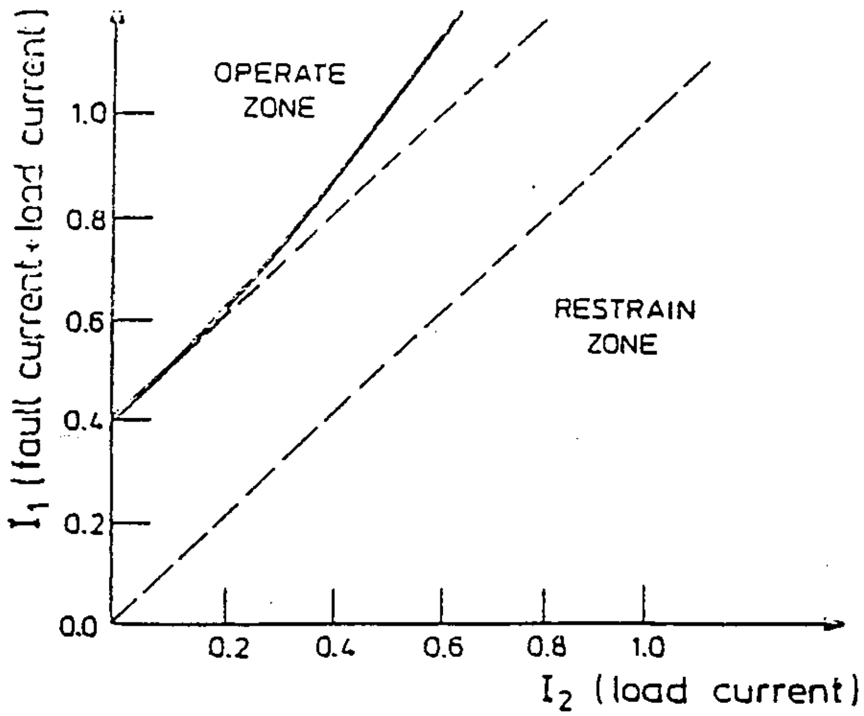


Figure 3 — b. Typical operating characteristic (load bias curve)

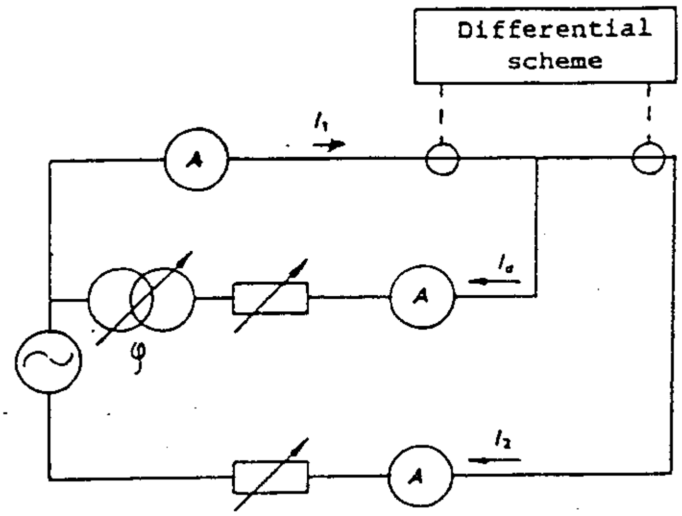


Figure 3 — c. Test simulation to measure polar characteristic.

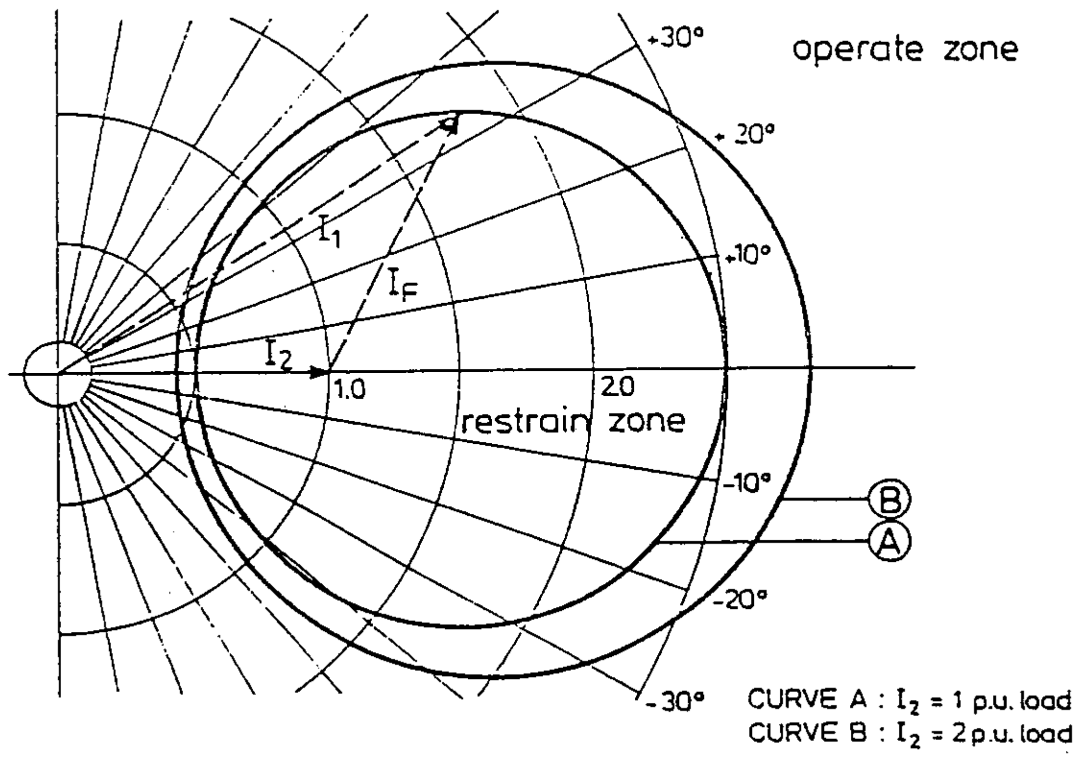


Figure 3 — d. Typical polar characteristic.

LIST OF TABLES

Influencing quantities or factors	3.1	
Tests in steady state conditions	3.2.a.	3.2.b.
Single source dynamic tests	3.3.a.	3.3.b.
Double source dynamic tests	3.4	
Tests with auto-recloser	3.5	
Estimated number of tests	3.6	

Comments

n Estimated number of tests.

X Observation during tests.

* Number of tests not indicated ; no test standards available.

1) Measurements are only necessary if the internal d.c. voltages are not independent of the stated variations of the input auxiliary voltage. In the number of tests, they are not taken into account.

2) Two different types of interruptions : short circuited and open circuited. Duration of interruptions refer to manufacturer specification.

3) For each test two limits are determined by varying the point on wave (0^o, 10^o ..... 180^o) :

   - upper limit : 0 operations out of N tests
   - lower limit : N operations out of N tests

   In the tables each of these limits is counted as one test result.

4) The point on wave is varied 0^o, 10^o ..... 180^o (1 test result).

5) Upper/lower operation limits in series/common mode for each independent circuit (current, D.C. voltage, channel input, channel output, auxiliary and tripping circuits) and between independent circuits, Identical circuits (e.g. current inputs) are not systematically tested but connected at random.
   High frequency disturbance test conforms to IEC 255 - 6 - Appendix C.

6) Maximum time constant as indicated by the manufacturer ; at least 100 ms.

7) The tests are repeated for each type of CT. The influence of CT saturation must be investigated.

8) The tests are repeated for each type of line.

9) The tests are performed using three different "pilot wire" line characteristics (RC values).

10) For a polyphase measuring unit, the test is performed at reference setting with all 10 fault types to determine the winding configuration of the summation transformer. Subsequently a test involving a single phase fault is applied to the least sensitive winding for internal faults and the most sensitive winding for external fault.

Influencing quantities or factors		Typical reference conditions (proposed by WG34-04)	Typical ranges (proposed by WG34-04)
Ambient temperature		20°C (± 2°C)	- 5°C to + 40°C (+ 55°C)
Relative humidity		45% to 75%	—
D.C. Auxiliary Source	Voltage Ripple Short interruptions	U_N (± 2%) zero (3% peak value) uninterrupted	80% U_N ...... 110% U_N 0 ..... 12% peak to peak 2 ms ..... 200 ms 2)
H.F. disturbances 5)		No disturbances	1kV/2.5kV -1MHZ - 200 Ω series/common mode current/D.C. circuit
Electromagnetic field susceptibility		No disturbances	Under consideration (IEC)
A.C. currents	Frequency Waveform Source time constant	f_n (± 0.5%) sinusoidal (total harmonic distortion < 2%) 50 ms (± 5 ms)	94% ...... 102% f_n 5% harmonics 3/5^n 3 phase positions 10 ms.... 150mS
Initial conditions	Initial current Initial point on wave	zero 0	I_N 0 ..... 180° in steps of 10 .... 30°
Line model or cable model	Capacitance Frequency of line oscillations	zero no oscillations	π cell representation (figure 1 - c) max 1 ..... 3KHZ
Current Transformer Model	Remanence factor Knee point voltage Secondary time constant Secondary burden angle	ideal performance 0 no transient saturation ≥ 10 sec 0°	0 ..... 0.8 5 .... 1200 times internal emf at rated current unsaturated: 50 ms... 100 s fully saturated: 0.2...3 ms 0...45°
Faults	Fault types	Single phase-to-ground two phase two-phase-to-ground three phase no fault	evolving faults (e.g. R-N → R-S-N) complex faults
Circuit Breaker Operation	At closing At tripping	Simultaneous pole operation Current interruption at natural zero crossing	0.... 10 ms between pole operation -
Pilot wires	Resistance and Capacitance	zero	0 ..... max
Transmission Links	Attenuation and Time delay	zero	0 ..... max
Relay setting		Reference setting	Setting range

TABLE 3.1 REFERENCE CONDITIONS AND RAGE OF INFLUENCING QUANTITIES AND FACTORS LIN DIFFERENTIAL PROTECTION

OBJECT OF TESTS	TEST CONDITIONS	n
Operating and returning values of (current) starting units	3 settings : ref, max, min	6
Sensitivity of measuring units (internal fault)	1 setting : ref 10) 10 fault types :	10
- I_2 = 0	3 settings : ref, max, min 4 fault types fig. 3 - a.	12
- I_2 in phase	1 setting : ref 5 current values I_2 =0.2 I_N, 0.4 I_N...1 I_N 4 fault types fig. 3 - a.	20
- I_2 phase shifted	1 setting : ref 1 fault type : R-S-T 2 current values I_2=1 I_N, 2 I_N $\varphi = 0^\circ \ldots 360^\circ$ in steps of 30° fig. 3 - c.	24
(I_2 = load current)	2 settings : max, min 1 fault type : R-S-T 1 current value I_2 = 1 I_N φ : 0°, 90°, 180°, 270° fig. 3 - c.	8
Stability characteristics (external fault)	1 setting : ref 4 fault types 5 current values I_2 =0.5 I_N, 1 I_N, 5 I_N, 10 I_N, 20 I_N fig. 3 - a.	20
Indications and output contacts	verification during other tests	-
Power consumption d.c. auxiliary supply and a.c. currents	at rated current: no fault, R-N fault, R-S fault, R-S-N fault, R-S-T fault	5
	at 2 I_N: R-N fault, R-S fault, R-S-N fault, R-S-T fault	4
		109

Table 3.2.a. Tests in steady - state conditions line differential protection

OBJECT OF TESTS	Ambient Temperature -5°C / +40°C	n	D.C. auxiliary voltage 80/110% U_N 1)	n	ripple 12% 1)	n	short interruptions (2 durations) 2)	n	Measuring frequency 94/102% f_N	n	Harmonic components 3rd 5th 5% 5%	n	H.F. Disturbance tests 1 MHz, 200 5)	n	Communication Channel: 3 different line characteristics + out of service 9)	n	Communication Channel: inductive coupling (f_N)	n	Electromagnetic fields susceptibility	n
Operating and returning values of (current) starting units reference setting	1 point	4	–		–		1 point	4	1 point	4	3 harmonic phase positions	12	1 point	54	–		–		*	–
Sensitivity (internal fault) - I_2 = 0, ref. setting	4 faults	8	–		–		1 fault	4	1 fault	2	1 fault 3 harmonic phase pos.	6	1 fault	54	4 faults	16	4 faults	4	*	–
- I_2 in phase ref. setting	1 fault 2 current values(I_2)	4	–		–		1 fault 2 current values (I_2)	8	1 fault 2 current values (I_2)	4	1 fault 3 harmonic phase pos. 2 curr.values	12	1 fault	54	–		–		*	–
other settings	1 fault 2 current values(I_2)	4	–		–		–		–		–		–		–		–			
-I_2 phase shifted, I_2 = 2I_N ref. setting	1 fault 4 angles (φ)	8	–		–		–		1 fault 4 angles (φ)	8	1 fault 3 harmonic phase pos. 4 angles (φ)	24	–		–		–		*	–
Stability (external fault) reference setting (through fault current)	4 faults 1 current value	8	–		–		1 fault 1 current value	4	1 fault 1 current value	2	1 fault 1 current value 3 harmonic phase pos.	6	1 fault	54	4 faults 2 current values	32	4 faults 2 current values	8	*	–
min. setting	4 faults 1 current value	8	–		–		–		–		–		–		4 faults 2 current values	32	4 faults 2 current values	8	*	–
Indications and output contacts	x		–		–		x		x		x		x		x		x		*	
Power consumption for d.c. auxiliary supply	rated load 4 faults + no fault	10	rated load, 4 faults + no fault	10	–		–		–		–		x		–		–			
Number of tests		54		10		-		20		20		60		216		80		20		-

480

TABLE 3.2.b TESTS IN STEADY STATE CONDITIONS LINE DIFFERENTIAL PROTECTION

OBJECT OF TESTS	TEST CONDITIONS	n
Dynamic accuracy of (current) starting units 3)	3 settings : ref, max, min 2 limits	6
Sensitivity of measuring units (internal fault) 3) - $I_2 = 0$	3 settings : ref, max, min 4 fault types 2 limits	24
- I_2 in phase	1 setting : ref 3 load current values : $I_2 = 1I_N, 5I_N, I_{MAX}$ 4 fault types 2 limits	24
- I_2 phase shifted (I_2 = load current)	1 setting : ref 1 load current value : $I_2 = I_N$ 1 fault type 2 limits φ = 4 phase angles $(0^\circ, 90^\circ, 180^\circ, 270^\circ)$	8
Operating times of starting units 4)	1 setting : ref 5 current values : $I_1 = 1I_N, 2I_N, 5I_N, 10I_N, I_{MAX}$	5
Operating times of the relay 4) - $I_2 = 0$	3 settings : ref, max, min 4 fault types 5 current values : $I_1 = 1I_N, 2I_N, 5I_N, 10I_N, I_{MAX}$	60
- I_2 in phase	1 setting : ref 4 fault types 5 current values : $I_1 = 1I_N, 2I_N, 5I_N, 10I_N, I_{MAX}$ 3 load current values : $I_2 = 1I_N, 5I_N, I_{MAX}$	60
- I_2 phase shifted	1 setting : ref 1 load current value : $I_2 = I_N$ 1 fault type 2 limits φ = 4 phase angles $(0^\circ, 90^\circ, 180^\circ, 270^\circ)$	8
Resetting times	3 settings : ref, max, min 3 fault types starting units and composite relay	18
Stability (external fault)	1 setting : ref 4 fault types 5 current values : $1I_N, 2I_N, 5I_N, 10I_N$, I_{MAX} (through fault current)	20
Relay logic, indications and output contacts	verification during other tests	-
		233

