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Simulation of protection functions in LV shipboard electrical power systems

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Abstract. The basic function of a shipboard electric power systems is to supply all consumers, both essential and non-essential, with electrical energy, as economically as possible and with an acceptable degree of quality. A shipboard electrical power system comprises three principal subsystems: generation (naval power plant-island mode plant), distribution and protection and automation. During operation all these subsystems may be affected by faults. In this aim all electrical installations on shipboards are to be protected against over-currents due to short-circuits or accidental overloads. The new ABB air circuit-breakers Emax 2 and Tmax T series can be used both as main circuit-breaker in low voltage generation and distribution systems. In addition to protection, the new air ABB circuit-breakers offer possibility of communication which are particularly suitable for automation, control, measurements, grid analysis, and energy savings. ABB Relays are high-performance electronic units for these circuit breakers. Their basic function is to monitor and protect the electric systems against fault current. The units also includes: measuring, data storage, communication, self-test, load control and zone selectivity functions for these circuit-breakers. This paper presents the analysis of protections and simulates how to trigger protections within shipboard power systems.

1. Introduction

A protection relay is a special type of relay which monitors the following electrical parameters such as: [1]

- intensity of current I[A]
- voltage U[V]
- frequency f[Hz]
- active power P[W]

from a generating source (alternators) or loads (electric motors and power transformers) with the purpose triggering one or more circuit breakers to open an one circuit or more circuits (feeders) in the case of a fault condition (overloads and short-circuits). For example in the low voltage shipboard power systems the protective function are implemented inside the circuit breaker itself.

The aim of protective relays are:

- to increase the shipboard safety of electric power systems
- to avoid the black-outs
- to prevent alternators, electric motors, power transformers damage in advance
- to be able detect already occurred faults (overloads and short-circuits) to limit further damage of electrical equipment

2. MNS 3.0 low voltage main switchboard for shipboard applications

Each section of MNS 3.0 LV main switchboard is divided into more compartments (cubicle) thus separating different functional zones (figure 1 and figure 2) [3]:

- Incoming circuit breaker technical solution
  - Electrical equipment compartment (circuit breaker compartment)
  - Bus-bar systems compartment
- Outgoing solution
  - Electrical equipment compartment (motor starter modules – motor control centre MCC)
  - Cable compartment (power cables and control cables, terminals and connection units)
  - Bus-bar system compartments

