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STUDY AND DESIGN OF ENLARGED
AUTOMATED TEST STATION FOR
GRID AUTOMATION CONTROL
CABINETS

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FOREWORD

This thesis is made for ABB Grid Automation unit as a part of Electrical Engineering studies in the School of Technology VAMK, University of Applied Science.

I would like to thank my thesis supervisor Sören Mattbäck, Solutions Manager, from ABB who gave me opportunity to do this work. I would also like to thank Olavi Mäkinen, Principal Lecturer, who was my mentor from VAMK, University of Applied Science.

Furthermore I would like to thank all those persons who gave me valuable advices and helped me during my thesis work.

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ABSTRACT

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The purpose of this thesis was to get acquainted with the routine testing of Control Cabinet which ABB manufactures as part of medium voltage product portfolio. The objective of the thesis was to study how product testing could be automatized due to increasing production volume. Due to the product family consisting of indoor and outdoor solutions the subject was limited to develop testing for GAO3 level outdoor control cabinets but keeping in mind that solutions need be modular for other cabinet models.

In our thesis launch meeting the need of test specification came up and decision to create it as a part of this thesis set the start further than originally was planned. Partly from that reason time was left for only comparing the hardware and the implementation itself was left to a later time period.

The theory part of this thesis presents how Control Cabinets are positioned in the distribution network and the construction of entire solution from primary device to control cabinet itself. ABBs manuals and brochures were used as sources for this.

The test specifications broadly define which standard are met when the testing is done according the specifications. Tests which may vary depending on the model, different options are given in the test specifications. The test specifications are based on the product related IEC – standards. In the hardware comparison some of the devices were asked for test use and some were compared according to available manuals and brochures.

Along with the creation of the test specification it became clear to which standard testing is related today and what changes are required if the testing is decided to be organized according to the “worst-case” situation. Also matters that need to be solved before the automatization were discovered during this thesis. The created test specifications and hardware comparison are as separate documents.

Keywords Smart Grid, Distribution Automation, Routine testing

TIIVISTELMÄ

Tekijä	Antti Puisto
Opinnäytetyön nimi	Jakeluverkon ohjainkaapin automatisoidun testiaseman tutkiminen ja suunnittelu.
Vuosi	2016
Kieli	englanti
Sivumäärä	52 + 1 liite
Ohjaaja	Olavi Mäkinen

Tässä työssä perehdyttiin ABB:n valmistamien keskijännitepuolen ohjainkaappien tuotannontestaukseen. Työn tavoitteena oli tutkia kuinka tuotannontestausta voitaisiin automatisoida kasvavan tuotantovolyymien vuoksi. Koska tuoteperheeseen kuuluu sekä ulko- että sisäkäyttöön tarkoitettuja eritasoisia ohjainkaappeja, päätettiin työtä rajata siten, että testauksen kannalta perehdyttiin ensisijaisesti ulkokäyttöön tarkoitettujen GAO3 -tason ohjainkaappien testauksen kehittämiseen, ottaen kuitenkin huomioon modulaarisuuden tarve muiden mallien osalta.

Aloituspalaverissa ilmennyt testispeksin tarve ja päätös sen tekemisestä osana tätä päättötyötä siirsi työn aloituspistettä kauemmaksi, kuin alun perin oli suunniteltu. Osaltaan tästä syystä aika riitti testispeksin lisäksi vain potentiaalisen laitteiston vertailuun itse toteutuksen jääden myöhemmälle ajankohdalle.

Tämän työn teoriaosuudessa on esitelty laitteiston rakenne ja tuoteperheen asemoituminen osana sähkönjakeluverkkoa sekä sen rooli osana verkostoautomaatiota. Lähteinä näihin on käytetty ABB:n omia manuaaleja ja esitteitä. Pääpiirteiltään kuvattuna testispeksi määrittelee, mitkä standardit täytyvät, kun tarkastukset ja testaus tehdään määrittelyjen mukaisesti. Testeihin, joiden toteuttaminen eri tuotteilla saattaa vaihdella, vaihtoehdot ovat kirjattuina testispeksiin. Testispesifikaatiot pohjautuvat tuotteelle relevantteihin IEC -standardeihin. Laitevertailuissa osaa laitteista pyydettiin saada kokeiltavaksi ja osaa vertailtiin saatavilla olleiden esitteiden ja manuaalien perusteella.

Testispesifikaatioiden tekemisen myötä selvisi, mihin standardiin nykyinen testausprosessi pohjautuu ja minkälaisia muutoksia tulisi käytäntöihin tehdä, mikäli halutaan testata tuote vaativamman näkökulman kautta. Myös testausprosessia hidastavat ja ennen automatisointia tarvittavat toimenpiteet selvisivät työn aikana. Tehty testispesifikaatio ja laitteistovertilu jätettiin erillisiksi dokumenteiksi.