TABLE 3.3.a Single source dynamic tests line differential protection

	Ambient temperature $-5^{o}C/+40^{o}C$	n	D.C. auxiliary voltage 80/110% U_N 1)	n	ripple 12% 1)	n	short interruptions (2 durations) 2)	n	A.C. Source measuring frequency 94/102% f_N	n	time constant 10/150ms 6)	n	Communication channel 3 different line characteristics + out of service 9)	n	inductive coupling (f_N)	n	CT models 7)	n	Line models 8)	n
Dynamic accuracy of (current) starting units reference setting 3)	–		–		–		–		–		1 setting 1 current value	2	–		–		–		–	
Sensitivity (internal fault) $-I_2 = 0$ 3)	4 faults 2 settings 2 current values (I_1)	32	–		–		–		–		4 faults 1 setting 2 current values	8	4 faults 1 setting 2 current values	32	4 faults 1 setting 2 current values	8	–		–	
Operating times of starting units $-I_2 = 0$ 4)	1 fault 1 setting 1 current value (I_1)	2	1 fault 1 setting 1 current value	2	–		1 fault 1 setting 1 current value	4	1 fault 1 setting 1 current value	2	1 fault 1 setting 5 current values	10	–		–		1 fault 2 settings 5 current values	10	1 fault 2 settings 5 current values	10
Operating times of the relay $-I_2 = 0$ 4)	4 faults 2 settings 2 current values (I_1)	32	1 fault 1 setting 1 current value	2	–		1 fault 1 setting 1 current value	4	1 fault 1 setting 1 current value	2	4 faults 1 setting 5 current values	40	4 faults 1 setting 2 current values	32	4 faults 1 setting 2 current values	8	1 fault 2 settings 5 current values	10	1 fault 2 settings 5 current values	10
$-I_2$ in phase ($I_2 = I_N$) (I_2 = load current)	4 faults 1 setting 2 current values (I_1)	16	–		–															
Resetting times $-I_2 = 0$	4 faults 1 setting 1 current value (I_1)	8	–		–		1 fault 1 setting 1 current value	4	–		4 faults 1 setting 5 current values	40	–		–		1 fault 2 settings 5 current values	10	1 fault 2 settings 5 current values	10
Stability (external fault)	–		–		–		–		–		4 faults 1 setting 5 current values	40	4 faults 1 setting 2 current values	32	4 faults 1 setting 2 current values	8	1 fault 2 settings 5 current values	40	1 fault 2 settings 5 current values	40
Relay logic indications and output contacts	x		–		–		x		–		x		x		x		–		–	
Number of tests		90		4				12		4		140		96		24		70		70	310

TABLE 3.3.b SINGLE SOURCE DYNAMIC TESTS LINE DIFFERENTIAL PROTECTION

OBJECT OF TESTS	TEST CONDITIONS	SCHEME	n
Starting units :	4 fault types, 3 loads (zero, both directions). 1 setting : ref	(fig 2-b)	
- transient accuracy	- 2 limits	I	24
- operating time	- 2 current values : $I_1 = 1I_N, 10I_N$		24
Measuring units :	4 fault types, 3 loads (zero, both directions). 1 setting : ref		
- sensitivity	- 2 limits	I	24
- operating time (internal fault)	- 2 current values : $I_1 = 1I_N, 10I_N$		24
Relay stability (external fault)	4 fault types, 2 load directions 1 setting : ref 2 current values : $1I_N$, $10I_N$ (through fault current) 2 fault positions : L2, L3	I	32
Fault clearance sequence on parallel line	4 fault types, 2 load directions 1 setting : ref 2 fault positions on parallel line Different breaker times on the parallel	II	32
Faults with change in source impedance	1 fault type, 2 load directions 1 setting : ref Breaker in B-L1 opens 40-100mS after fault inception 2 fault positions : L1, L2.	II	4
Correct behaviour with Evolving fault	single phase fault evolving to two phase to earth fault after 5 ... 50mS 2 time values, 2 fault positions 2 load directions	I	8
Simultaneous fault on parallel line	phase-phase fault involving L_1 and L_2 2 load directions.	II	2
			174

Table 3.4 Double source dynamic tests.
Line differential protection

OBJECT OF TESTS	TEST CONDITIONS	SCHEME	n
Functional control	4 fault types, 2 load directions 1 setting : ref 1 current value: $I_1 = 10I_N$	(fig 2-b) I	8
Sensitivity of measuring units (internal fault)	Auto - reclosing on L_1 4 fault types : 2 load directions 1 setting : ref 1 current value: $I_1 = 10I_N$	I	8
Stability (external fault)	Auto-reclosing on L_2 4 fault types, 2 load directions 1 setting : ref 1 current value: $10I_N$ (through fault current)	II	8
Faults during auto-reclosing dead time (internal fault)	Auto-reclosing on L_1 Faults on other phases on L_1 4 fault types, 2 load directions 1 setting:ref 1 current value: $I_1 = 10I_N$ (through fault current)	I	8
Faults during auto-reclosing dead time (external fault)	Auto-reclosing on L_2 Faults on other phases on L_2 4 fault types, 2 load directions 1 setting : ref 1 current value: $10I_N$ (through fault current)	II	8
			40

Table 3.5 Tests with auto - recloser.
line differential protection

		n	$\sum n$
STEADY-STATE TESTS			
Table 3.2 - part a		109	
Table 3.2 - part b			
- Temperature	54		
- DC auxiliary voltage	30		
- Frequency	20		
- Harmonics	60		
- H.F. disturbance tests	216		
- Communication channel	100		
- Electromagnetic fields	-	480	589
SINGLE-SOURCE DYNAMIC TESTS			
Table 3.3 - part a		233	
Table 3.3 - part b			
- Temperature	90		
- D.C. auxiliary voltage	16		
- A.C. source	144		
- Communication channel	120		
- CT models	70		
- line models	70	510	743
DOUBLE-SOURCE DYNAMIC TESTS			
Table 3.4		174	174
TESTS WITH AUXILIARY EQUIPMENT			
Table 3.5 (auto-recloser)		40	40
			1546

Table 3.6 Estimated number of tests

Line differential protection

CHAPTER 4

FUNCTIONAL TESTS FOR CURRENT DIFFERENTIAL BUSBAR PROTECTION

4.1 GENERAL

See chapter 1, § 1.1

1. The operational principle of a current differential busbar protection is based on the measurement of the differential current, this is the sum of the instantaneous current values at each feeder on the protected busbar. To avoid unwanted tripping when the CT's are saturated two main operating principles are used :

   - high impedance differential relays (biased or not),
   - low impedance differential relays (biased).

   In the first case stability is obtained by reducing the differential current during the saturation periods; in the latter case by stabilizing the relay when saturation occurs.

2. This chapter is relevant for both high impedance and low impedance differential protection relays. In a relay, the measurement can be made using either the current from each separate phase or alternatively using a combination value of current derived from all three phases.

   Especially for low impedance and biased high impedance relays the rated current values of the main current transformers can be different for each feeder. If intermediate (ratio compensating) current transformers are required, the rated current used to define the test conditions is the common rated value at the secondary side of the intermediate current transformers.

   The extent of the busbar protection depends on the busbar configuration. For the type tests, it is possible to choose a more simple scheme which nevertheless has to include the essential elements of the busbar : isolators, bus coupler, bus selection isolators and at least three feeders.

3. Reference conditions and ranges of influencing quantities are shown in table 4.1.
   If auxialiary CT's are used, all measurements will be made with the auxiliary CT's supplied by the relay manufacturer.

4. The measuring units will be checked individually. When, however, the equipment contains one measuring unit per phase, the complete tests need to be made on only one of these units. The performance of the other units may be verified during selected "typical" tests. The estimated number of tests is based on one measuring unit per phase.

   If the three phase currents are combined in one measuring unit, all types of faults (one phase, two phase with and without earth, three phase) will be simulated.

4.2 STEADY-STATE TESTS

4.2.1 Object

See chapter 1, § 1.2.1

1. These tests are intended to measure the operating and returning values of the starting units, the sensitivity of measuring units for internal faults, the stability characteristics of measuring units for external faults, the logic of the protection scheme for different busbar configurations and the AC and DC power consumption.

2. When the protection relay is equipped with an visual indication of the busbar configuration and with an (automatic) test system, the correct behaviour of these facilities must be observed.

4.2.2 Test procedures

See chapter 1, § 1.2.2

1. For both high and low impedance schemes the sensitivity of a measuring unit should be measured with the :

   - load current in phase with the fault current (figures 4-a and 4-d)
   - load current phase shifted with respect to the fault current "polar characteristics" (figures 4-b and 4-e).

2. For a high impedance scheme and the selected CT the maximum permissible value of the loop resistance at which the stability under external fault condition is maintained has to be checked (figure 4-c).

3. The busbar protection must give correct tripping commands for various internal fault positions and no tripping for external fault positions in all possible busbar configurations as illustrated in figure 4-f.

   The correct behaviour of the protection should be observed :

   - after each change of the busbar configuration (steady-state situation),
   - during the change from one configuration to another,
   - in the case of an incorrect configuration signal from the busbar system.

4.2.3 Test program

See particular examples in tables 42-a and 42-b.

4.3 Single-source dynamic tests

4.3.1 Object

See chapter 1, § 1.3.1.

These tests are mainly intended to measure the sensitivity and the operating time of the protection for an internal fault and to check its stability for an external fault.

4.3.2 Test procedures

See chapter 1, § 1.3.2.

1. For testing a busbar protection it is essential to incorporate either actual CT's or a realistic CT simulation. The latter must have the same dynamic properties as the actual CT, see Appendix B34.

   This means :

   - the form of the saturated current on the secondary side of the auxi liary CT's must be reproduced correctly,
   - when an interaction exists between the secondary sides of the CT's in different feeders, the secondary impedance of each CT must be reproduced correctly.

   To comply with these conditions all dynamic tests must be made with real auxiliary CT's. For reference tests the main CT's are assumed ideal. Real or models of the main CT's will be used for parametric tests.

   For low impedance scheme only, the CT's response can be simulated and the protection fed by amplifiers.

   In any case, the type of the CT's used (or simulated) for the tests must be indicated in the test report.

2. The basic scheme of testing is shown on figure 4-f, practical examples are represented in figure 4-g.

4.3.3 Test program

See particular examples in tables 43-a and 43-b.
Table 43-c gives some examples of particular or complex faults.
Dynamic tests with H.F. disturbances are often limited to a few points.

4.4 DOUBLE-SOURCE DYNAMIC TESTS

4.4.1 Object

See chapter 1 § 1.4.1

These tests are intended to verify the correct behaviour of the protection when the time constant and the phase angle of each source are not identical.

4.4.2 Test procedure

See chapter 1 § 1.4.2 and 4.3.2-1 of this chapter.

4.4.3 Test program

See particular examples in table 4.4

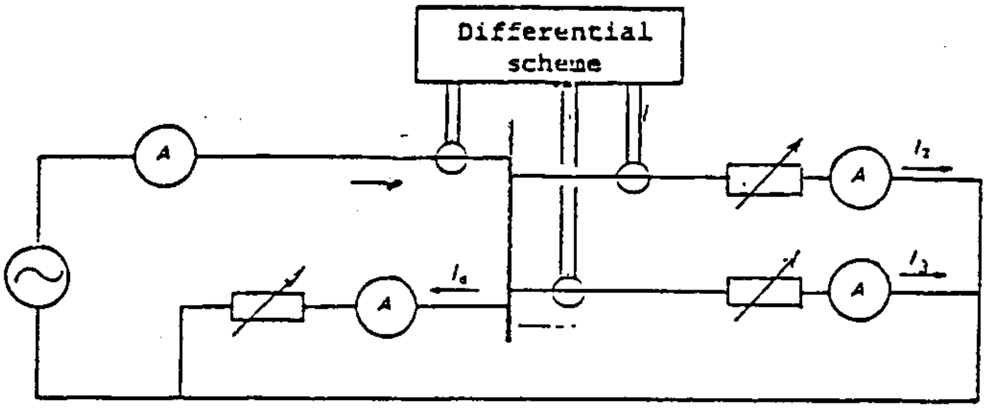


Fig.4 -. a Operating characteristic

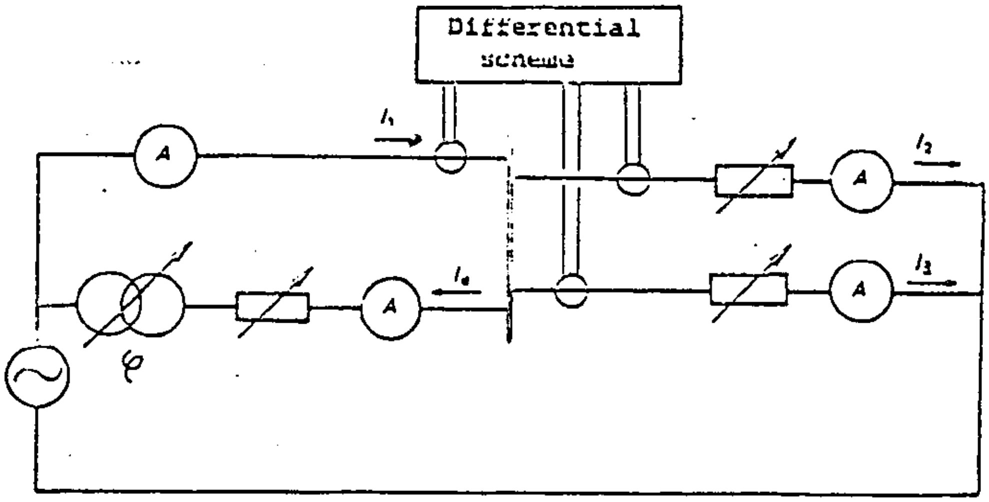


Fig 4 -. b Polar characteristic

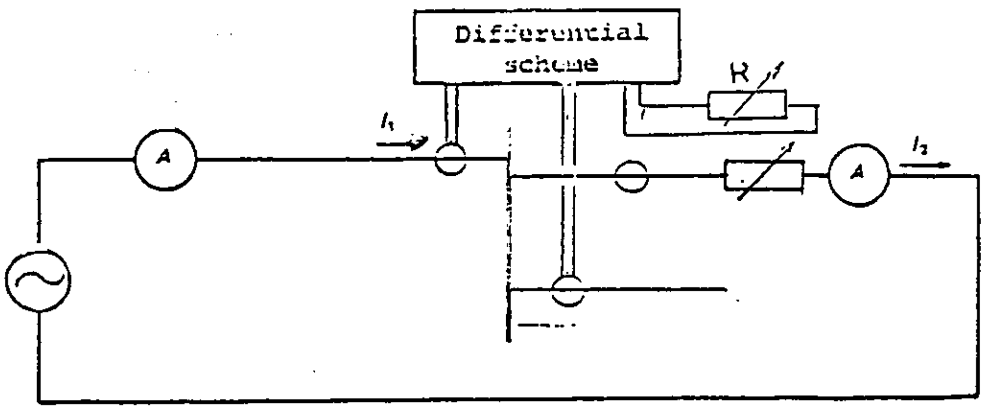


Fig 4 - c Stability characteristic
for high impedance scheme

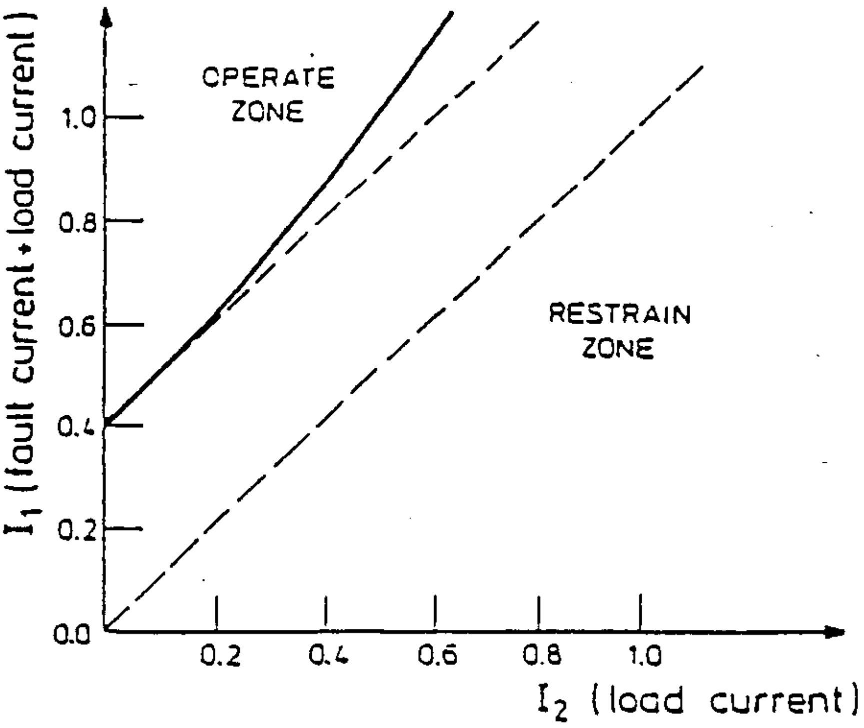


Fig 4 - d Typical load bias curve (I_3 = 0)