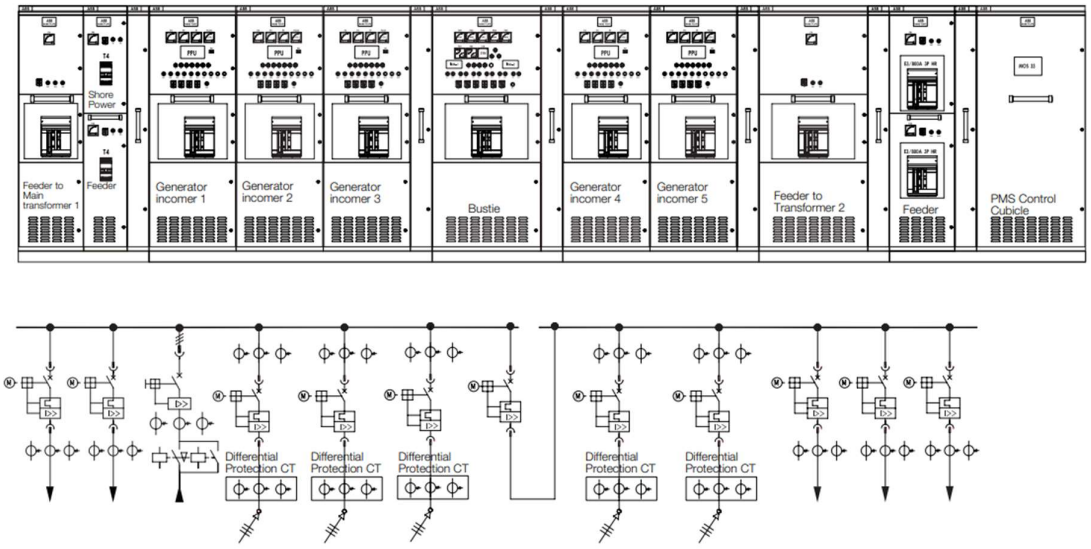
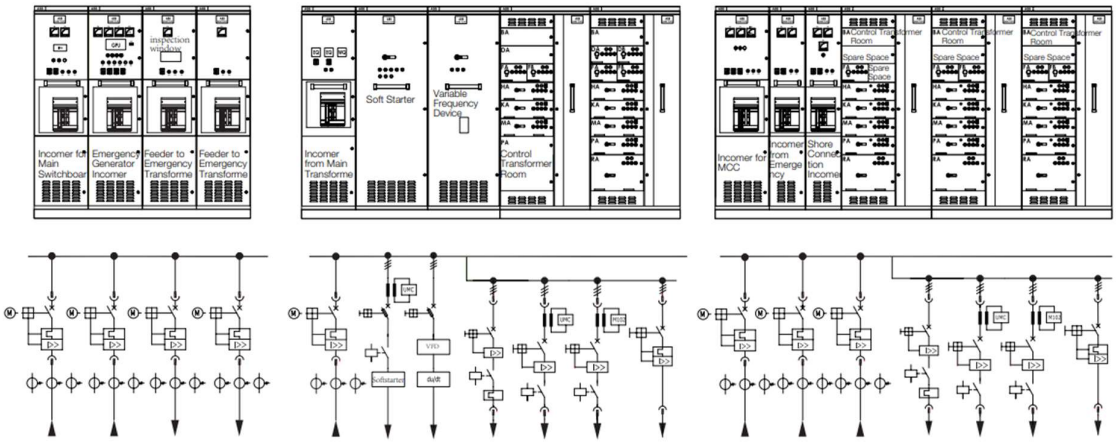


Figure 1. A general arrangement drawing and single line diagram of MNS 3.0



a) b) c)

Figure 2. MNS 3.0
a) Emergency Switchboard
b) MCC (motor control centre) cubicle
c) Emergency MCC (motor control centre) cubicle

In order to satisfy all requirements there are three main switch incoming options (figure 3):

- Load break switches
- Molded case circuit breakers (MCCBs)
- Air circuit breakers (ACBs).

In addition to the above ABB circuit breakers offer a series of integrated programmable releases (PRs), where combinations of protection functions maybe selected with [3]:

- Overload protection (LTD – long time delay)– L
- Selective short circuit protection (STD – short time delay)– S
- Instantaneous short circuit protection (INST – instantaneous)– I
- Earth (ground) fault protection – G (in case of alternators)

Figure 3. 3D view of the MNS breaker compartment and Emax breaker with PR123/P trip unit

Figure 4. Synchronizing and distribution cubicle of MNS 3.0

3. Single line diagram of shipboard power systems and time-current characteristics

In order to simulate the protections as input data, the following are taken into account [2], [7], [8]:

- single line diagram of electric power system (figure 5)
- ACB (air circuit breaker) trip setting list and trip diagram (LSI) (figure 6)
- Single line diagram of protection systems and measuring and control equipment (figure 7)