Avainsanat	älykkäät sähköverkot, sähkönjakeluverkon automaatio, rutiinitestaus
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CONTENTS

FOREWORD

ABSTRACT

TIIVISTELMÄ

LIST OF FIGURES AND TABLES

DEFINITIONS AND ABBREVIATIONS

1	INTRODUCTION	11
1.1	Objective of Thesis	11
1.2	ABB	11
1.3	ABB Grid Automation, Control Cabinets.....	12
2	SMART GRID.....	13
2.1	Definition	13
2.2	ABB`s Definition for Smart Grid	14
2.3	Distribution Automation	14
2.4	Advanced Distribution Automation.....	14
3	ABB ZONE CONCEPT	16
3.1	Means to Increase Reliability.....	16
3.2	Zones.....	17
3.3	Benefits and Opportunities	17
3.4	Properties of Disconnecter, LBS and Recloser.....	18
3.5	Future	19
3.6	Communication.....	19
4	REMOTE CONTROLLABLE LBS.....	21
4.1	Primary Switching Device SECTOS	21
4.1.1	Structural Features	24
4.2	Optional Measurements	25
4.2.1	Current transformer	25
4.2.2	Voltage Transformer	28
4.2.3	Sensors	30
4.3	Control Cabinet.....	34
4.3.1	Features	36

	5
4.3.2 IED	36
4.3.3 Wireless gateway RER601 and RER603	41
5 FACTORY TESTING DEVELOPMENT	43
5.1 Quality management systems	44
5.2 Factory Testing Today	44
5.2.1 Visual Inspection.....	45
5.2.2 Wiring Inspection (“Ringing” According Wiring Diagrams).....	45
5.2.3 Isolation Resistance Test.....	45
5.2.4 Functional Tests	45
5.3 Control Cabinet Testing and Related Standards	45
5.4 Creation of Test Specification	46
5.4.1 Defined Inspection Order	46
5.4.2 Differences Between Used Standards	47
6 CONCLUSIONS	49
APPENDICES	

LIST OF FIGURES AND TABLES

Figure 1. Different zones presented. /10/	17
Figure 2. Simple disconnecter and controlgear combination. /7/	18
Figure 3. Remote Controllable LBS with build in measurements. /5/	19
Figure 4. Different SECTOS models. /5/	22
Figure 5. SECTOS NXA parts described more precisely. /9/	23
Figure 6. The operate box without a motor controller and with it. /9/	23
Figure 7. Principle switching positions of different SECTOS models. /5/	24
Figure 8. Principle picture from CT structure. /20/	26
Figure 9. SECTOS LBS with mounted CTs. /5/	27
Figure 10. TDO 6 type of voltage transformer. /2/	28
Figure 11. Typical connection options for VT: s. /20/	29
Figure 12. Cross section of a VT and its main parts. /14/	29
Figure 13. Principle of resistive voltage divider. /14/	31
Figure 14. Principle of capacitive voltage divider. /14/	31
Figure 15. Rogowski-coil principle. /28/	32
Figure 16. Cross-section from combi sensor and its main parts. /14/	33
Figure 17. SECTOS with three combi sensors and voltage sensors. /5/	34
Figure 18. Control Cabinet /8/	35
Figure 19. Principle of Control Cabinet & primary device solution. /8/	35
Figure 20. Positioning of Relion 615 –series relay slots/connections. /13/	40

Figure 21. Communication module options. /13/	40
Figure 22. Module options for Slot X130. /11/	41
Figure 23. Wireless gateway RER601. /6/	42
Figure 24. Communication solution example. /33/	43
Table 1. REC615 number of physical connections. /13/	38
Table 2. Location of different modules in REC615. /13/	39
Table 3. Features of RER601 and RER603 /6/	42

DEFINITIONS AND ABBREVIATIONS

ABB	ASEA Brown Boveri, multinational industrial company
ADA	Advanced Distribution Automation
ANSI	American National Standards Institute
CB	Circuit Breaker
CT	Current Transformer
DA	Distribution Automation
DMS	Distribution Management System
EDGE	Enhanced Data rates for GSM Evolution
FLIR	Fault Location, Isolation and Restoration
GOOSE	Generic Object Oriented Substation Event, communication protocol for horizontal data transfer between IED devices defined in IEC 61850 standard
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
ICT	Information and Communications Technology
IEC	International Electro technical Commission
IED	Intelligent Electronic Device
ISO	International Organization for Standardization
LBS	Load Breaker Switch
LCD	Liquid-Crystal Display

RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SF6	Sulfur hexafluoride
VT	Voltage Transformer

LIST OF APPENDICES

APPENDIX 1. Connection diagrams for REC615

1 INTRODUCTION

1.1 Objective of Thesis

Increasing demands on the quality of electricity sets network companies pressure to level up their network dependability. In 2010 Energiateollisuus ry. gave recommendations to distribution reliability levels to be met in 2030.

The majority part of interruptions takes place in over-head line sections and in many cases the interruption is caused by climatic conditions such as storms bringing down trees or snow weight on the lines. /22/

Grid automation helps locating faults, limits fault zones and helps repairing and shorten distribution interruptions by these means. /7/

All this becomes apparent as increasing demand of grid automation and furthermore sets challenges to production volume of these devices.

1.2 ABB

ABB (ASEA Brown Boveri) is the world's leading power and automation technology company. ABB headquarters are located in Zürich Switzerland. ABB has approximately 140 000 employees in 100 different countries, 5200 of those work in Finland. ABB's business activities consists of four different divisions which are divided according to customer segments and different industrial sectors.

The company was founded in 1888 but its history reaches over 120 years back. The key to ABB's success has particularly been strong investment in research and development. The company has seven research centers all over the world and investment in development has continued in all marketing situations.

The result of that is a long list of innovations. ABB has developed and commercialized many technologies which work as a base to modern society. ABB is also the leader supplier in industrial electric motors, frequency convertors, wind turbine generators and power grid networks.