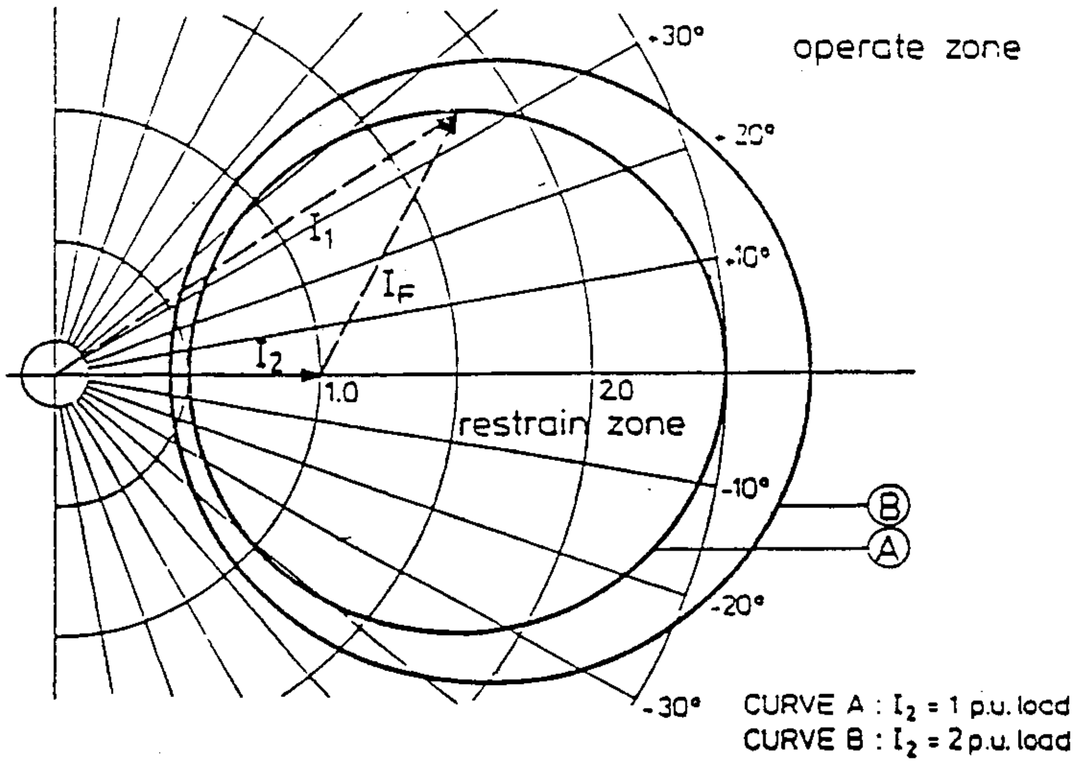
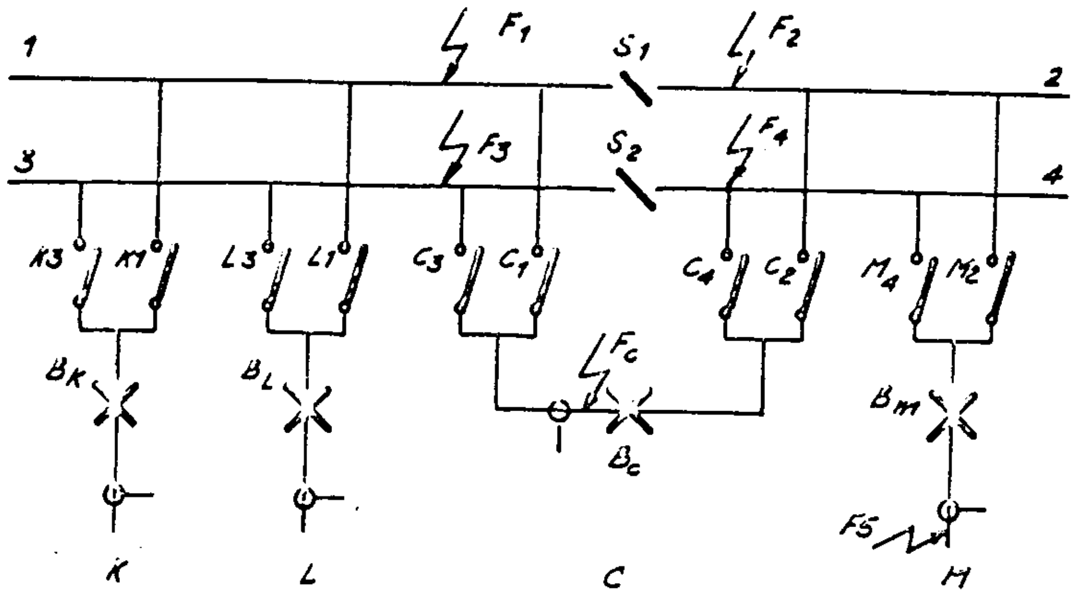


Fig 4. - e Typical polar characteristic (I_3 = 0)



1,2,3,4	busbar	$K_3 \ldots M_2$	isolators
K,L,M	feeders	B	breakers
C	bus coupler	O–	current transformers
S	bus section isolator	F	fault position

Fig.4.- f Typical multi-busbar model

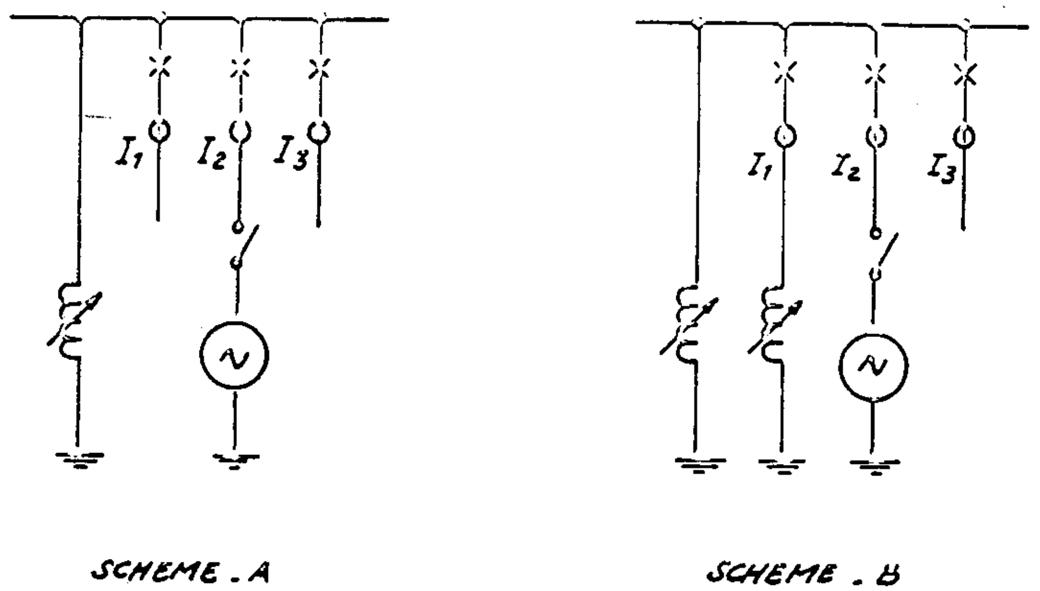


Fig 4. - g Dynamic test schemes

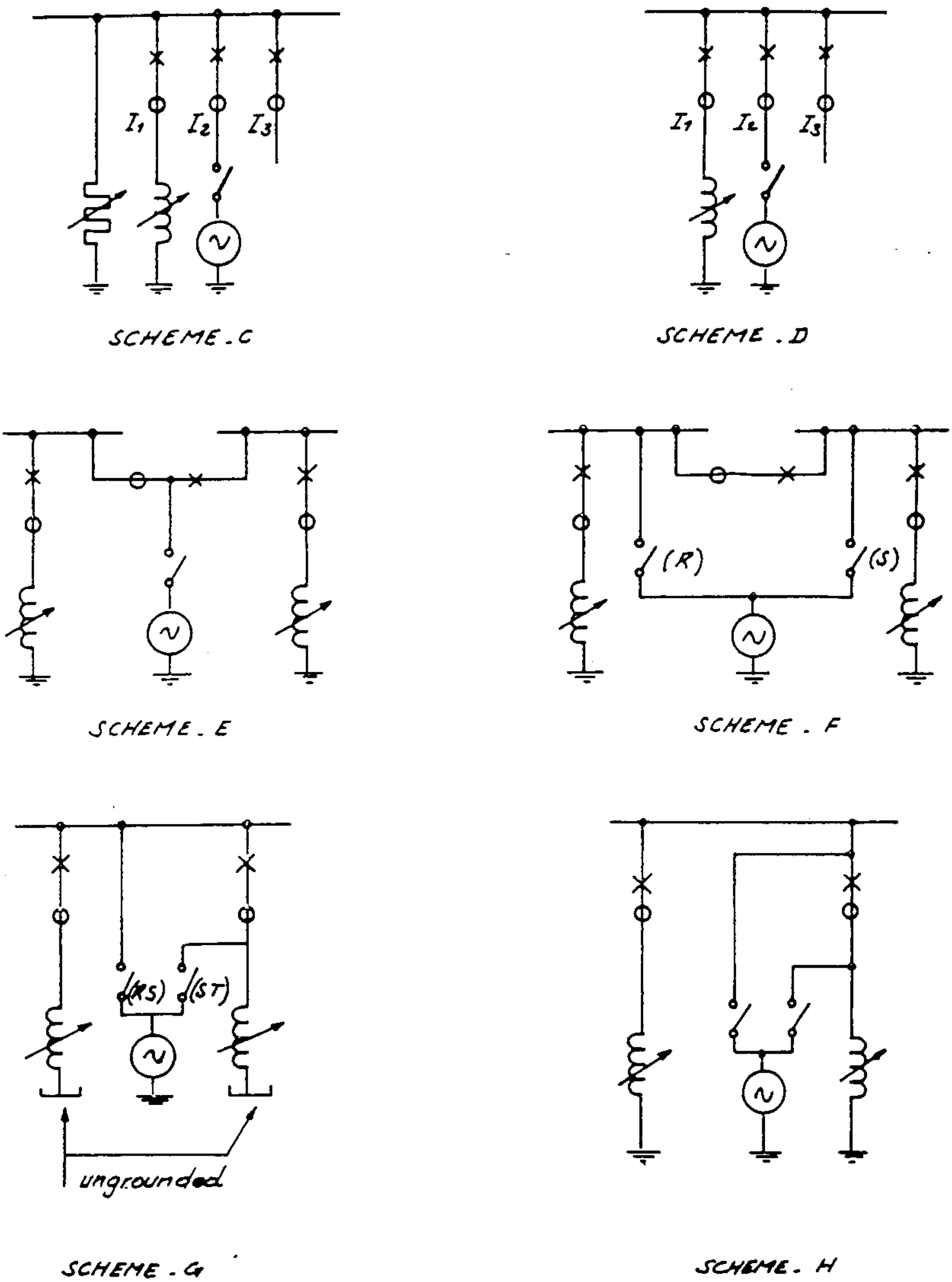


Fig 4 —g Dynamic test schemes (continued)

Functional tests for busbar current differential protection

List of tables -

Influencing quantities or factors	41		
Test in steady-state conditions	42-a	42-b	
Single source dynamic tests	43-a	43-b	43-c
Double source dynamic tests	44		
Estimated number of tests	46		

Comments

x Observation during the tests

1) Measurements are only necessary if the internal d.c.voltages are not independent of the stated variations of the input auxiliary voltage. In the number of tests, they are not taken into account.

2) Two different types of interruptions : short circuited and open circuited. Durations of interruptions refer to manufacturer specification.

3) For each test two limits are determined by varying the point-on-wave (0°, 10°...180°) :
   - normal operation (1 test result)
   - non operation (1 test result)

4) The point-on-wave is varied 0°, 10° ...180° (1 test result).

5) Upper/lower limits in serie/common mode for each independent circuit (current, D.C.voltage, input circuit, auxiliary and tripping circuits, for busbar protection : input circuits for the busbar replica) and between independent circuits. Identical circuits (e.g. current inputs) are not supplementically tested but connected at random.
HF disturbances test conforms to IEC-255-6 appendix C.

6) Maximum time-constant as indicated by the manufacturer ; at least 100 ms.

7) Only measurement of the busbar replica input (signal input) and the time delays.

8) Test of the configurations n° 1 to 19 of list.

9) The tests are repeated for each type of CT. The influence of CT-saturation must be investigated.

Influencing parameters	Reference conditions (1)	Range of influencing (*) parameters
Ambient temperature	20° C (± 2°C)	- 5° C... + 40° C (+ 55°C)
Relative humidity	45 % to 75 %	
d.c. auxiliary voltage — voltage	U_N (± 2 %)	80 % U_N ... 110 % U_N
d.c. auxiliary voltage — ripple	zero (3 % peak value)	0 ... 12 % peak-to-peak
d.c. auxiliary voltage — short interruptions	uninterrupted	2 ms ... 200 ms
H.F. disturbances	no disturbances	1 kV/2.5 kV - 1 MHz - 200 serie/common mode current/D.C.circuit
Electromagnetic field susceptibility	no disturbances	under consideration (IEC)
Frequency	f_N (± 0.5 %)	94 % f_N... 102 % f_N)
Waveform of a.c.current	sinusoidal (total harmonic distorsion < 2 %)	5 % harmonics 3/5 3 phase positions
Source time constant	50 ms (± 5 ms)	10 ms... 150 ms
Initial point-on-wave (dynamic tests)	0	0 ... 180° in steps of 10 ... 30°)
CT model	ideal performance	
- remanence factor	0	0 ... 0,8
- kneepoint	no transient saturation	5 ... 1200 times internal e.m.f.at rated current
- secondary time constant	> 10 sec	unsaturated : 50 ms ... 10 s fully saturated: 0,2ms...3 ms
- secondary burden angle	0°	0 ... 45°
Relay setting	reference setting	setting range