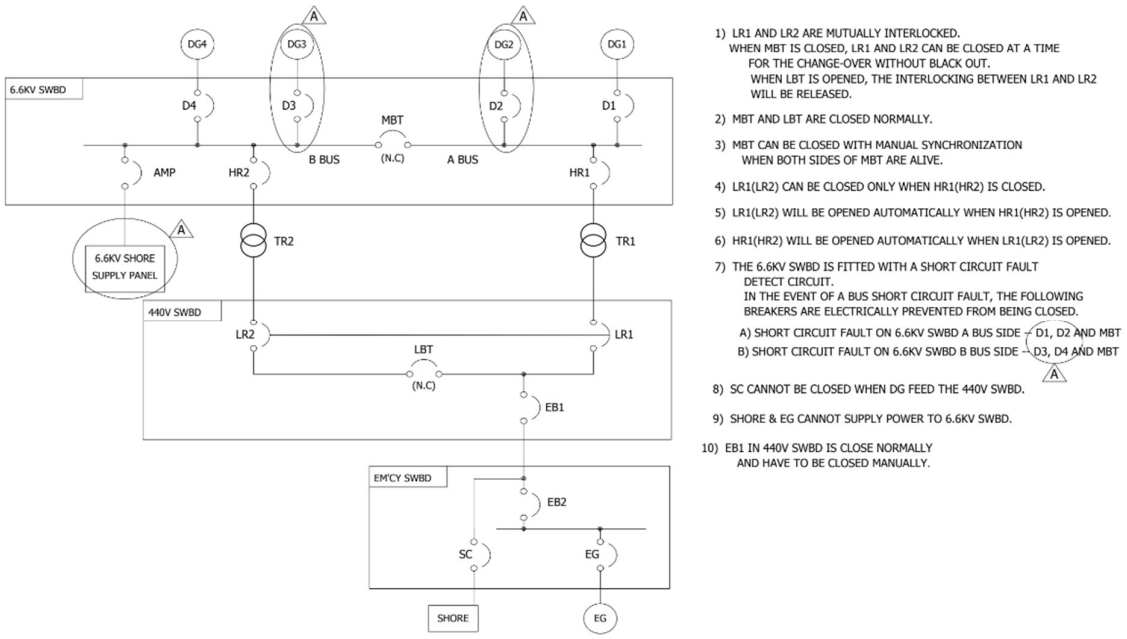


Figure 5. Single line diagram of Electric Power System of container ship

					HM1502A~V HM2302A~V		BUS TIE		LM1215A~D	
AIR CIRCUIT BREAKER	TYPE				UAN-63D(MRD)		UAN-63D(MRD)		UAN-08A(MRD)	
	NUMBER OF POLE				3P		3P		3P	
	VOLTAGE				AC 450V		AC 450V		AC 450V	
	FREQUENCY				60Hz		60Hz		60Hz	
	AMPEREFRAME				6300AF		6300AF		800AF	
	BASE CURRENT			Ict / In	6300A / 5004A		6300A		700A	
	OVERCURRENT TRIP	TYPE			UPR-SA		UPR-SA		UPR-SA	
		LONG TIME DELAY TRIP (LTD)	PICK UP CURRENT Ir = In x RANGE	RANGE	0.8-1.25-NON		0.8-1.25-NON		0.8-1.25-NON	
				SET / AMP	1.0	5004A	NON	-	1.0	700A
			OPERATING TIME(IrxX120%)		40SEC AT I1x120%		40SEC AT I1x120%		40SEC AT I1x120%	
		SHORT TIME DELAY TRIP (STD)	PICK UP CURRENT Is = Io x RANGE	RANGE	2.0-5.0-NON		2.0-5.0-NON		2.0-5.0-NON	
				SET / AMP	3.0	15012A	2.0	12600A	4	2800A
			OPERATING TIME		400mSEC		300mSEC		200mSEC	
		INST TRIP	PICK UP CURRENT Ii = Io x RANGE	RANGE	4-16-NON		4-16-NON		2-15-NON	
				SET / AMP	10	50.04KA	NON	-	NON	-
	TRIPPING DEVICE		UVT OR SHT		UVT(0.5 SEC)					
			TYPE		UANS-V2					
			OPERATING TIME							
			OPERATING VOLTAGE							

<< NOTE >>
1. ACB TYPE DESIGNATION

UAN-63 - M R D
(1) (2) (3) (4)

(1) ACB TYPE

(2) CLOSING MECHNISM
E- ELECTROMAGNETIC SOLENOID OPERATION
M- STORED ENERGY (MOTOR & MANUAL CHARGE)
H- STORED ENERGY (MANUAL CHARGE)