In Finland ABB has business activities in 21 places and factories in three different places: Helsinki, Porvoo and Vaasa. /19/

1.3 ABB Grid Automation, Control Cabinets

ABB manufactures many solutions for grid automation and making it more intelligent. One of the solutions ABB offers is control cabinets which are used to control medium voltage primary devices such as disconnectors, LBSs (Load Breaker Switch) or CBs (Circuit Breaker). Control cabinets include functions such as: communication, control, monitoring, protection and self-surveillance. Control cabinets are divided to 4 different levels according to its functions. /17/

In this thesis the focus was on studying the testing of control cabinets: which tests should be performed, how to do them, how testing is done today and to plan how it should be done in the future. The goal was to propose how to develop factory routine testing to be more automatized, safe, faster, and completed in the same way regardless from the test operator. The work was started by getting acquainted with the situation today, monitoring how testing was done and comparing the test procedure to the relevant standards. To ensure that tests are made according to relevant and up to date standards, the creation of test specifications was decided to be done as a part of this thesis.

2 SMART GRID

In this thesis the focus was on developing testing for devices which are used in medium voltage distribution networks. Because of that reason this thesis covers smart grids mainly on the part of distribution automation.

2.1 Definition

The definition of intelligent distribution network - Smart Grid - is still nonspecific. Basically it is a renewal concept for energy systems where new energy and data solutions are used in every field of the energy system from production to consumption. /3/

Inventions such as self-healing electrical grid has not been developed yet. Self-healing in this case means operation which returns power distribution to its normal state. A self-healing network locates the fault, isolates it from the healthy part of network and returns power to other parts. Requirements for this are suitable network structure, spare feeder route, distribution automation, precise fault locating and intelligence to sum and utilize all this. /15/

The Smart Grid should be defined by its functionality and functional properties more than just according to its technical solutions. Usually Smart Grid definition means change towards multi-vendor environment in power transfer and distribution networks where the customer can be both an energy producer and consumer. When distributed intelligence and IEDs (Intelligent Electronic Device) utilize advanced ICT (Information and Communications Technology) data processing, the operator in control room can work more efficiently by the means of automatic functions in local apparatus and device level. /3/

The entire state of the system is known and supervised at all times with the help of increasing measurement- and system information. The distributed intelligence of the system can control devices which automatically supervise energy production and consumption, maintain the necessary quality of electricity as well as increase reliability and usability. /3/

2.2 ABB`s Definition for Smart Grid

ABB defines Smart Grid based on general properties. Those are:

- Adaptive: Reacts to changing situations fast and automatically.
- Predictive: Utilizes gathered functional data to device service schedule and anticipation to possible take outs.
- Integrated: Interoperable for real time data transfer and control functions.
- Optimized: Maximizes reliability, usability, performance and financial functionality.
- Secure: Notices fault situations caused by outsiders as well as those which are caused by nature and prevent those if possible. /3/

2.3 Distribution Automation

DA (Distribution Automation) means generally control, operation and supervision of various distribution networks. Applications vary from electricity and district heating systems to water and gas networks. Common for all these networks is that automation is used to perform different control and metering functions as well as transmitting certain status and alarm information. /16/

2.4 Advanced Distribution Automation

The quality of electricity has been improved with ADA (Advanced Distribution Automation). With intelligent switch and disconnecter stations the faulty parts of network can be isolated effectively. With ADA the network becomes self-healing and a fully remote controlled level of distribution network can be achieved. DMS (Distribution Management System) with integrated distributed resources helps to optimize functionality and performance of electrical network. /32/

Self-Healing Grid. One of the major improvements with smart grids is the increasing level of reliability in distribution. Automation which controls the distribution network and communication it needs increases in the distribution network hand in hand. One of the reasons for increasing distribution reliability is the usage of smart switches which can disconnect or connect parts of the network in e.g. if a

sudden fault occurs or the network is overloaded. In this way smart switches can prevent larger take outs in power distribution. Besides these the reliability of distribution can be increased by building the network structure to form a physical ring. /32/

SCADA (Supervisory Control and Data Acquisition) is surveillance and control system for distribution networks. With SCADA substations and remote controllable devices can be monitored and controlled from distance through local RTU (Remote Terminal Unit). The SCADA system must expand at the same time when the amount of IEDs increases in distribution networks. For that reason SCADA needs an encompassing data network to handle critical communication between DA and DMS systems which support each other. /32/

3 ABB ZONE CONCEPT

Continuousness is the number one criteria to power distribution quality. The main goal in distribution network development in the long term is to cost effectively raise the reliability of delivery and quality of electricity. Zone concept with intelligent device solutions combined with the primary network structure creates a good and flexible baseline to this overall development.

3.1 Means to Increase Reliability

Fault probabilities can be decreased by investing in primary network structure e.g. replacing overhead lines with cable lines and equipping transformers with surge protection. The full benefit from these implementations can be achieved when the zone concept is used along these. With the help of remote controllable switching devices and DMS, the zone concept can be fully utilized. Fault locating in control assistance and on a substation level becomes more accurate when main switch current measurements are utilized.

By adding light substations, zone breakers, zone disconnectors and investing to automation, the goal to raise delivery reliability can be achieved quickly and cost effectively. This solution benefits both customers and network companies. The main principle in the zone concept is to limit the area of effect caused by a fault in the network to as restricted as possible. In traditional distribution network a fault causes interruption to the whole feeder bay and all consumers behind that.

By placing protective and switching devices deeper to the distribution network and closer to consumers, interruptions and reclosing actions will impact only the malfunctioning part of the network. In this way interruptions elsewhere can be avoided. This is done by dividing the feeder line in to segments, or in the other words, zones. Studies show that the number of consumers suffering from interruptions decreases by over a half compared to situation without zone partition.

3.2 Zones

Usually the main feeder line is divided into zones by feeder line reclosers, remote controlled disconnectors or LBS. Depending on the zone dividers the capacity zone is either a control or a protective zone. The main feeder line is typically protective zone and reclosers dividing it are zone selective. Branch lines can form either protective or control zones. Usually they form control zones and they are divided from main the feeder line by a remote controlled disconnector.