Table 41 - Reference conditions and range of influencing parameters

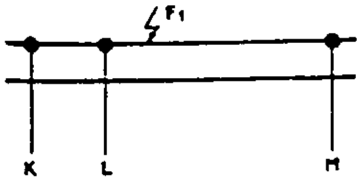
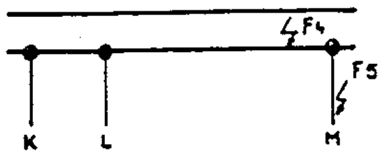
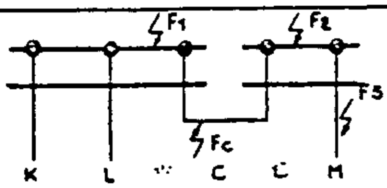
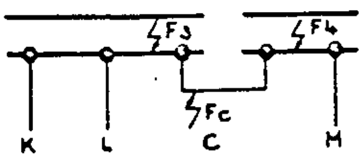
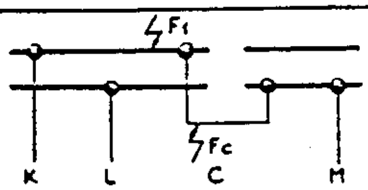
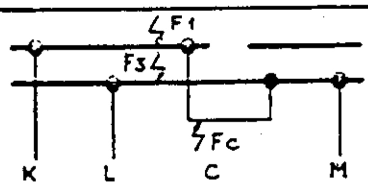
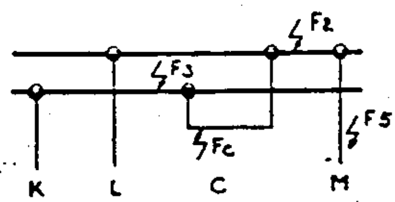
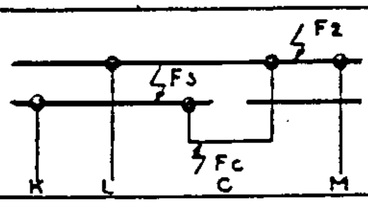
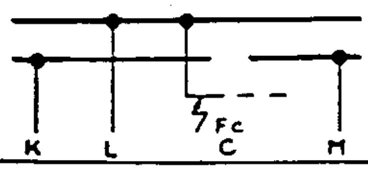
(*) values proposed by WG 34-04

OBJECT OF TESTS	TEST CONDITIONS	n
Operating and returning values of (current) starting units	3 settings : ref, max, min	6
Sensitivity of measuring units (internal fault) I_2 = 0 fig.4 -a	3 settings : ref, max, min $I_2 = I_3 = 0$	3
I_2 in phase fig.42-2-a	3 settings : ref, max, min 6 current values : $I_2 = 0.5\ I_N,\ 1\ I_N,\ 2\ I_N$ $3\ I_N,\ 4\ I_N,\ 5\ I_N$ $I_3 = 0$	18
	1 setting : ref 3 current values : $I_2 + I_3 = 1\ I_N,\ 2\ I_N,\ 5\ I_N$ $I_2 = I_3$ (three feeders)	3
I_2 phase shifted fig.4. -b	1 setting : ref 2 current values : $I_2 = 2\ I_N,\ 5\ I_N$ $I_3 = 0$ $\varphi = 0° \ldots 360°$ in steps of 30°	24
	2 settings : max, min 1 current value : $2\ I_N$ $I_3 = 0$ φ: 4 phase values	8
	1 setting : ref 1 current value : $I_2 = I_3,\ I_2 + I_3 = 2\ I_N$ (three feeders) φ: 4 phases values	4
Stability characteristics (external fault) – High impedance relay fig.4 -c	1 setting : ref 5 current values : $I_2 = 0.5\ I_N,\ 1\ I_N,\ 5\ I_N$ $10\ I_N,\ 20\ I_N$ (maximum permissible value of the loop resistance at which the stability is maintained during saturation)	5

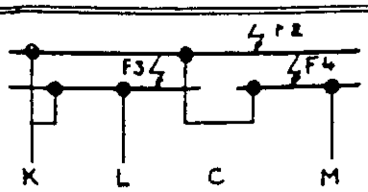
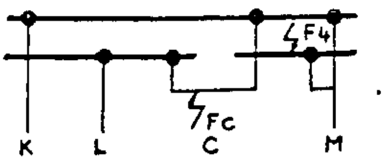
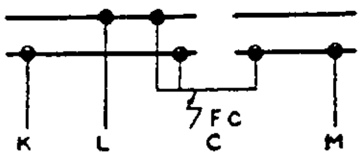
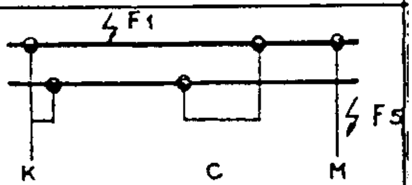
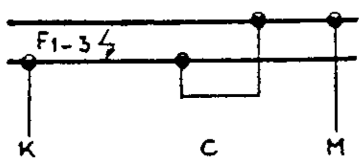
Table 42- -a Tests in steady-state conditions

OBJECT OF TESTS	TEST CONDITIONS	n
Indications and output contacts	verification during other tests	-
Power consumption - a.c. currents	2 current values 4 CT's ratios internal and external fault	16
- d.c. auxiliary supply	maximum power consumption for . measuring unit . feeder unit . bus coupler unit with and without fault	6
Busbar replica (logic of the protection scheme in different busbar configurations, fig.4 -f)	steady-state configuration (see list 4 -a)	35
	fault during configuration change (see list 4 -b)	20
	wrong isolator position signal Reaction of the relay ("Alarm" or "Blocking" and time delay) on a wrong position signal of: . feeder isolator (e.g. K_1) . bus coupler (B_c) . bus isolator (e.g. C_1) . section isolator (e.g. S_1) (With an isolator closed, the signal is "open" and vice versa)	8
		156

Table 42- a (continued)

Configuration	Test no.	Fault pos.	Trip command to B_k	B_l	B_m	B_c	Remark
	1	F_1	X	X	X		
	2	F_4	X	X	X		
	3	F_5					
	4	F_1	X	X		X	
	5	F_2			X	X	
	6	F_c	2	2	1	1	note 2
	7	F_5					F_c and B_c in at same moment
	8	F_3	X	X		X	
	9	F_4			X	X	
	10	F_c	2	2	1	1	note 2
	11	F_1	X			X	
	12	F_c	2		1	1	note 2
	13	F_1	X			X	
	14	F_3		X	X	X	
	15	F_c	2	1	1	1	note 2
	16	F_2		X	X	X	
	17	F_3	X			X	
	18	F_c	2	1	1	1	note 2
	19	F_5					
	20	F_2+F_5	X	X	X		fault F_2 : R - S fault F_5 : S - T
	21	F_2		X	X	X	
	22	F_3	X			X	
	23	F_c	2	1	1	1	note 2
	24	F_c		X			breaker B_c open
	25	F_c		X		(X)	breaker B_c closed

List 4.[illegible]-a Steady-state configurations

Configuration	Test no.	Fault pos.	Trip command to B_k	B_l	B_m	B_c	Remark
	26 27 28	F_2 F_3 F_4	X X 	X X 	 X	X X X	
	29 30	F_4 F_c	X 1	 2	X 1	X 1	 note 2
	31	F_c	2	2	1	1	note 2
	32 33 34	F_1 F_1 F_5	X X 		X X 	(X) (X) 	K closed, I_{bc}=0...$\pm$ 1 I_k. note 3 K open (I_k=0), I_{bc}=0...1 I_m note 3 I_{bc}=0...1 I_k, note 3
	35	F_{1-3}	X		X	(X)	fault: from busbar 1, phase R to busbar 3 phase S

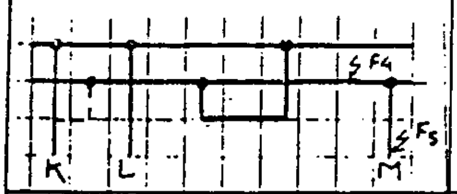
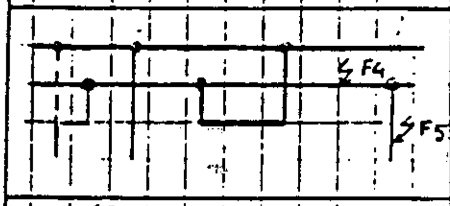
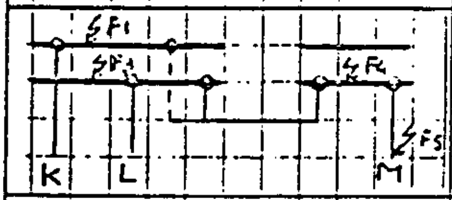
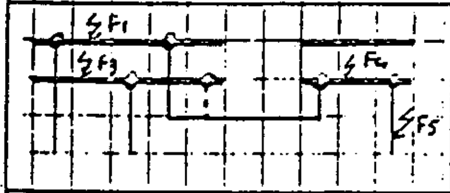
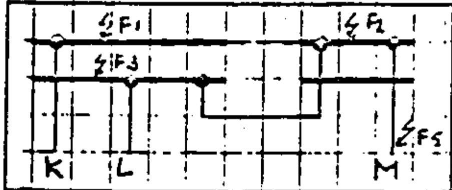
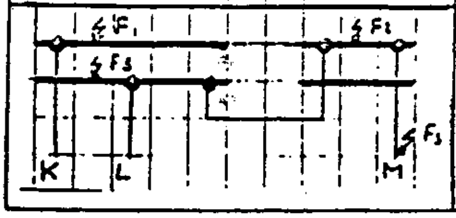
Notes: 1. For fault positions refer to fig. 4-f

2. After the first trip commands (indicated "1") the current in the tripped feeders must be switched off (e.g. with time delay 40 ms) and the signals must be changed. The second trip commands are indicated "2".

3. The test must be made for different values of the current in the buscoupler, e.g. I_{bc} = 0.2, 0.5, 0.8 I. These values may be chosen in accordance with the settings. For test nr. 32 also the direction of the current must be changed.

4. The test current in each generator feeder can be chosen, e.g. $2I_N$.

List 4 -a (continued)

Configuration	Test no.	Configuration change	Fault pos.	Trip command to B_k	B_L	B_m	B_c
	1	closing of k_3	F_5				
	2		F_4	x	x	x	x
	3	opening of k_1	F_5				
	4		F_4	x	x	x	x
	5	closing of C_1	F_5				
	6		F_1	x	x		x
	7		F_3	x	x		x
	8		F_4			x	x
	9	opening of C_3	F_5				
	10		F_1	x	x		x
	11		F_3	x	x		x
	12		F_4			x	x
	13	closing of S_1	F_5				
	14		F_1	x		x	x
	15		F_2	x		x	x
	16		F_3		x		x
	17	opening of S_1	F_5				
	18		F_1	x		x	x
	19		F_2	x		x	x
	20		F_3		x		x

List 4 .b Faults during configuration changes

	Ambient temperature $-5^{0}C/+40^{0}C$	n	D.C. auxiliary voltage: 80/110% U_N 1)	n	D.C. auxiliary voltage: ripple 12% 1)	n	D.C. auxiliary voltage: short interruptions (2 durations) 2)	n	Measuring frequency 94/102% f_N	n	Harmonic components 3rd 5% 5th 5%	n	H.F. Disturbance tests 1 MHz, 200 Ω 5)	n	Electromagnetic fields susceptibility	n
Operating and returning values of (current) starting units . reference setting	1 point	4	-		-		1 point	4	1 point	4	3 harmonic phase positions	12	1 point	54	*	-
Sensitivity (internal fault) $I_2 = 0$	2 settings	4	-		-		-		1 setting	2	1 setting 3 harmonic phase pos.	6	1 setting	54		-
I_2 in phase, $I_1 = I_2 + 180°$ ref. settings $I_3 = 0$	2 current values	4	-		-		2 current values	8	2 current values	4	2 current values 3 harmonic phase pos.	12	1 current value	54	*	-
. other settings, $I_3 = 0$	2 current values	4	-		-		-		-		-		-			-
. reference setting, $I_3 = I_2$	1 setting 1 current value 1 setting	2	-		-		-		-		-		-			-
I_2 phase shifted, $I_2 = 2I_N$. reference setting	4 points	8					-		4 points	8	4 points 3 harmonic phase pos.	24	-			-
Stability (external fault) - high impedance relay (loop resistance) - low impedance relay	1 current value 2 settings	4							1 current value	2	1 current value 3 harmonic phase pos.	6	1 point	54	*	-
Busbar replica - steady-state situation - configuration change - incorrect configuration signal	8) 7) -	18 4	7) 7) -	2 4	7) 7) -	2 4	4 configurations - -	16	- - -		- - -		x 1 point -	54		-
Indications and output contacts	x		x		x		x		x		x		x		*	-
Power consumption for d.c. auxiliary supply	different units	12	diff. units	12	-		-		-		-		-			
Number of tests		94		18		6		28		20		60		270		-
																486

Table 42- b Tests in steady-state conditions

* Without estimation of the number of tests

OBJECT OF TESTS	TEST CONDITIONS	scheme (x)	n
Transient accuracy of (current) starting units 3)	3 settings : ref, max, min 2 limits	A	6
Sensitivity of measuring units (interal fault) 3) $I_2 = 0$	3 settings : ref, max, min 2 limits	A	6
I_2 in phase	1 setting : ref 3 current values : $I_2 = 1\ I_N,\ 5\ I_N,\ I_{max}$ $\angle I_1 = \angle I_2 + 180°,\ I_3 = 0$ 2 limits	B	6
I_2 phase shifted	1 setting : ref 3 current values : $I_2 = 1\ I_N,\ 5\ I_N,\ I_{max}$ $I_3 = 0$ 2 limits	C	6
Operating times of starting units 4)	1 setting : ref 5 current values : $1\ I_N,\ 2\ I_N,\ 5\ I_N,\ 20\ I_N$ I_{max}	A	5
Operating times of the relay 4) $I_2 = 0$	3 settings : ref, max, min 5 current values : $I_2 = 1\ I_N,\ 2\ I_N,\ 5\ I_N,$ $20\ I_N,\ I_{max}$	A	15
I_2 in phase	1 setting : ref current values : $I_1 = 1\ I_N,\ 2\ I_N$ $I_2 = 5\ I_N,\ 20\ I_N,\ I_{max}$ $\angle I_1 = \angle I_2 + 180°,\ I_3 = 0$	B	6
I_2 phase shifted	1 setting : ref current values : $I_1 = 1\ I_N,\ 2\ I_N$ $I_2 = 5\ I_N,\ 20\ I_N,\ I_{max}$ $I_3 = 0$	C	6
Resetting times	3 settings : ref, max, min 3 fault types starting units and composite relay	A	18
Stability (external fault)	1 setting : ref 5 current values : $I_2 = 1\ I_N,\ 2\ I_N,\ 5\ I_N,$ $20\ I_N,\ I_{max}$ $I_3 = 0$ $\angle I_1 = \angle I_2 + 180°$ (through fault current)	D	5
Indications and output contacts	verification during other tests	-	–
			79

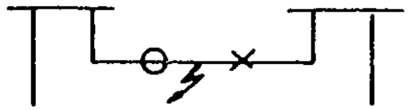
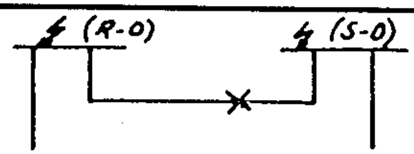
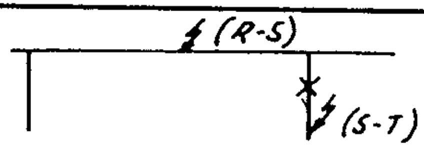
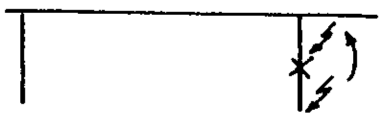
(x) See figure 4 – 9

Table 43- ·a Single source dynamic tests

	Ambient temperature $-5^{0}C/+40^{0}C$	n	D.C. auxiliary voltage: 110/110% U_N	n	D.C. auxiliary voltage: ripple 12%	n	D.C. auxiliary voltage: short interruptions (2 durations)	n	A.C. source: measuring frequency 94/102% f_N	n	A.C. source: time constant 30 ms/1 max	n	CT models	n	scheme
			1)		1)		2)				6)		(9)		(x)
Transient accuracy of (current) starting units . reference setting 3)	-		-		-		-		-		1 setting 1 current value	2	-		A
Sensitivity (internal fault) $I_2 = 0$ 3)	2 settings 2 current values	8	-		-		-		-		1 setting 1 current value	2	-		A
Operating times of starting units 4)	1 setting 1 current value	2	1 setting 1 current value	2	-		1 setting 1 current value	4	1 setting 1 current value	2	1 setting 5 current values	10	2 settings 5 current values	10	A
Operating times of the relay $I_2 = 0$ 4)	2 settings 2 current values	8	1 setting 1 current value	2	-		1 setting 1 current value	4	1 setting 1 current value	2	1 setting 5 current values	10	2 settings 5 current values	10	A
I_2 in phase	2 settings 2 current values	8	-		-		-		-		-				B
Resetting times	1 setting 1 current value	2	-		-		1 setting 1 current value	4	-		1 setting 2 current values	4	2 setting 2 current values	4	A
Stability . external fault	-		-		-		-		-		1 setting 5 current values	10	2 setting 5 current 2 values	10	D
Indications and output contacts	x		x		-		x		-		x		*		
Number of tests	28		4		-		12		4		38		34		