(3) OVERCURRENT TRIP DEVICE
R (APR)-SOLID STATE TYPE LTD & STD TRIP
L (APL)- THERMAL MAGNETIC TYPE STD TRIP
N - NONE

(4) MOUNTING
F- FIXED TYPE
D- WITHDRAWABLE TYPE

2. INST TRIP DEVICE
AIT - ELECTROMAGNETIC TYPE INST TRIP

3. DEFINITION OF EACH CURRENT AND OPERATING TIME

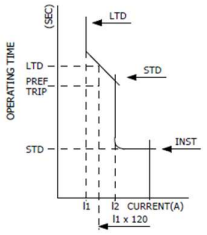


Figure 6. ACB trip settings list and trip diagram

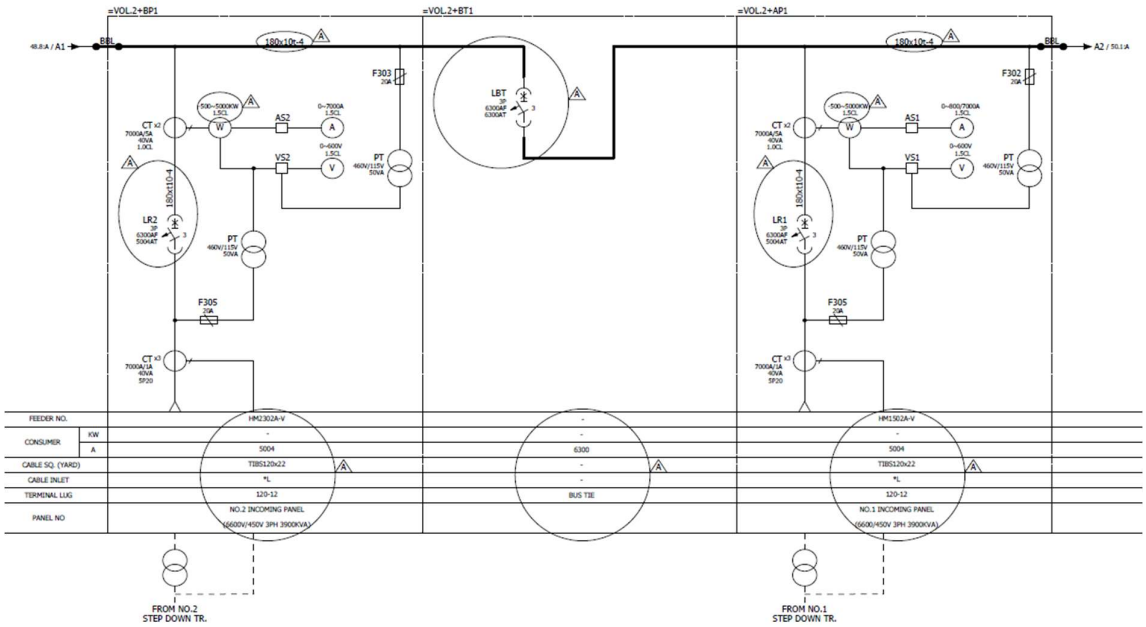


Figure 7. Single line diagram of protection systems, measuring and control equipment

4. Protection simulation results with the ABB PR123/P trip unit

ABB PR123/P is a high-performance trip unit, capable of offering a complete set of functions for protection, measurement, signalling, data storage, command and control of the low voltage Emax series of ABB air circuit-breaker.

The protection functions of PR123/P trip unit are [4], [5], [6], [9], [11]:

- overload (L) (In accordance also with IEC 60255-3 Standard)
- selective short-circuit (S)
- instantaneous short-circuit (I)
- earth fault with adjustable delay (G) (The current values is disabled and are indicated in the installation manual)
- directional short-circuit with adjustable delay (D)
- phase unbalance (U)
- protection against over-temperature (OT)
- load control (K)
- under-voltage (UV)
- overvoltage (OV)
- residual voltage (RV)
- reverse power (RP) (only in the case of generators)
- under-frequency (UF)
- over-frequency (OF)
- phase sequence (alarm only).

The data presented in Figure 6 are used to simulate the tripping of protection for HM1502A ~ V HM2302A ~ V circuits.

Figure 7 shows the protection simulation results using the PR123/P trip unit. ABB trip simulator was used to achieve this.