The zone concept offers many options to dividing the electrical grid into zones. The most traditional way is to increase the amount of substations dividing an electrical grid into parts limiting the harm from voltage dips to a restricted area.

On long less loaded feeder lines the end of the line can be galvanically separated from the beginning using an intermediate transformer which transforms voltage to e.g. 1000V near consumption points. In that way possible disturbance limits to its own 1000V distribution area. Different zones are shown in Figure 1.

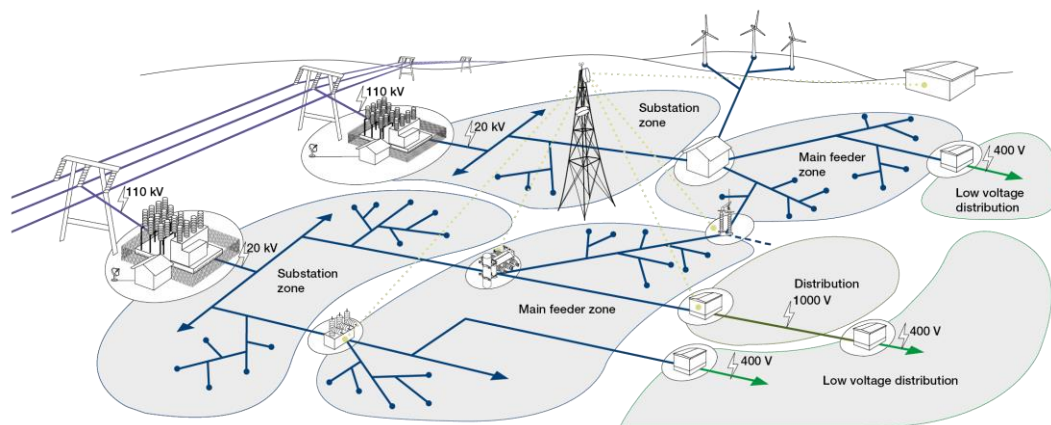


Figure 1. Different zones presented. /10/

3.3 Benefits and Opportunities

Owing to the zone concept the average power interruption time for customers behind the feeder lines decreases. This is possible because the zone recloser can separate the damaged zone when the fault is permanent. When the fault is located near a substation and before the first zone recloser, power can be returned to the

rest of the line by changing the switching state of disconnectors and reclosers through DMS. This of course requires that the grid structure enables this kind of activity.

3.4 Properties of Disconnector, LBS and Recloser

Zone reclosers and zone disconnectors are always equipped with the possibility for remote control. Zones which are divided from the feeder line by a disconnector cannot separate live heavily loaded line from the feeder line. In this case distribution automation is needed to measure if the line is loaded or not and disconnect the feeder line before opening the disconnector if the current on the line exceeds the breaking capability of the disconnector. On loaded lines where zone dividing possibility needs to be done without taking out the main feeder line LBS or a recloser is a more suitable solution. Pictures of a remote controlled disconnector and LBS shown in Figure 2 and Figure 3.



Figure 2. Simple disconnector and controlgear combination. /7/

1 Tank | 2 Mechanism box | 3 Control cable | 4 CT measure cable1 | 5 CT junction box | 6 Electric control cabinet | 7 Control unit

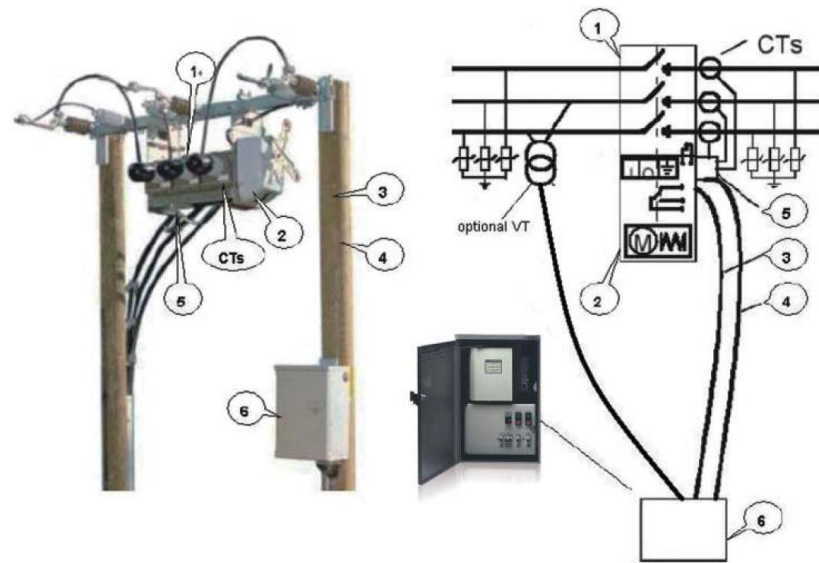


Figure 3. Remote Controllable LBS with build in measurements. /5/

3.5 Future

The zone concept adjusts to challenges in the future and is a suitable solution to be carried out in stages. Most critical consumption points are defined first and they form their own zones by adding a light substation or a zone recloser. When the network is expanded or the structure gets more complicated, new zones are formed naturally by dividing the network to rational sections. For example, in a case a new distributed energy production unit is connected to distribution network via a recloser, the recloser forms a new zone where the production unit can be separated from the network if needed.

3.6 Communication

A basis to the overall solution of zone concept is versatile data transfer and communication. Wireless cost effective and safe data transfer can be implemented using satellite connection or by using terrestrial communication solutions e.g. GPRS/EDGE (General Packet Radio Service/Enhanced Data rates for GSM Evolution). By using these techniques all active components in the zone concept can easily be connected to control assistance. Suitable communication solutions depends on the controlled object, where a substation needs a fast, accurate and time

dependent connection such as satellite communication, GPRS connection is more suitable for remote controllable switching devices, such as zone disconnectors.