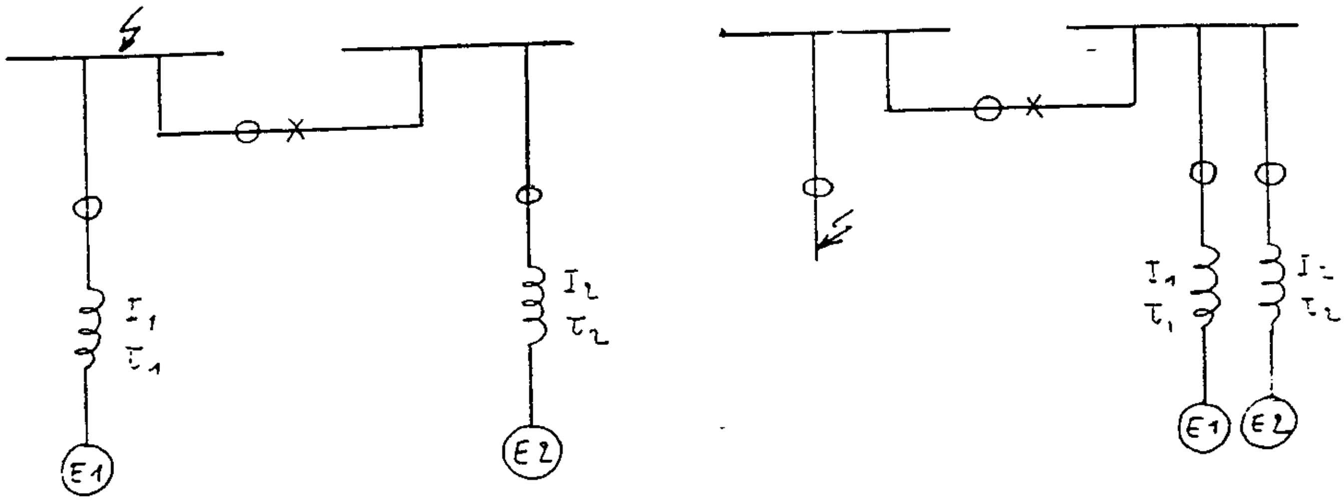
(x) See figure 4 – 9

table 43- b Single source dynamic tests

		AC source				CT models		
		measuring frequency 94/102% f_N	n	Time constant 30 ms/ t_{max} (6)	n	(9)	n	Scheme (x)
Internal fault operating time				1 setting 1 current value	2	1 setting 1 current value	1	E
Double Internal fault operating time				1 setting 1 current value	2	1 setting 1 current value	1	F
Internal and external fault Operating time				1 setting 1 current value	2	1 setting 1 current value	1	G
Evolving fault (External to internal) Operating time				1 setting 1 current value	2	1 setting 1 current value	1	H
Indications and output contacts				*		*		
Number of tests				8		4		
						132		

(x) see figure 4g

Table 43-c - Single source dynamic tests



	I_1	τ_1	E_2	I_2	τ_2	n
Internal fault	2 IN	30 ms	= E1	max(1)	max(2)	1
	2 IN	max	= E1	max(1)	30 ms	1
	2 IN	30 ms	= E1 $\angle$ +30°	max(1)	30 ms	1
	2 IN	30 ms	= E1 $\angle$ -30°	max(1)	30 ms	1
External fault	2 IN	30 ms	= E1	max(1)	max(2)	1
	2 IN	max	= E1	max(1)	30 ms	1
	2 IN	30 ms	= E1 $\angle$ +30°	max(1)	30 ms	1
	2 IN	30 ms	= E1 $\angle$ -30°	max(1)	30 ms	1
Number of tests						8

(1) At least 20 IN

(2) At least 300 ms

Table 44 - Double source dynamic tests

		n	Σn
<u>Steady state tests</u>			
table 42 -a		156	
table 42 -b			
- T°	84		
- D.C. aux. voltage	52		
- Frequency	20		
- Harmonics	60		
- HF disturbances	270	486	642
<u>Single source dynamic tests</u>			
table 43 -a		79	
table 43 -b et 43 -c			
- T°	28		
- D.C. aux. voltage	16		
- Frequency	4		
- Time constant	38		
- CT models	34		
- Particular faults	12	132	211
<u>Double source dynamic tests</u>			
table 44		8	8
			861

Table 4-6 Estimated number of tests
Busbar differential protections

CHAPTER 5

FUNCTIONAL TESTS FOR TRANSFORMER CURRENT DIFFERENTIAL PROTECTION

5.1 GENERAL

See chapter 1, § 1.1

1. The operating principle of a transformer differential protection is based on the measurement of the differential current, which is the sum of the instantaneous currents entering each winding of the protected transformer.

   To avoid unwanted tripping during external faults, when some CT's may be saturated or when the load-tap-changer is in the extreme position, one main operating principle is used :

   - low impedance biased differential protection

   Stability is maintained by biasing the operating differential current with the through current (load curent + external fault current).
   To avoid unwanted operation during energization of the power transformer most transformer differential protection systems incorporate harmonic restraint circuitry (2^{nd} harmonic restraint) which prevent relay operation on inrush currents during energisation. In addition some manufacturers incorporate harmonic restraint circuitry based on 5^{th} harmonic; this is designed to prevent relay operation due to possible overexcitation of the transformer.

   In a relay,the differential measurement, is performed on a single phase basis, however the through current biasing and harmonic restraint can use a combination value obtained by mixing the three single phase quantities.

   If required, auxiliary CT's are an integral part of the protection and consequently the tests should be performed with these CT's.

2. The tests as indicated in this chapter are applicable for two or three winging power transformer current differential protections.

3. Reference values and ranges of influencing quantities and factors, valid for the different tests, are shown in table 5.1

4. The measuring units shall be checked individually. When however, the equipment contains one measuring unit per phase, the complete tests may be made on only one of these units. The performance of the other circuits are verified during selected typical tests.

   If the three currents are combined in one measuring unit, all types of faults (one-phase-to-ground, two-phase with an without earth, three-phase) shall be simulated.

   The estimated number of tests is based on one measuring unit per phase.

5.2 STEADY-STATE TESTS

5.2.1 Object

See chapter 1, § 1.2.1

1. These tests are intended to measure :

   - the operating characteristics of current differential functions for internal faults without load current (sensitivity),

   - the operating characteristics of current differential functions with through currents - external faults (stability characteristics),

   - the harmonic restraint characteristics.

2. The correct behaviour of visual indicators, output contacts, etc. are examined. The power consumption on a.c current and d.c. auxiliary voltage circuits is also measured.

5.2.2 Test procedures

1. The sensitivity of the differential measuring units should be measured by simulating the fault current at one end of the protection scheme whilst maintaining the remaining terminals open or unenergised. The test is performed by slowly increasing the magnitude of the fault current using the test simulation in figure 5-a.

2. The above tests are repeated with through currents superimposed (with one terminal open on three ended scheme) to measure operating characteristics (fig. 5-a and 5-b).
   The polar characteristics are measured using the test simulation in figure 5-c. Figure 5-d shows a typical polar operating characteristic.
   The inrush restraint (harmonic restraint respect) characteristic is measured using the test simulation in figure 5-e.

5.2.3 Test program

Examples of tests are given in tables 5.2 part a and 5.2. part b.

5.3 SINGLE-SOURCE DYNAMIC TESTS

5.3.1 Object

See chapter 1, § 1.3.1

1. These tests are intended to measure the sensitivity, the operating and resetting times of the protection for an internal fault and to check the stability for an external fault.

2. The dynamic tests are repeated for different values of the initial point-on-wave (e.g. from 0° to 180° in steps of less than 30°).

5.3.2 Test procedures

The dynamic tests should be performed using the test simulation in figure 5-g with ideal models of CT's.

5.3.3 Test programs

1. Examples of tests in dynamic conditions are given in table 5.3 part a, assuming ideal models of CT's and power transformer (see figure 5-g). Dynamic tests with H.F. disturbances are often limited to a few points.

2. To investigate the behaviour of the differential protection under more realistic conditions, examples of tests are given on table 5.3 part b. Non-ideal models of CT's and power transformer are assumed. Table 5.3 part c gives examples of some particular more complex faults.

5.4 DOUBLE-SOURCE DYNAMIC TESTS

Double-source dynamic tests are normally not necessary.