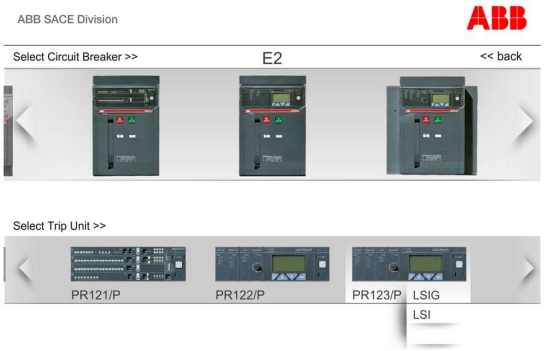


ABB SACE Division
Select Circuit Breaker >>
E2
<< back
Select Trip Unit >>
PR121/P
PR122/P
PR123/P
LSIG
LSI

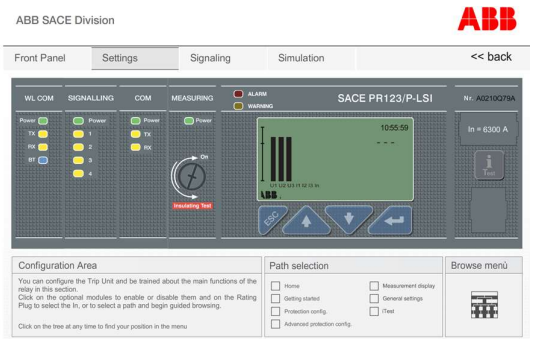


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
In = 6300 A
Configuration Area
Path selection
Browse menù

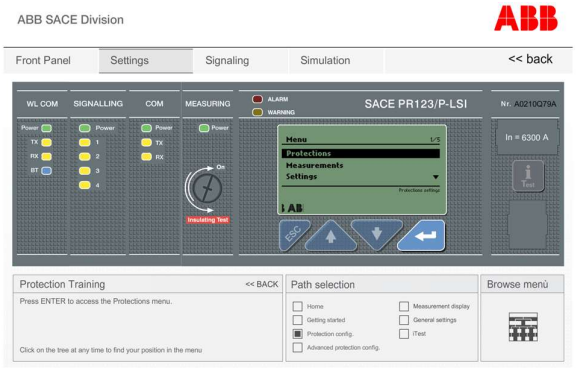


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
Menu
Protections
Measurements
Settings
In = 6300 A
Protection Training
<< BACK
Press ENTER to access the Protections menu.
Path selection
Browse menù

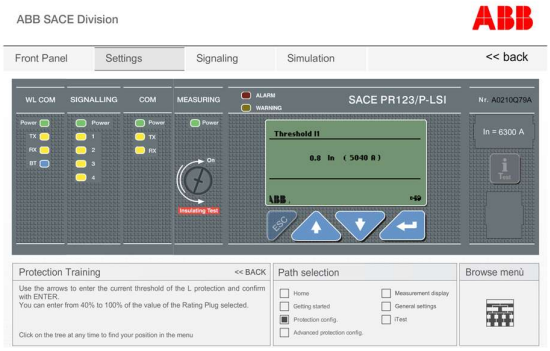


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
Threshold I1
0.8 In (5040 A)
In = 6300 A
Protection Training
<< BACK
Use the arrows to enter the current threshold of the L protection and confirm with ENTER.
You can enter from 40% to 100% of the value of the Rating Plug selected.
Path selection
Browse menù

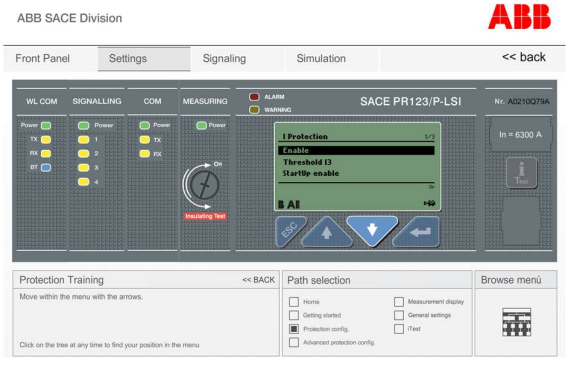


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
I Protection
Enable
Threshold I3
StartUp enable
In = 6300 A
Protection Training
<< BACK
Move within the menu with the arrows.
Path selection
Browse menù