By using a fiber optic cable and differential relays, fast data transfer and fast protection can be implemented between energy production zone and substations. This enables optimized utilization of distributed energy production in a part of distribution networks reliability of delivery. /1/

4 REMOTE CONTROLLABLE LBS

4.1 Primary Switching Device SECTOS

SECTOS is a product family name for three different type of LBS. The three types are named more specified to NXA, NXB and NXBD. All SECTOS switches are SF6 (Sulfur hexafluoride) -insulated pole mounted outdoor switches designed for overhead lines and precisely for use in a part of DA where switches are remote controlled via SCADA. SECTOS products offer a reliable maintenance free solution for outdoor use and it is designed to work in demanding climate conditions such as ice, snow, corrosive pollution and salt laden atmospheres. The SF6-insulated structure enables compact structure, excellent load breaking capability, capacity to resist faults and it meets specified isolation demands for LBS. The metal tank is earthed to prevent possible leakage currents while LBS is open. SECTOS can be operated manually or by a motor and it is suitable for local and remote electronic control. SECTOS can also easily be upgraded from manual to motor operated version by installing the retrofit motor package. /5/

NXA

- Two-position load breaker switch
- for rated voltages 24 kV / 36 kV according IEC standards
- for rated voltages 27 kV / 38 kV according ANSI standards
- rated current 630 A
- short time withstand current $I_{th}(3s)$ 16 / 12.5 kA
- peak withstand current I_{dyn} 31.5 kA
- number of making current 3/5 31.5 kA / 25 kA
- mechanical endurance 5000 CO

NXB

- 2- or 3-position load breaker switch
- for rated voltages 12 - 24 kV according IEC standards
- rated current 630 A

- short time withstand current $I_{th}(3s)$ 20 kA
- peak withstand current I_{dyn} 50 kA
- number of making current
 - main switch 3/10 50 kA / 31.5 kA
 - earthing switch 3/5
- mechanical endurance
 - main switch 5000 CO
 - earthing switch 2000 CO

NXBBD

- 2 or 3-position 3-way LBS using NXB components
- two independent LBS in one enclosure
- third tapped way usable for reliable and easy line branching
- option for combined and integrated sensors (current and voltage)
- same electrical properties with NXB

Different SECTOS models are presented in Figure 4.

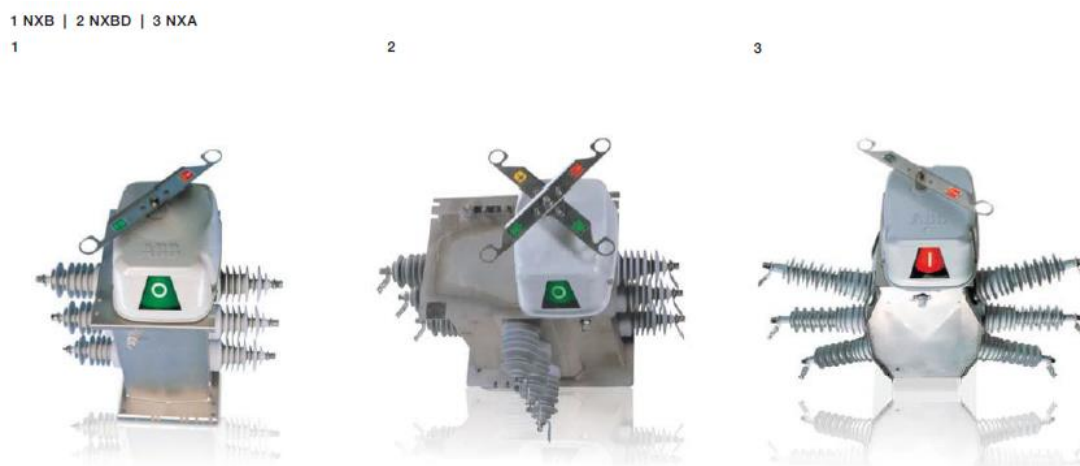


Figure 4. Different SECTOS models. /5/

Different parts of SECTOS NXA can be seen from Figure 5 below.

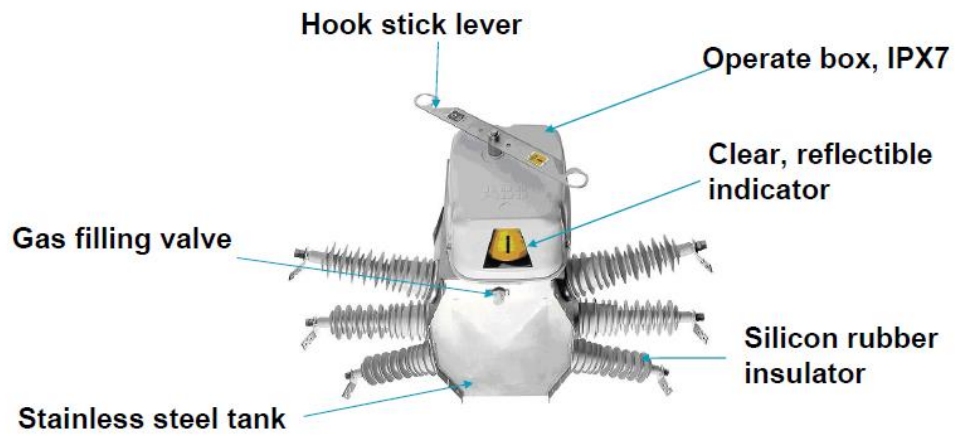


Figure 5. SECTOS NXA parts described more precisely. /9/

The motor controller is located inside the operate box, as seen in Figure 6 below.