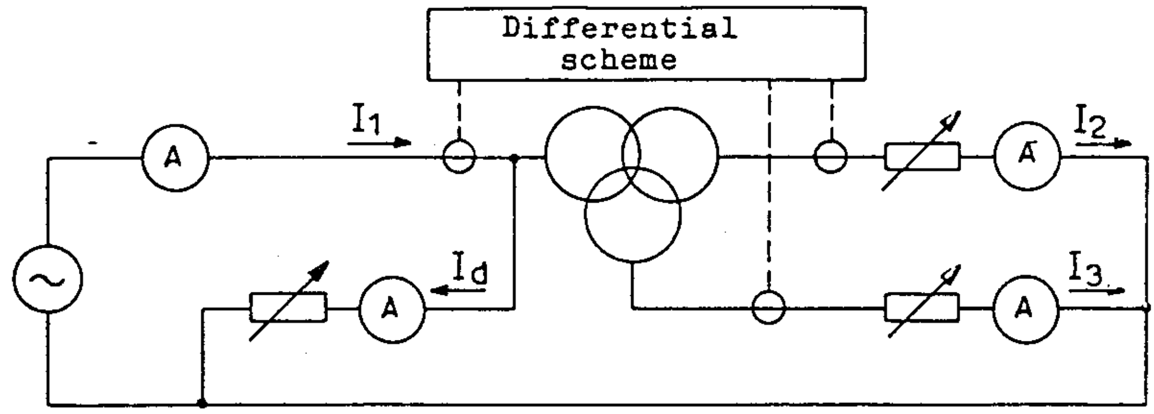


Fig. 5-a Operating characteristic

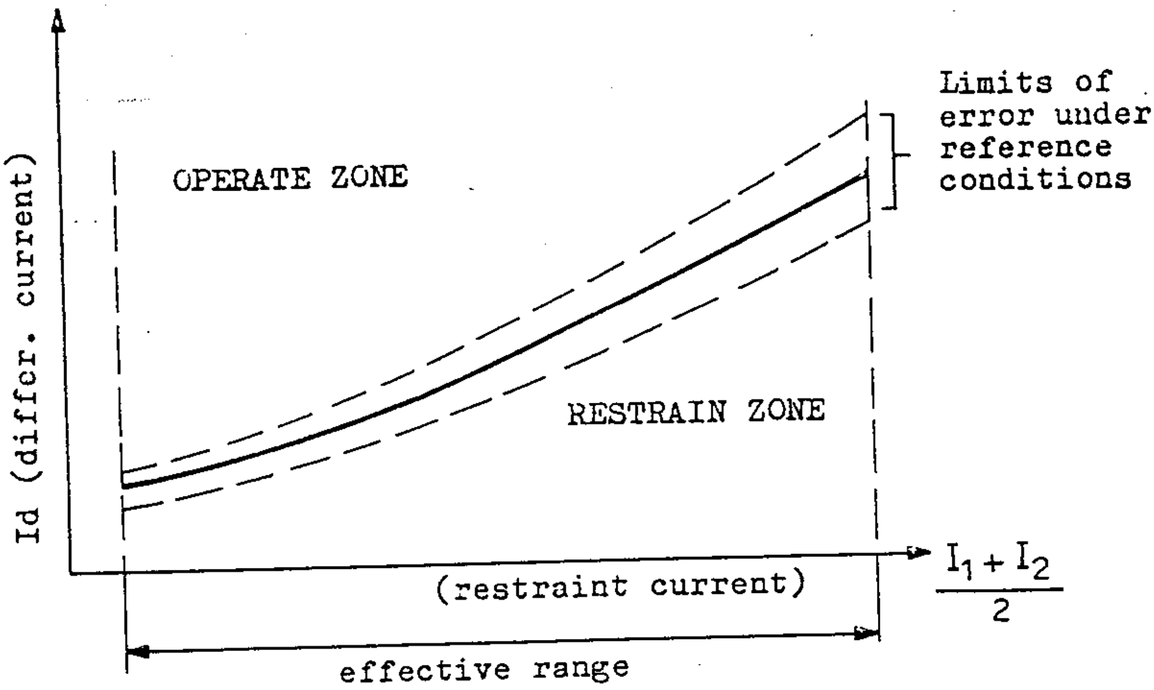


Fig. 5-b Operating characteristic under reference conditions

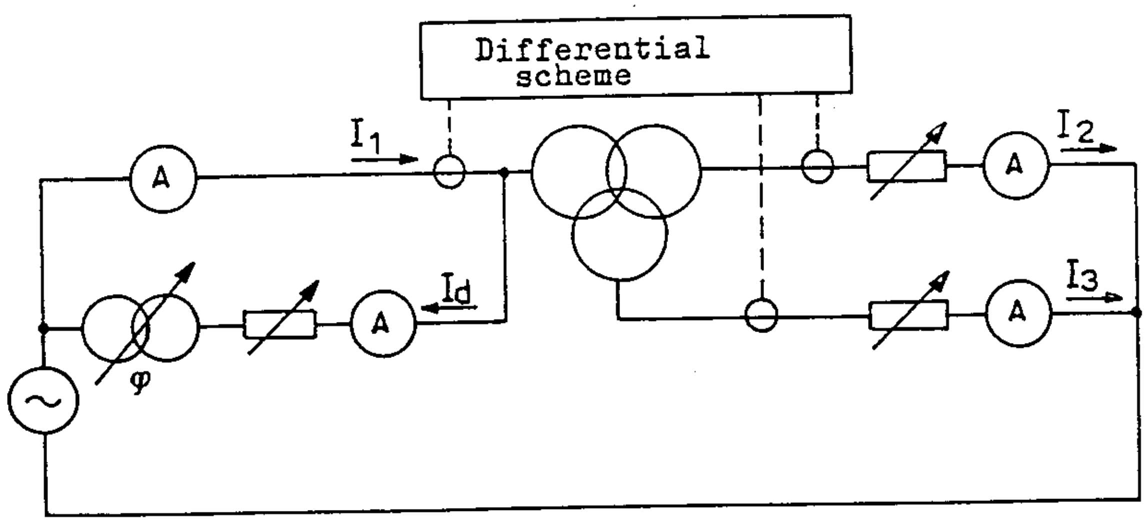


Fig. 5-c Polar characteristic

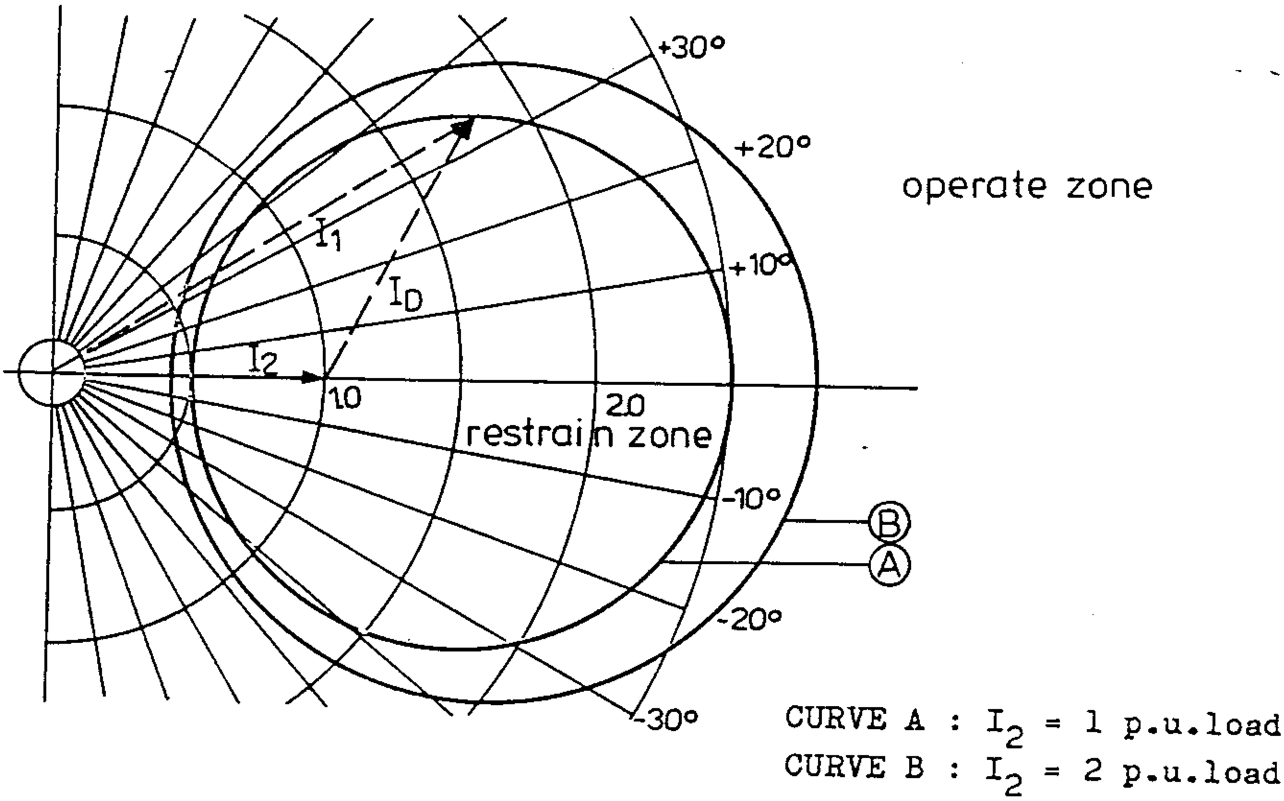


Fig. 5-d Typical polar characteristic

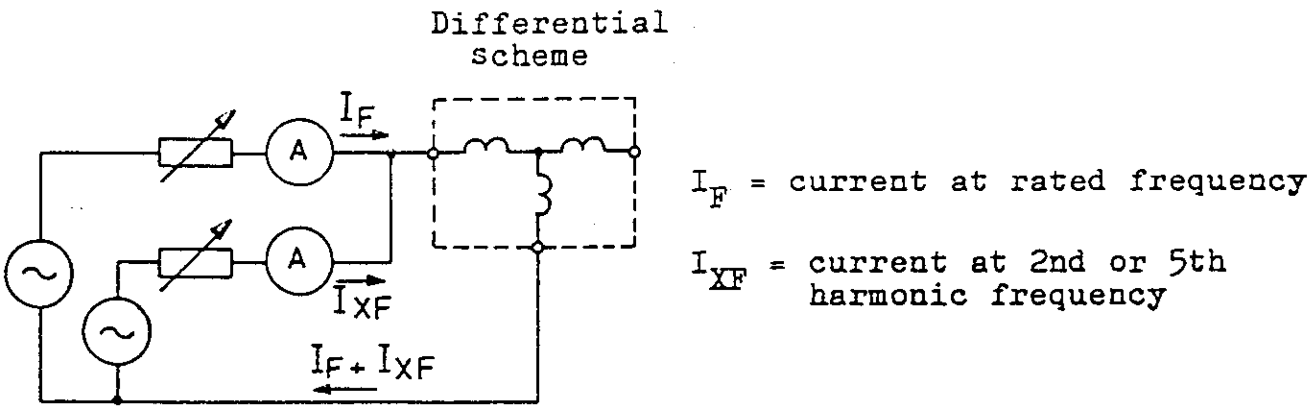


Fig. 5-e Harmonic restraint test

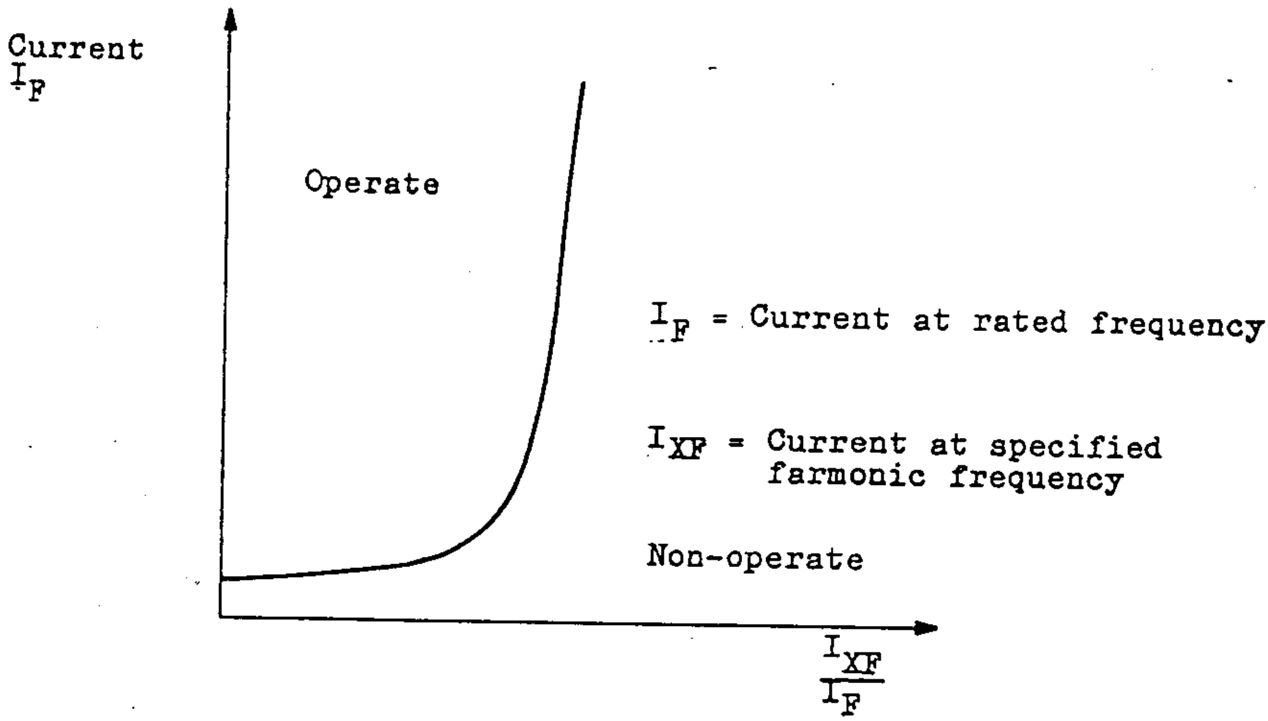


Fig. 5-f Harmonic restraint characteristic showing response to a single harmonic frequency

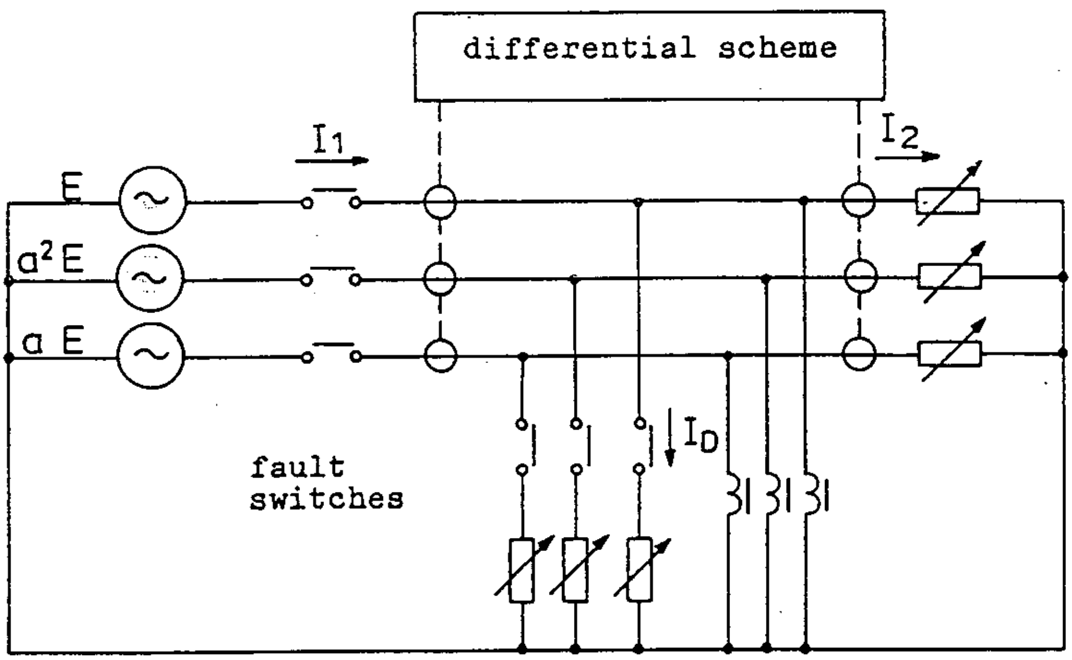


Fig. 5-g Single - source dynamic tests

TYPE TEST FOR POWER TRANSFORMER CURRENT DIFFERENTIAL PROTECTION

LIST OF TABLES

Influencing quantities or factors	5.1	
Tests in steady- state conditions	5.2	- a and b
Tests in dynamic conditions	5.3	- a and b
Tests on single - source power system model	5.3.	- c
Estimated number of tests	5.6	

Comments:

n Number of tests

x Observation during the tests

* Number of tests not indicated; no test standards available

1) Measurements are only necessary if the internal d.c. voltages are not indep dent of the stated variations of the input auxiliary voltage. In the number of tests, they are not taken into account.

2) Two different types of interruptions: short circuited and open circuited. Durations of interruptions refer to manufacturer specification.

3) For each test two limits are determined by varying the point-on-wave (0°, 10°... 180°) :
- no operation at external tault (1 test result)
- operation at internal fault (1 test result)

4) The point-on-wave is varied 0°, 10...180° (1 test result)

5) Upper/lower limits in serie/common mode for each independent circuit (current, D.C. voltage, input circuit, auxiliary and tripping circuits) and between independent circuits. Identical circuits (e.g. current inputs) are not supplementically tested but connected at random.
High frequency disturbance test conformes to IEC 255-6

6) Maximum time-constant as indicated by the manufacturer; at least 100 ms.

7) The tests are repeated for each type of CT. The influence of CT-saturation must be investigated.

Influencing parameters		Reference conditions (a) (proposed by WG 34-04)	Range of influencing parameters (Values proposed by WG 34-04)
ambient temperature		20°C (∓ 2°C)	-5°C ....+40°C (+ 55°C)
relative humidity		45% to 75%	------
d.c. auxiliary voltage	voltage	UN (+2%)	80% UN ....110% UN
	ripple	zero (3% peak value)	0..... 12% peak-to-peak
	short interruptions	Uninterrupted	2 ms .... 200 ms
H.F. disturbances		no disturbances	1 kV/2,5 kV - 1 MHz-200 ohm series/common mode current / D.C. circuits
Electromagnetic field		no disturbances	under consideration (IEC)
a.c. currents	frequency	fN (∓ 0,5%)	94% ....102% fN
	waveform	sinusoidal (total harmonic distortion < 2%)	5% harmonics 3/5 3 phasepostions
	time source constant(b)	50 ms (∓ 5 ms)	10 ms .... 150 ms
initial condition (b)	initial current	zero	I_N (c)
	initial point onwave	0	0° .....180° in steps of 10 .... 30°
CT model		ideal performance	
- remanence factor		0	0 0,8
- kneepoint		no transient saturation	5 ....1200 times internal e.m.f. at rated current
- secondary time constant		10 sec	unsaturated: 50ms ...10s fullysaturated: 0,2ms...3ms
- secondary burden angle,		0°	0....45°
power transformer magnetising		zero (ideal model)	power transformer model (b)
Relay setting		reference setting	settingrange

a/ test tolerances are indicated into brackets
b/ dynamic test only
c/ load currents superimposed with variable phase-angles

Table 5.1. Rererence conditions and range of influencing parameters

OBJECT OF TESTS	TEST CONDITIONS	N
Sensitivity of measuring units (internal fault) $I_L = 0$	3 settings: :ref, max, min 4 fault types $I_2 = I_3 = 0$ fig.5-a	12
I_L in phase	3 setting :ref, max, min 6 current values $:I_2=0,2I_N,0,5\ I_N,\ 0,8\ I_N$ 1 fault type $1I_N,\ 2I_N,\ 5I_N$ fig.5-a $I_3 = 0$	18
	deviations due to the tertiary winding 1 setting :ref 3 current values $:I_2 + I_3 = 0.5I_N,\ 1I_N,\ 1.5I_N$ $I_2 = I_3$ fig.5-a	3
I_L phase shifted	1 setting :ref 2 current values $I_2 = 1I_N,\ 2I_N,$ 1 fault type $I_3 = 0$ φ =0°...360° in steps of 30° fig.5-c	24
	2 settings :max, min 1 current value $:I_2 = 2I_N$ 1 faulttype 4 phase values $I_3 = 0$ fig.5-c	8
($I_L = I_2+I_3$=load current)	deviations due to the tertiary winding 1 setting :ref 1 faulttype $I_2 + I_3 = 2I_N$ $I_2 = I_3$ fig.5-c	4
Stability characterstics (external fault)	1 setting :ref 4 fault types 4 current values: $I_2=1I_N,\ 2I_N,\ 5I_N,\ 10I_N, I_3=0$ fig.5-a	16
Harmonic restraint characteristic (I_F = fault current)	1 setting :ref 7 current values $:I_{XF}=0.2I_N, 0.3I_N, 0.5I_N, 1I_N, 2I_N,\ 3I_N,\ 5I_N,$ I_{XF}: 2 nd and 5th harmonic curve $I_F = f\left(\frac{I_{XF}}{I_F}\right)$ is measured (fig.5-f) fig.5-e	14
Indications and output constants	verifications during other tests	
Power consumption d.c. auxiliary supply a.c.current	at rated current: no fault, R-N fault,	2
	at 2 I_N: R-N fault,	1
		102

Table 5.2. part a Tests in steady state conditions
Transformer differential protection

Test	Ambient temperature -5°C/+40°C	n	D.C. auxiliary voltage: 80/110% U_N 1)	n	D.C. auxiliary voltage: ripple 12% 1)	n	D.C. auxiliary voltage: short interruptions (2durations) 2)	n	Measuring frequency 94/102% fN	n	Harmonic components 3rd 5% 5th 5%	n	H.F. Disturbance tests 1 MHz 200 ohm 5)	n	Power transfor. winding connections	n	Elektromagnetic fields susceptibility	n
Sensitivity (internal fault - I_L = 0 reference setting	1 fault	2	-		-		1 fault	4	1 fault	2	1 fault 3 harmonic phase pos.	6	1 fault	44	4 faults each end 2 winding connections	16	x	
- I_L in phase reference setting, I_3=0 I_2=	1 fault 2 current values	4	-		-		1 fault 1 current value	4	1 fault 1 current value	2	1 fault 2 current values 3 harmonic phase pos.	12	1 fault	44	idem	16	*	
min setting I_3=0	2 current values 1 setting	4	-		-		-		-				-		-			
- I_L phase shifted $I_2=I_3=I_N$ reference setting	1 fault 4 phase angles	8	-		-		-		1 fault 4 phase angles	8	1 fault 4 phase angl. 3 harmonic phase pos.	24	-		-			
Stability (external fault reference setting I_3=0 (throughfault current)3)	4 faults 1 current value	8	-		-		1 fault 1 current value	4	1 fault 4 current values	8	-		1 fault	44	4 faults 2 winging conn max.curr.	8	x	
Harmonic restraint char. reference setting	1 fault 2nd and 5th harmonic 3 current values	12	-		-		-		1. fault 2nd and 5th harmonic 3 current values	12	-		-		-			
Indications and output contacts	x		x		x		x		x		x		x		x		x	
Power consumption for d.c. auxiliary supply	1 fault no fault rated load	4	1 fault no fault rated fault load	4														
Number of tests		42		4		-		12		32		42		132		40	304	