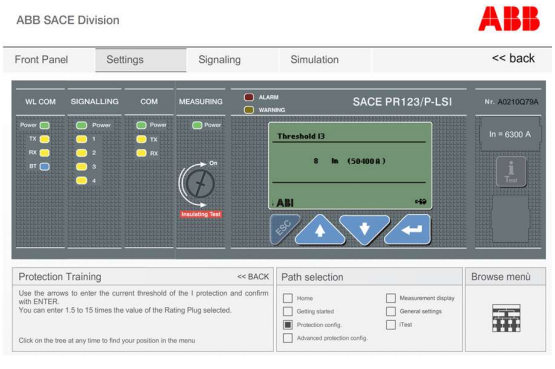


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
Threshold I3
8 In (50400 A)
In = 6300 A
Protection Training
<< BACK
Use the arrows to enter the current threshold of the I protection and confirm with ENTER.
You can enter 1.5 to 15 times the value of the Rating Plug selected.
Path selection
Browse menù

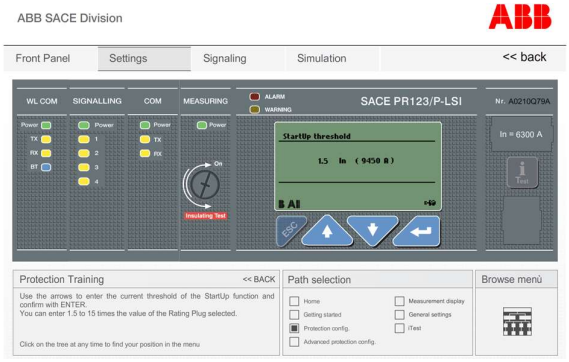


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
StartUp threshold
1.5 In (9450 A)
In = 6300 A
Protection Training
<< BACK
Use the arrows to enter the current threshold of the StartUp function and confirm with ENTER.
You can enter 1.5 to 15 times the value of the Rating Plug selected.
Path selection
Browse menù


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
SACE PR123/P-LSI
L Prealarm
Prealarm
L protection simulation
Prealarm condition: current value between 90% and 105% of I1, current threshold set for L protection.
Orange Warning LED on with steady light and protection in prealarm message on display.
Click on NEXT>> to proceed
Select protection
NEXT >>
In = 6300 A

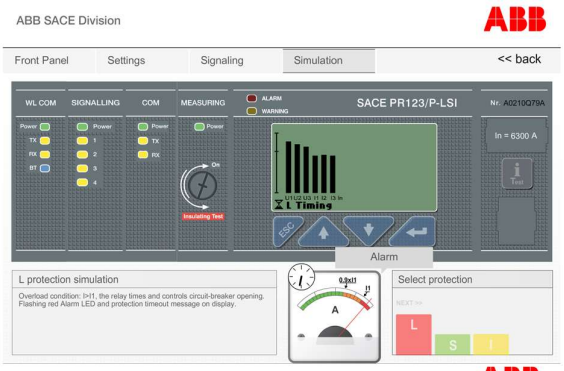


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
In = 6300 A
Σ L Timing
Alarm
L protection simulation
Overload condition: I>I1, the relay times and controls circuit-breaker opening.
Flashing red Alarm LED and protection timeout message on display.
Select protection
NEXT >>
L
S
I