Figure 6. The operate box without a motor controller and with it. /9/

Principle pictures of different type of SECTOS are shown in Figure 7 below.

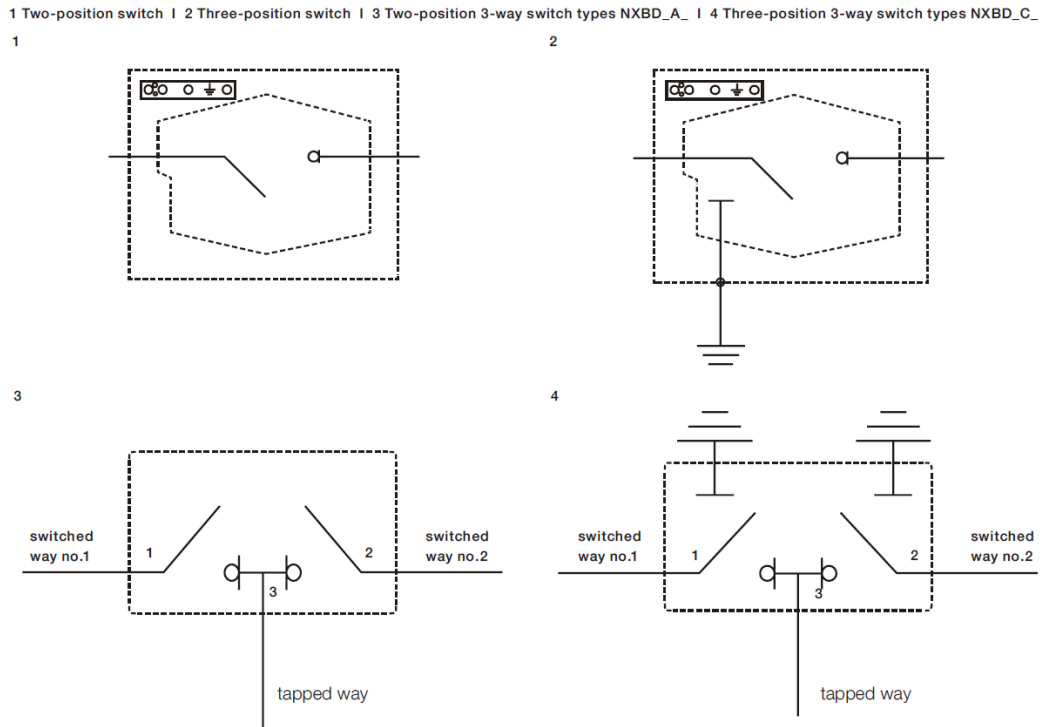


Figure 7. Principle switching positions of different SECTOS models. /5/

4.1.1 Structural Features

The frame of the SECTOS forms an enclosure which also works as a tank for SF₆ gas. The enclosure is manufactured from 3 mm stainless-steel and it is designed to be robust and specially guarantee the safety of the person operating LBS. SECTOS is designed to withstand an internal arc fault with full tanks without venting any hot gases out.

SECTOS utilizes an independent spiral spring operation mechanism. The mechanism guarantees load breaking capacity by ensuring sufficient opening and closing speed.

SECTOS offers standard SF₆ pressurized units with temperature compensation. The pressure switch is a standard solution for motor operated models and the pressure gauge for manually operated models. These solutions prevent misuse by

indication or by locking the switch if the pressure level is too low for switching operation.

The position indicator in SECTOS is equipped with light reflecting material and the position indicator is directly contacted to a main shaft operating switch providing unambiguous and clear position indication. Because of the light reflecting material switch position can be seen from the ground level even in challenging conditions such as torrential rain at night. /5,9/

4.2 Optional Measurements

SECTOS can be equipped with CT, VT and sensor measurement functions. Possible variations in measurements affect also to the IED configuration version used. /5,13/

1. REC615 configuration A
 - 3 phase current inputs (1/5 A)
 - 3 phase voltage inputs (60...210 V)
 - 1 residual current input (0,2/1 A)
2. REC615 configuration B
 - 3 phase current inputs (1/5 A)
 - 1 residual current input (0,2/1 A)
 - 6 phase voltage sensor inputs
3. REC615 configuration C
 - 3 combi sensor inputs (three phase current and voltage)
 - 1 residual current input (0,2/1 A)

4.2.1 Current transformer

- Standard solution: ring type CT KOKU072G4
- Special solution: example with fault indicators KOKU072G3 can be used (same size than KOKU072G4)
- Conversion ratio: 400/0,1 A

KOKU_ type of CTs are suitable for phase current measurement and KOKU072G_ type of CTs are specially designed for use with pole mounted LBS SECTOS. The dimensions of CT are adjusted according to the bushings of SECTOS switch and the busbar works as a primary conductor. Principle picture of a CT can be seen in Figure 8. The structure of CT consists of a ring shaped iron core and a secondary winding which are resin cast. /4,5/

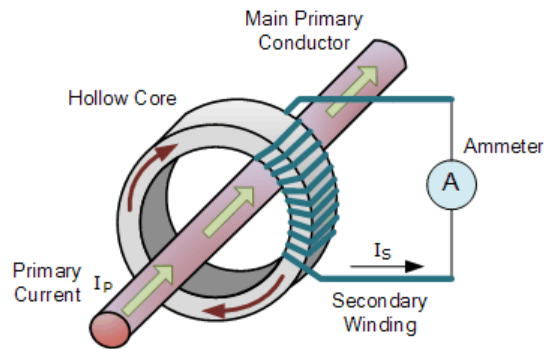


Figure 8. Principle picture from CT structure. /20/

A picture of the KOKU072G type of CT mounted in SECTOS seen in Figure 9.