Table 5.2. part b Tests in steady state conditions
Transformer differential protection

OBJECT OF TESTS	TESTS CONDITIONS (fig. 5.3.1)		n
Sensitivity of measuring units (internal fault)			-
- $I_2 = 0$	3 settings: 4 fault types 2 limits	ref. max, min $I_2 = 0$	24
- I_2 in phase	1 setting: 1 fault type 2 limits	ref. $I_2 = I_N$	2
- I_2 phase shifted	1 setting: 1 fault type φ: 4 phase values 2 limits	ref. $I_2 = I_N$	8
Operating times - $I_2 = 0$	1 setting 1 fault type 4 current values:	ref. $I_2 = 0$ $I_1 = 1I_N, 2I_N, 5I_N, 10I_N$	16
	2 settings: 1 fault type 4 current values:	ref., max, min $I_2 = 0$ $I_1 = 1I_N, 2I_N, 5I_N, 10I_N$	8
- I_2 in phase	1 setting: 1 fault type 4 current values:	ref. $I_1 = 1I_N, 2I_N, 5I_N, 10I_N$	4
- I_2 phase shifted	1 setting: 1 fault type 4 current values: φ: 4 phase values	ref. $I_2 = I_N$ $I_1 = 1I_N, 2I_N, 5I_N. 10I_N$	16
Resetting times	3 setting: 1 fault type	ref. max, min	3
Stability (external fault)	1 setting: 4 fault types 4 current values:	ref. $I_2 = 1I_N, 2I_N, 5I_N, 10I_N$	16
Indications and output contacts	Verification during other tests		
			79

Table 5.3. part a
Tests in dynamic conditions

	Ambient temperature -5°C/+40°C	n	D.C. auxiliary voltage 80/110% U_N 1)	n	ripple 12% 1)	n	short interruptions (2 durations) 2)	n	A.C. Source measuring frequency 94/102% f_N	n	time constant 30 ms/ τ max 6)	n	C.T. models 7)	n
Sensitivity (internal fault) - $I_2 = 0$ 3)	1 fault 2 settings 2 current values	8	-		-		-		-		1 fault 1 setting 2 current values	4	-	
Operating times of the relay - $I_2 = 0$ 4)	1 fault 2 settings 2 current values	8	1 fault 1 setting 1 current value	2	-		1 fault 1 setting 1 current value	4	1 fault 1 setting 1 current value	2	1 fault 1 setting 2 current values	4	1 fault 2 settings 2 current values	4
- I_2 in phase	1 fault 2 settings 2 current values	8			-		-		-		-			
Resetting times $I_2 = 0$	1 fault 1 setting 1 current value	2	-		-		1 fault 1 setting 1 current value	4	-		1 fault 1 setting 2 current values	4	1 fault 2 settings 2 current values	4
Stability (external fault)	-		-		-		-		-		1 fault 1 setting 2 current values	4	1 fault 1 setting 2 current values	2
Indications and output contacts	x		x		-		x		-		x		x	
Number of tests		26		2		-		8		2		16		10
														64

Table 5.3. part b Single source dynamic tests
Transformer differential protection

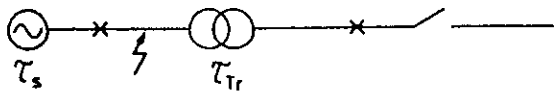
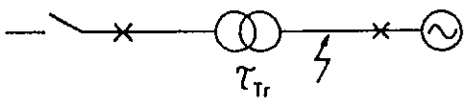
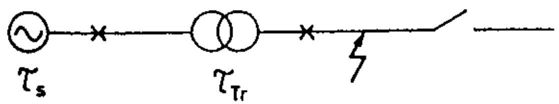
TESTS	COMBINED PARAMETERS			n
	current values	time constant	CT model	
Internal fault  The alternator currents must be simulated correctly	$20\ I_N$, $I\ max$	30 ms, τmax 6)	7)	4
Internal fault 	$20\ I_N$, $I\ max$	30 ms, τmax 6)	7)	4
External fault (stability) 	$\frac{I_{max}}{2}$, I_{max}	τ_{Tr}	7)	2
Inrush current	$I = 5I_N$, $10I_N$, $15I_N$	-	7)	3
				13

Table: 5.3 part C Single - source dynamic tests
Transformer differential protection

		n	Σn
<u>Steady - state tests</u>			
Table 5.2 - parta		102	
Table 5.2 - part b			
T^o	42		
D.C. aux. voltage	16		
Frequency	32		
Harmonics	42		
H.F. Disturbance	132		
Winding connections	40	304	406
<u>Dynamic tests</u>			
Table 5.3 - part a	79		
Table 5.3 - part b and part c			
T^o	26		
D.C. aux. voltage	10		
Frequency	2		
Time constant	16		
CT models	10		
Tests on model	13	77	156
			562

Table 5.6 Estimated number of tests
Transformer differential protection

CONCLUSION

1. Functional tests for power system protection relays are costly and time consuming. At this time, comparison of test results for similar protection equipment tested in different laboratories is difficult because test methods and forms of presentation of test results are not standard.

2. The number of measurements for steady-state and single source dynamic tests form a major part of the total amount of tests. Most of these tests are uncomplicated and repetitive in nature and can be carried out on simple test installations. Therefore such tests should be performed within a standardised test program, using reference voltage and current waveforms.

3. For the remaining tests, it is necessary to define the reference characteristics for the power system components, instrument transformers and test configurations. Such tests are more complex and require a power system model with more accurate simulation of the real power system components.

ACKNOWLEDGMENTS

WG 34-04 thanks the SC 34 Chairman, SC 34 Regular Members and WG 34-04 Corresponding Members for their support and valuable contributions.

APPENDIX A

Synthetic tests

A.1 GENERAL

These tests are performed by applying conventional waveforms of signals on the measuring inputs of the relay, using separate sources of signals. Most conventional steady-state tests are performed in a synthetic way, by using separate sources of a.c. signals and slowly varying the magnitude and/or phase angle of some of these signals. Single-source dynamic tests can also be performed in a synthetic way, by using separate sources of a.c. and d.c. signals and combining them with appropriate synchronization. Such methods can be extended to the generation of more complex waveforms of signals such as : trapezoïdal representation of arc voltage, etc ...
Synthetic methods can ensure a high level of flexibility, accuracy and reproducibility of the test signals, but they are not ideal for simulating typical or particular fault or switching sequences in more complex power systems. In the latter case, power system models are more appropriate (see appendix B).

A.2 CHARACTERISTICS OF A.C. SIGNALS

Table A.2 summarizes the characteristics of a.c. signals to be generated to perform the majority of steady-state and single-source dynamic tests.

A.3 ANALOG SYNTHETISERS

In order to perform the steady-state measurements independant current and voltage sources must be available with good setting possibilities for amplitude and phase and in some cases for the harmonics content. The modern approach of using current and voltage amplifiers to produce the input signals for a protection relay opens the possibility to use measuring signals at low levels so that the generation of these signals is relatively simple.
Accurate and good reproducible phase shifts, frequency changes, harmonics, switching angles, etc ... can be generated with eventually parameters set by a computer or by a programmable logic controller. An extension of the electronic steady-state test-equipment with units for the generation of several current and voltage waveforms can be useful for investigation tests or development (figure A-3).
The function-generators can produce asymmetric sine-waves with adjustable time constants, inrush currents, arc voltages, etc ... In this way the steady-state test-equipment is used as a "catalogue" of waveforms. Timing of test sequences and control of switching angles is performed by the synchronization unit. Settings can be made by hand or - after further extension - by means of a controller.

With cascading of electronic circuits it must be emphasized that careful design is required with respect to offset and drift.
The introduction of computer control will clearly influence the design of the test-equipment for steady-state as well as for dynamic tests.

A.4 DIGITAL SYNTHETISERS

Synthetic tests can also be performed from digital computers with D/A outputs and amplifiers (fig A.4). See Appendix B, paragraph B.4.

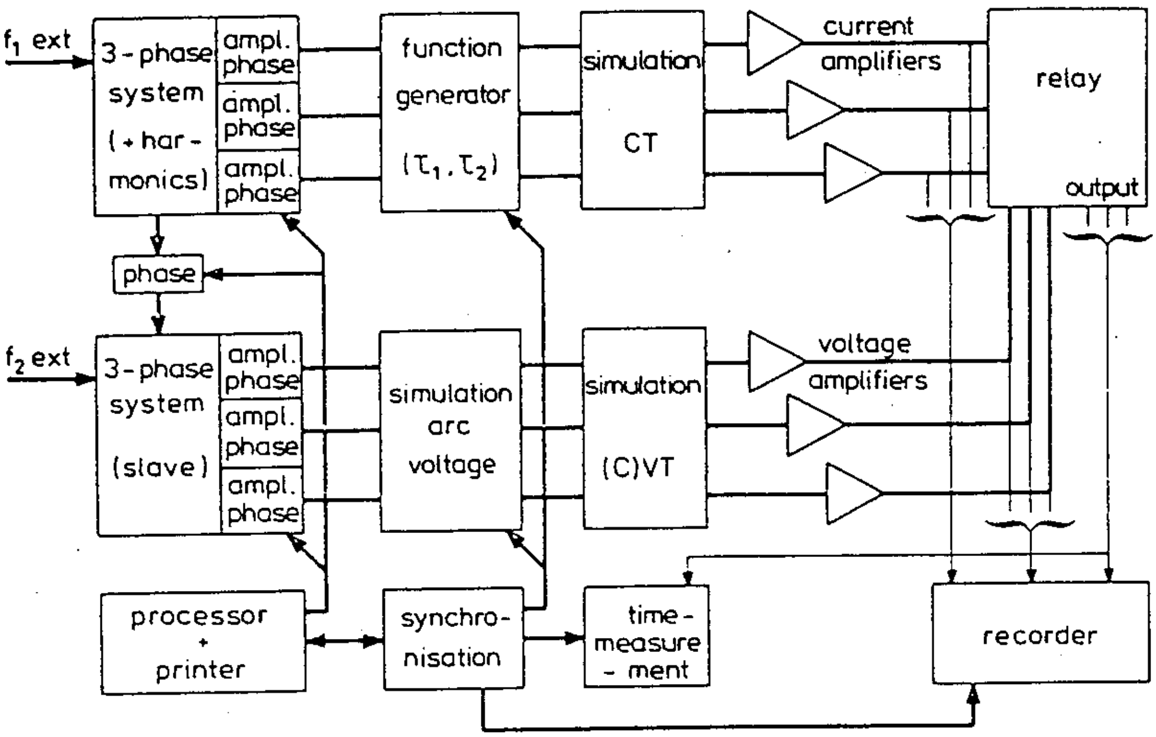


Fig A.3 : Analog synthetic test set up

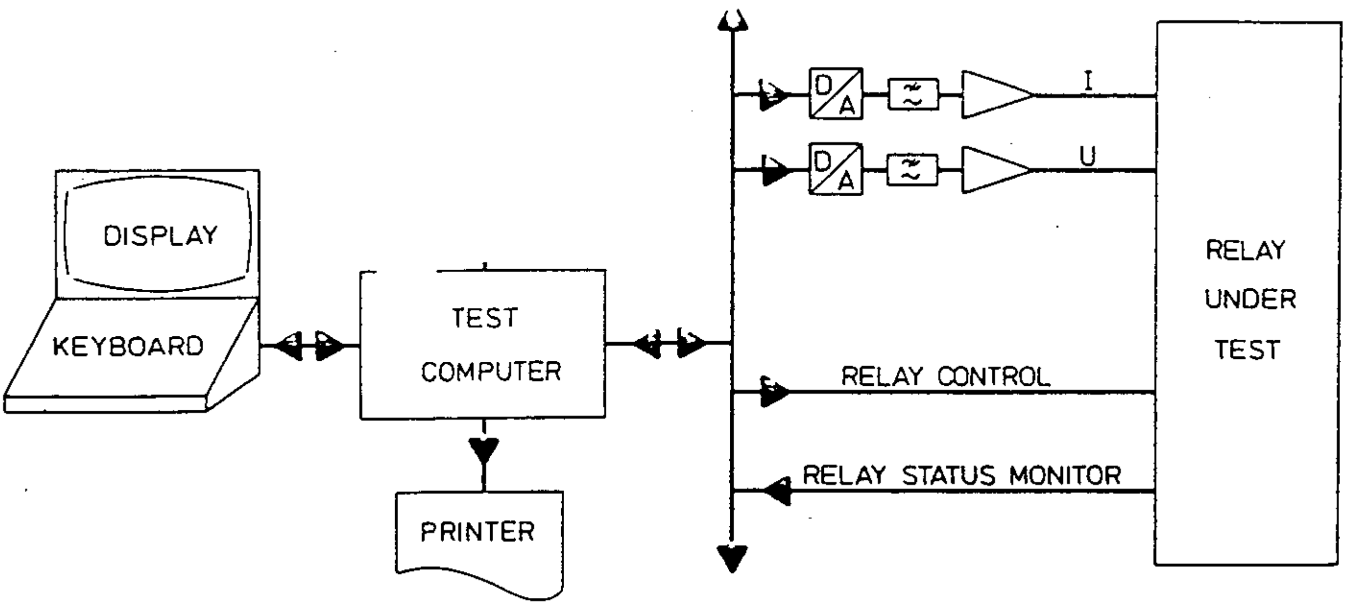


Fig A.4 : Digital synthetic test set up

a.c. signals		Steady-state tests	Single-source dynamic tests
frequency	range	0.9 .... 1.1 times rated frequency	0.94 ... 1.02 times rated frequency
	resolution	0.2 % of rated frequency	0.5 % of rated frequency
phase-angle	range	0 ... 360°	0 ... 360°
	resolution	1°	1°
a.c. currents	range	0.05 ... 10 times rated current	0.2 ... 40 times rated current
	resolution	1 % of applied value	1 % of applied value
	distortion	max 1 % divided by rank of harmonic	max 1 % divided by rank of harmonic
a.c. voltages	range	0.1 % ... 2 times rated phase-to-earth voltage	0.1 % ... 2 times rated phase-to-phase earth voltage
	resolution	1 % of applied value	1 % of applied value
	distortion	total harmonic distortion < 2 %	total harmonic distortion < 2 %
superposition of harmonics	orders	at least ranks 2, 3, 5, 7, 9 separately or simultaneously (*)	-
	phase-angle	0 ... 360° relative to power(*) frequency signals	-
d.c. components	time constants	-	5 ... 500 ms
	switching moment	-	resolution 1°
	magnitude	-	currents : 0 ... 100 % / voltages : 0 ... 20 %
number of a.c. signals		1 ... 6	1 ... 6

Table A.2 : a.c. signals for synthetic tests

(*) see also note 1) on page 23

APPENDIX B

Tests on power system models

B.1 GENERAL

These tests are performed by simulating typical or particular power system configurations during fault or switching conditions.
Modern power system models for testing relays utilize current and voltage amplifiers which can be driven by low level test signals. The latter can be generated from low power analog models or from digital computers with D/A outputs.

B.2 CHARACTERISTICS OF AMPLIFIERS

Tables B.2-a and B.2-b summarize the characteristics of current and voltage amplifiers to perform the majority of dynamic tests on power system models.