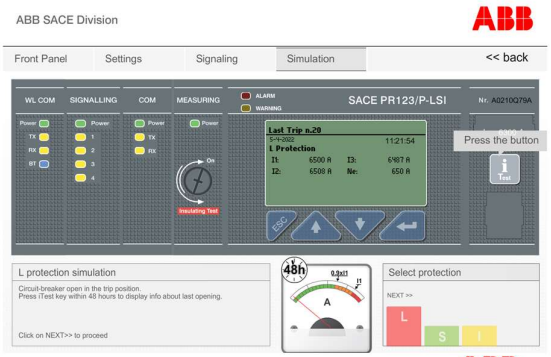


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
Last Trip n.20
11:21:54
L Protection
Press the button
L protection simulation
Circuit-breaker open in the trip position.
Press iTest key within 48 hours to display info about last opening.
Click on NEXT>> to proceed
48h
Select protection
NEXT >>
L
S
I

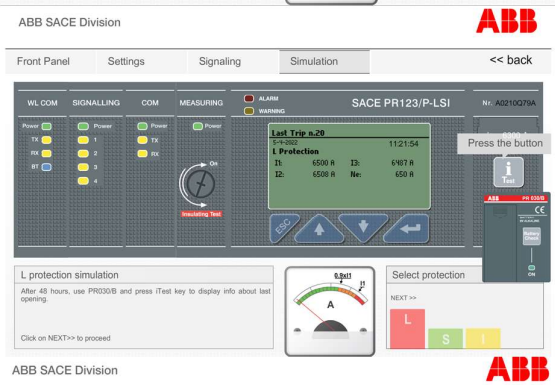
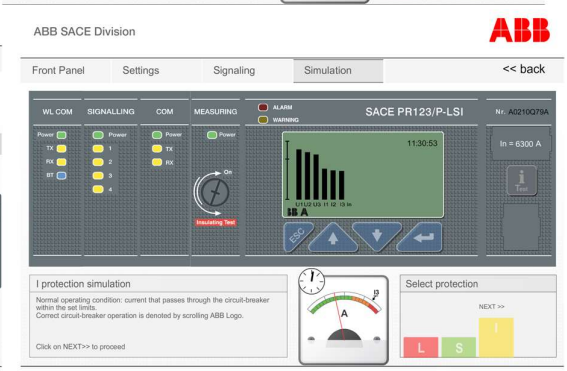


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
Last Trip n.20
11:21:54
L Protection
Press the button
L protection simulation
After 48 hours, use PR030/B and press iTest key to display info about last opening.
Click on NEXT>> to proceed
Select protection
NEXT >>
L
S
I


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
11:25:17
In = 6300 A
S protection simulation
Normal operating condition: current that passes through the circuit-breaker within the set limits.
Correct circuit-breaker operation is denoted by scrolling ABB Logo.
Click on NEXT>> to proceed
Select protection
NEXT >>
L
S
I


ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
Last Trip n.20
11:29:37
S Protection
Press the button
S protection simulation
After 48 hours, use PR030/B and press iTest key to display info about last opening.
Click on NEXT>> to proceed
Select protection
NEXT >>
L
S
I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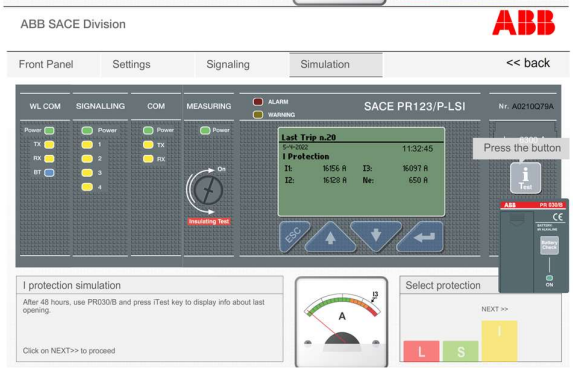
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
11:30:53
In = 6300 A
I protection simulation
Normal operating condition: current that passes through the circuit-breaker within the set limits.
Correct circuit-breaker operation is denoted by scrolling ABB Logo.
Click on NEXT>> to proceed
Select protection
NEXT >>
L
S
I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Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
Last Trip n.20
11:32:45
I Protection
Press the button
I protection simulation
After 48 hours, use PR030/B and press iTest key to display info about last opening.
Click on NEXT>> to proceed
Select protection
NEXT >>
L
S
I