Figure 9. SECTOS LBS with mounted CTs. /5/

4.2.2 Voltage Transformer

TDO 6 type of outdoor VT is provided and in addition other type of VT: s according to the local requirement can be used. /5/

TDO 6 features:

- Highest voltage for equipment 12, 17.5, 24, 25 [kV]
- Power frequency test voltage 28, 38, 50 [kV]
- Lightning impulse test voltage 75, 95, 125 [kV]
- Max. rated burden, classes 50/0.2–100/0.5-burden [VA/cl]

The TDO 6 are insulated double-pole VTs designed to outdoor use up to 25 kV voltage level. The primary winding of the VT is insulated from the earth at the rated insulation voltage level including the terminals. Most of the transformers are manufactured with a single secondary winding for either protection or measurement use. A picture of TDO 6 transformer is shown in Figure 10. /2,5/



Figure 10. TDO 6 type of voltage transformer. /2/

The primary winding of the transformer is connected to ground or across the phases depending from the requirements, see Figure 11.

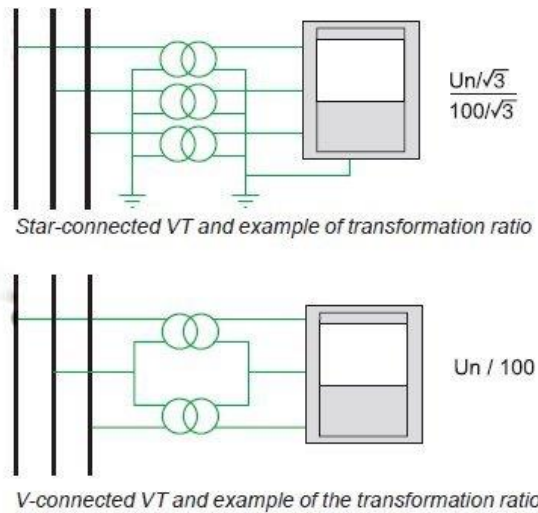


Figure 11. Typical connection options for VT: s. /20/

Voltage instrument transformer theory is similar to a general purpose step down transformer. The voltage is transformed to a lower level in order to measure it in IEDs. The transformer separates the primary high voltage circuit from the low voltage secondary circuit galvanically. The cross section of a VT presented in Figure 12 below.

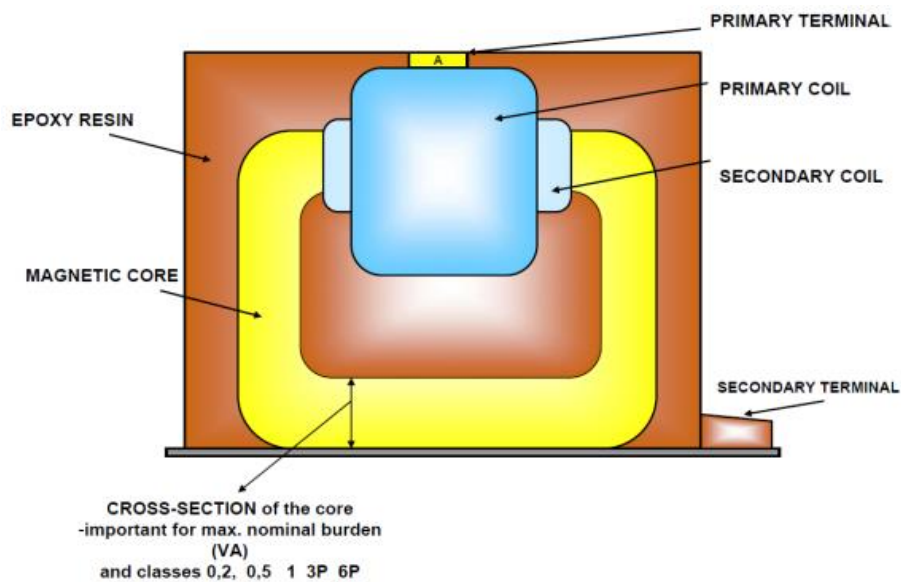


Figure 12. Cross section of a VT and its main parts. /14/

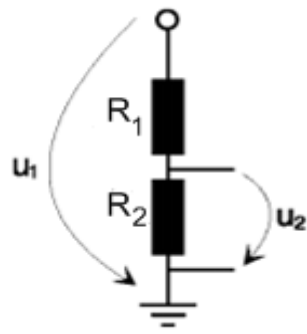
4.2.3 Sensors

Sensors are more compact solution for implementing measurements compared to traditional instrument transformers. The secondary voltage level from sensors is usually very low and cables need to be double shielded against external disturbance such as magnetic fields. /14,30/

1. Voltage sensor

The principle in voltage sensors is to divide incoming voltage between two components which usually are either resistive or capacitive when it comes to high voltage measurements. Out coming voltage U_2 is a fraction from incoming voltage U_1 . By dividing the voltage to a lower level it is possible to transfer a signal to IEDs safely and by scaling it diversely according to the sensor fraction ratio in the IED, primary voltage can be monitored. In sensor technology the scaled voltage has the same wave form and frequency than in the primary voltage. That makes the monitoring of frequency also possible. The monitoring of frequency and waveform can be utilized for example in a case where synchronization is needed in recloser control. Principle pictures of a resistive divider in Figure 13 and a capacitive divider in Figure 14 can be seen below. /14/