B.3 ANALOG POWER SYSTEM MODELS

B.3.1 General

The transient phenomena occuring in the power network, as well as the transient behaviour of the measuring transformers may influence the response of the protection relay.
With the help of the analog simulator, the generation of the input data (voltages and currents) for protection relays should be possible with acceptable deviations from the real network data.
In the elementary form, the analog simulator consists of a 3-phase generator and a single 3-phase line model with possibilities of varying fault positions and fault types.
Simulating the power system will at least ask for the modelling of HV lines, power sources, circuit-breakers, fault switching and arcing resistance.
For some applications, additional elements will be required like series capacitors or reactors, power transformers, etc.
In the design of some of these elements the eventual computer control should be taken into account e.g. for switching moments, fault position, etc.
Although realization of this control is possible for medium as well as for low power models, it is clear that the latter is more fitted for it.

B.3.2 Line models

The use of power amplifiers with adjustable input sensitivity as coupling element between line model and protection relay gives a certain degree of freedom in the dimensioning of a power line model.

Practical limits, however, will be set by factors like maximum required overcurrent, amplifier drift and offset and the current sensing in the power line.
The miniaturizing of the line model is limited by the attainable L/R-ratio of small coils and by the resistance of wires, printed wiring and relay contact for line or fault switching.
With careful design a correct response up to 8 kHz is possible for single or double lines with moderate dimensions. In many cases a correct frequency response up to 1 ... 3 kHz will be sufficient, which means a small number of π-cells. The sensing of the relative low currents in the line model with enough accuracy and without influencing the model can be realized by low shunts and differential amplifiers or by application of a current to voltage transformer. The latter solution may set a limit in the measuring of large time constants.

B.3.3 Source models

In a low power line model the power source can be realized as an electronic circuit with good possibilities for computer control, frequency changes, etc. Also electronic means should be considered for the realization of the source impedance with large time constants.
However, the correct simulation of the generator, including the transient behaviour is rather complicated.

B.3.4 Current transformer models

The basic philosophy in developing CT-models should be that they have the same parametric properties as the real CT and that also they enable the test operator to arbitrarily set the starting conditions for the different parameters.
Once the test sequence is started from a given set of parameters the model should display the actual parameter values at different times during the sequence.
For the representation of the magnetic curve a better approximation than a two segment straight line is desirable. It is assumed that the simulation of hysteresis can be neglected but that the representation of remanence is necessary for gapless-type transformers.
In the CT-model local core saturation is not taken into account.
The modelling of CT's has been described in different papers before

B.3.5 Voltage transformer models

Modelling of inductive or capacitive voltage transformers has been described before .
It appeared that one limiting factor for a scale down of a magnetic VT was the instantaneous power drawn from the primary when the magnetic core enters saturation. Likewise a CVT-model based on the equivalent diagram would require less power than one based on the real diagram.
For magnetic voltage transformers the magnetic circuit should be represented correctly because it interacts with the power system model and amplifiers are not allowed to be interposed.

An isolating amplifier between the network model and the CVT is recommended.
In the modelling of the magnetic characteristics of the core one should take into account the fact that the non-linearity around the kneepoint at high fluxes is important for the correct representation of the line discharge phenomena while the non-linearity at low flux values is also important in the determination of the response of the system during ferro-resonance conditions.

B.3.6 Transmission link models

The transmission link must be modelled in order to get a correct assessment of the response of the protection scheme in the case where the information is transmitted in an analog way, for instance current or voltage balance signals in a differential protection.
The proper attenuation and phase shift of the received signal must be obtained irrespective of the medium or the technique used for transmission (pilot wires, micro wave, PLC, ...). In the case where the information is transmitted in a digital way, for example blocking or permissive signal in directional comparison schemes or phase information in phase comparison schemes the proper time delay must be introduced.
In both above-mentioned cases the influence of externally generated and coupled noise and disturbance is desirable but difficult to reproduce for each specific type of information link.
In most cases the real terminal equipment can be used and only the transmission medium has to be modelled.

B.4 DIGITAL POWER SYSTEM MODELS

B.4.1 General

A typical computer test system is illustrated in fig A.4 .The test conditions are specified from the keyboard of the test computer, using a man-machine dialogue to allow introduction or modification of the test parameters. The corresponding a-c signals (voltages and currents) are calculated, using the appropriate computation routines. In most cases, the calculation of signals cannot be made in real time during the tests, because real time calculation of signals would require a very high computation speed. The signals are calculated off-line and the digital data is stored in the central memory or in the mass memory (magnetic disc) of the test computer. An alternative solution is to use auxiliary memories (e.g. : one memory for each signal to be generated). Then the pre-calculated signals are read at the appropriate speed corresponding to the required power system frequency, converted into analog form through the D/A converters, and applied to the tested relay through low-pass filters (to eliminate sample harmonics) and output amplifiers. The test computer can also apply control signals to the relay under test (e.g. : to simulate tele-signalling from remote end) and monitor the response of the relay to allow further edition or display of test results.

B.4.2 Simulation programs

The basic simulation programs model a three-phase transmission system before and after a single-phase-to-earth fault, a two-phase fault, a two-phase-to-earth fault, or a three-phase fault.
The values of the power system frequency, the system impedances, the point-on-wave of fault initiation are variables in the simulation equations. The position of the fault and the direction in which the relay is looking are adjustable. This information can be declared to the simulation program either by the operator responding to questions from the programs or when it is necessary to prepare a batch of fault programs, pre-loaded data files can be used. This latter technique is particularly valuable when loading library discs. Since the simulation programs used on the test computer are developed using it, they are readily available for modification if required.

When using general purpose simulation programs (e.g. : on main-frame computers) for testing relays, the output data has to be organized into a suitable format by a short utility program.
The test computer may provide test signals simultaneously to two relays located at different points in the power system. For example, with a double-end fed system a fault may be applied between the two sources of generation and the first relay to operate established.
This information is built into the simulation program such that on a subsequent test the relevant circuit-breaker is opened in the power system simulation corresponding to the operation of the first relay. The second relay will therefore experience the correct system conditions following the operation of the first relay.

B.4.3 Digital representation of test signals

Bit resolution

With regard to the large dynamic range of currents and voltages on dynamic tests and to ensure sufficient accuracy on small signals (e.g. : small voltages on close up faults), a high bit resolution is necessary. For instance, a 16 bit resolution will obviate the need for gain switching of output amplifiers.

Sample rate

Figure B 4 .-a gives the total harmonic distortion of a sinusoïdal signal for different values of the number of samples per cycle (sample rate).
Harmonic distortion can be reduced using filtering techniques. Total percentage harmonic distortion has been measured for a system where the output is formed by a linear integration between the sample steps from a pure sinusoïdal waveform.
It can be seen from figure B 4 .-b that the harmonic distortion falls rapidly for sample rates in excess of three samples per cycle and is less than 5 % at 8 samples per cycle.
It is important to recognize that the overall harmonic distortion in each channel is influenced further by the frequency response of the output amplifier.

The magnitude of the phase angle error in the output signal due to the sample rate can be calculated. The magnitude of the maximum error due to linear integration between the samples has been plotted in figure B 4 -c.
This error can cause the output signal to lead or lag the intended signal depending on the point-on-wave of the samples. The overall phase angle error in each channel has to include the influences of the output amplifiers together with the errors indicated in figure B 4 -c.

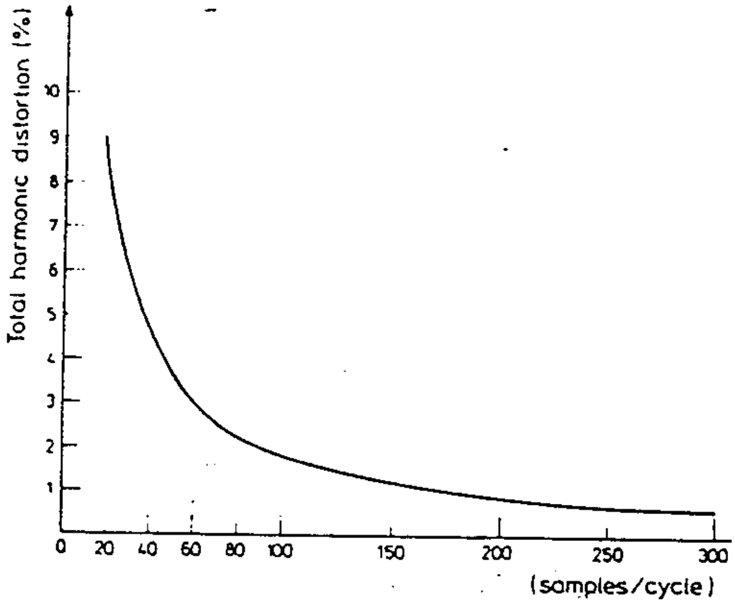


Fig B 4 -a :
relationship between sampling frequency and harmonic distortion

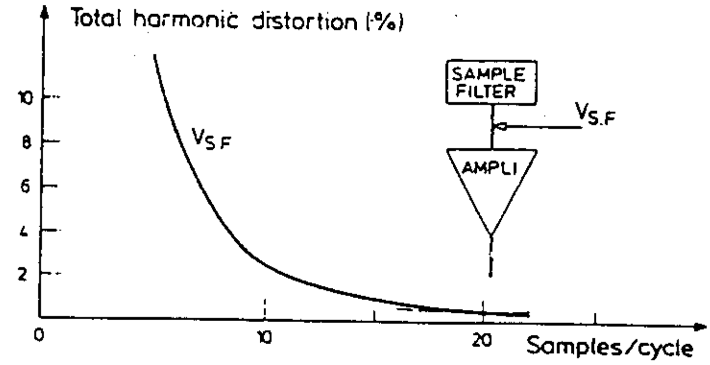


Fig B 4 -b :
reduction of sampling frequency by filtering

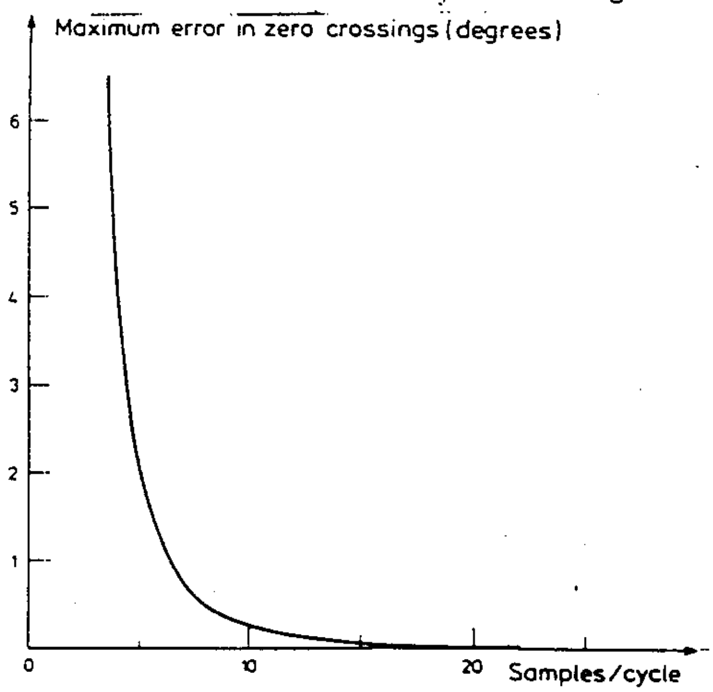


Fig B 4 -c : relationship between sampling frequency and phase angle error

Table B.2-a : Current amplifiers for tests on power system models

<table>
<tr><td rowspan="8">Power frequency currents</td><td colspan="2">frequency range</td><td>0.94 ... 1.02 times rated frequency</td></tr>
<tr><td colspan="2">current range</td><td>0.2 ... 40 times rated current</td></tr>
<tr><td rowspan="3">maximum amplitude and phase-angle errors</td><td>at rated current</td><td>1% - 1°</td></tr>
<tr><td>at maximum current</td><td>3% - 3°</td></tr>
<tr><td>at minimum current</td><td>2% - 2°</td></tr>
<tr><td rowspan="2">current capacity</td><td>continuously</td><td>3 times rated current</td></tr>
<tr><td>short time</td><td>40 I_N during 0.1 s</td></tr>
<tr><td colspan="2">peak current (*)</td><td>100 I_N (full d.c. offset)</td></tr>
<tr><td rowspan="2">D.c. components</td><td colspan="2">maximum time constant</td><td>150 ms (500 ms)</td></tr>
<tr><td colspan="2">maximum instantaneous error</td><td>for max. output current (40 I_N) with 100% d.c.-offset, the instantaneous error shall not exceed 5% of the peak value of the a.c.-component</td></tr>
<tr><td rowspan="3">Power frequency harmonics</td><td colspan="2">max. harmonic rank</td><td>2 ... 10 times rated frequency</td></tr>
<tr><td colspan="2">max. harmonic current</td><td>100% divided by K (K = f/f_N)</td></tr>
<tr><td colspan="2">max. amplitude and phase-angle errors</td><td>5% - 1° times K (K = f/f_N)</td></tr>
<tr><td rowspan="3">Line oscillations (**)</td><td colspan="2">frequency band</td><td>up to 1 ... 3 kHz</td></tr>
<tr><td colspan="2">current range</td><td>0.2 ... 2 I_N</td></tr>
<tr><td colspan="2">max. amplitude and phase-angle errors</td><td>5% - 1° times K (K = f/f_N)</td></tr>
<tr><td colspan="3">Max. harmonic distortion</td><td>1% divided by K (K = f/f_N)</td></tr>
<tr><td colspan="3">Offset output current</td><td>max. 5 mA (Monitoring for excessive offset and automatic balancing should be provided)</td></tr>
<tr><td rowspan="3">Step response</td><td colspan="2">response time (95%)</td><td>< 60 µs (3 kHz, 10 A)</td></tr>
<tr><td colspan="2">slew rate (100 A step)</td><td>0.5 ... 1 A/µs</td></tr>
<tr><td colspan="2">overshoot</td><td>< 2%</td></tr>
<tr><td colspan="3">Common mode rejection factor</td><td>60 dB through whole frequency band</td></tr>
<tr><td colspan="3">Signal-to-noise ratio</td><td>50 dB at rated current</td></tr>
<tr><td colspan="3">Rated burden</td><td>0.5 - 1 - 2 VA, time constant 0.5 ... 1 ms</td></tr>
</table>

(*) corresponding peak voltage 100 P_N/I_N where P_N = rated burden

(**) e.g. pi - cell representation of the line

Table B.2-b : Voltage amplifiers for tests on power system models

Power frequency voltages	frequency range		0.94 ... 1.02 times rated frequency
	voltage range		0.1 ... 200 of rated phase-to-earth voltage
	maximum amplitude and phase-angle errors	from 20% to max. voltage	1% - 1°
		at 5% of rated voltage	2% - 2°
		at 0.1% of rated voltage	5% - 3°
	current capacity	continuously	2 times rated phase-to-earth voltage with rated burden
		short time	1 A during 0.1 s
D.c. components	maximum time constant		150 ms (500 ms)
	maximum instantaneous error		for rated output voltage with 20% d.c.-offset, the instantaneous error shall not exceed 5% of the peak value of the a.c.-component
Harmonics and line oscillations	frequency band		20 Hz ... 3000 Hz
	voltage range		0.1% ... 100% of rated phase-to-earth voltage
	max. amplitude and phase-angle errors		5% - 1° times K (K = f/f_N)
Max. harmonic distortion			2%
Offset output voltage			max. 5 mV
Step response	response time (95%)		< 60 µs (3 kHz, 60 V sine wave)
	overshoot		< 2%
Max. common mode voltage			250 V (for connection to line model)
Common mode rejection factor			60 dB through whole frequency band
Signal-to-noise ratio			70 dB at rated voltage
Rated burden			5 VA, power factor 0.7 (lead or lag)

Publié par le CIGRÉ
21, rue d'Artois
FR-75 008 PARIS
Tél. : +33 1 53 89 12 90
Fax : +33 1 53 89 12 99

Published by CIGRE
21, rue d'Artois
FR-75 008 PARIS
Tel : +33 1 53 89 12 90
Fax : +33 1 53 89 12 99