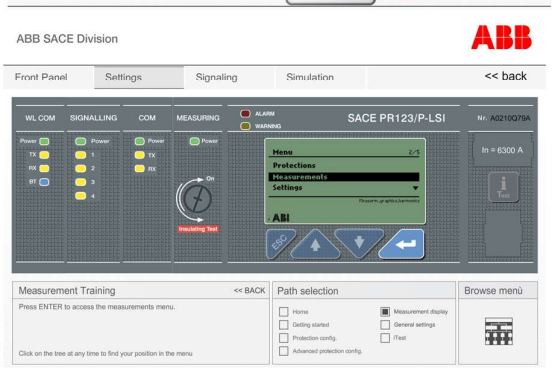
ABB SACE Division
Front Panel
Settings
Signaling
Simulation
<< back
WL COM
SIGNALLING
COM
MEASURING
ALARM
WARNING
SACE PR123/P-LSI
Nr. A0210Q79A
In = 6300 A
Menu
Protections
Measurements
Settings
Measurement Training
<< BACK
Press ENTER to access the measurements menu.
Click on the tree at any time to find your position in the menu
Path selection
Home
Getting started
Protection config.
Advanced protection config.
Measurement display
General settings
iTest
Browse menù

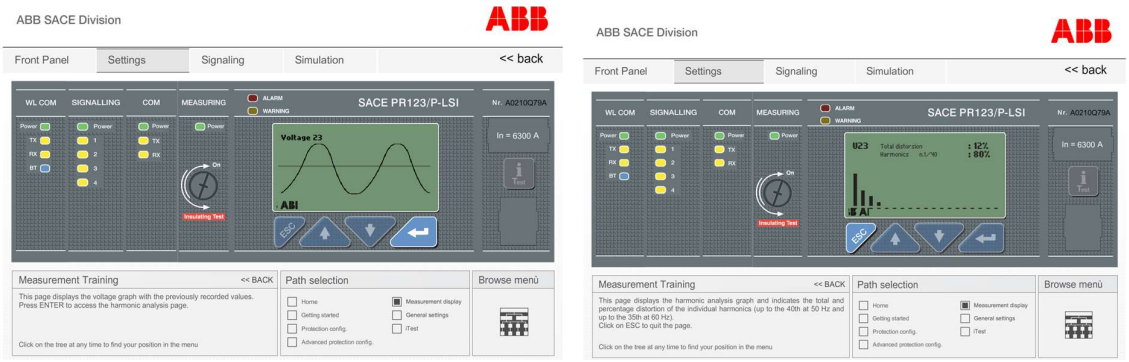

Figure 8. Protection simulation results with the PR123P trip unit that equips the ABB EmaxX1 circuit breakers

5. Conclusions

The protection relay of an electrical networks as complex as electrical ship power plants must be designed as a whole. The process of designing protection systems is laborious and difficult because it requires the calculation of short-circuit currents in order to choose the switching equipment.

Figure 8 shows the steps of the simulation algorithm for the main protection functions: overload (L), selective short-circuit (S) and instantaneous short-circuit (I). For this, the ABB simulation program was used with the electronic circuit breaker trip unit SACE PR123/P which includes three main parts: settings, signalling and simulation of protection functions.

Also another important feature of the trigger unit is the ampere-frame. In the simulation presented in figure 8 the value of the nominal current of two identical circuits is 5004A. Particular importance must be paid to the correct choice of circuit breaker tripping unit.

The tripping threshold of the protection is calculated according to the rated current for both overload protection and short circuit protection. At the same time, a correct evaluation of the short-circuit currents as a result of the thermal and electro-dynamic effects resulting from their occurrence is necessary. As can be seen from Figure 7, the two circuits have the same rated current because the two 6.6 / 0.45kV distribution transformers have the same nominal rated power of 3900kVA. The rated current corresponding to the choice of the two circuit breakers LR1 and LR2 is the rated current of the secondary winding of the two identical transformers.

The PR123/P trigger unit also includes the measurement part of the main electrical parameters (currents, voltages, powers, power factor, THD, energies). During the measurement simulation, only two parameters were analysed, namely voltage wave and total harmonic distortion.

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