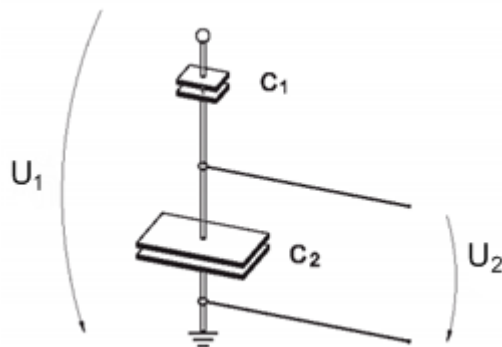
A resistive divider is a passive element which is based on a matched resistor pair. The divider ratio in the sensor designed for 24 kV is 1:10 000 and resistors are: $R_1=250M\Omega$ and $R_2=25k\Omega$. /14/



$$U_2 = \frac{R_2}{R_1 + R_2} U_1$$

Figure 13. Principle of resistive voltage divider. /14/

A **capacitive divider** is a passive element which is based on a matched capacitor pair. The divider ratio in sensor designed for 24 kV is 1:10 000 and capacitors: $C_1=15\text{pF}$ and $C_2=150\text{nF}$. /14/



$$U_2 = \frac{C_1}{C_1 + C_2} U_1$$

Figure 14. Principle of capacitive voltage divider. /14/

- Accuracy limit factor 60
- Accuracy using calibration factor Class 5 Class 3/10 P60

Voltage sensor

- Rated primary value $20/\sqrt{3}$ kV
- Rated secondary value $20/\sqrt{3}$ V
- Accuracy using calibration factor Class 6 P

The cross-section of a combi sensor and its main parts are presented in Figure 16.

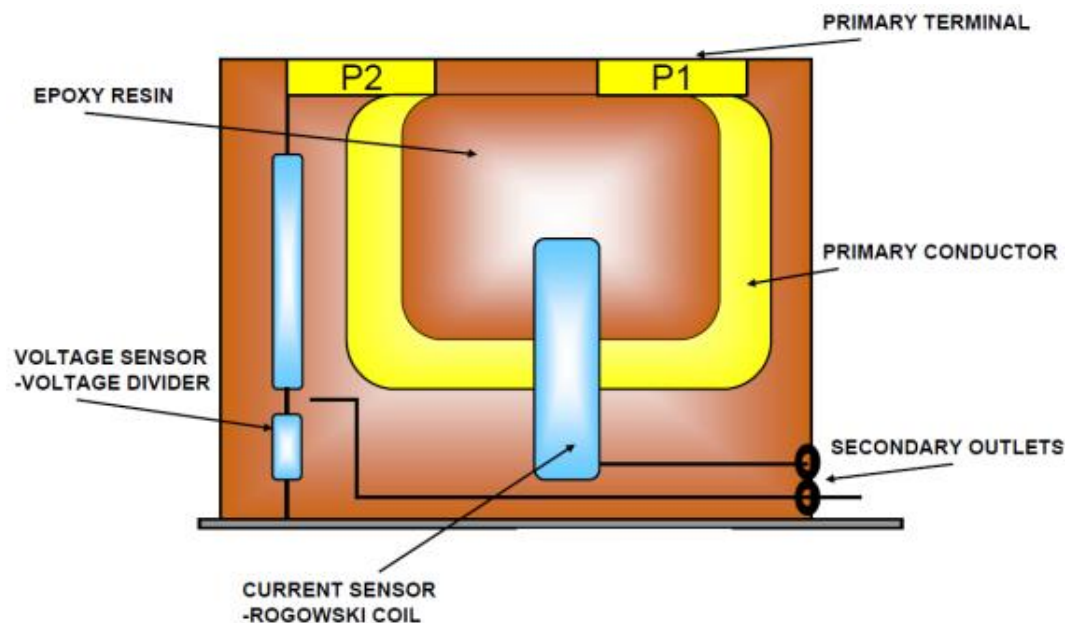


Figure 16. Cross-section from combi sensor and its main parts. /14/

A picture of SECTOS with three combi sensors and three voltage sensors mounted are shown in Figure 17. When voltage is measured from both sides breaking action can be verified after the operation. /14/

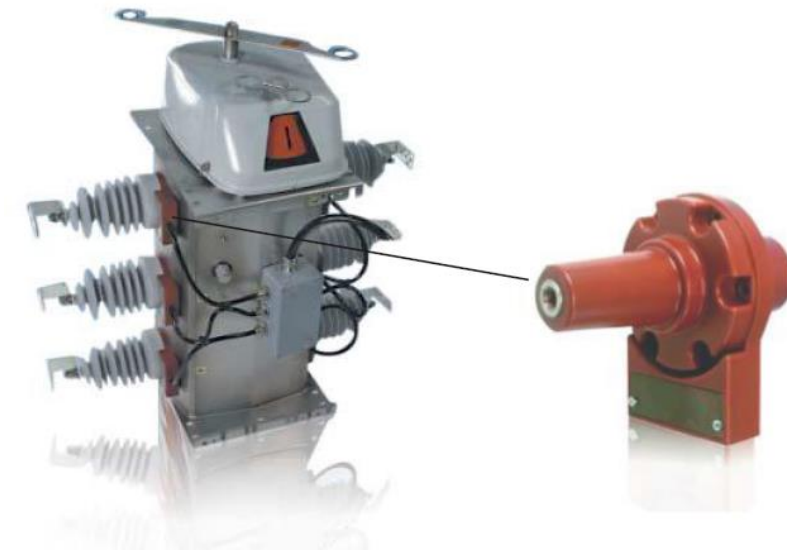


Figure 17. SECTOS with three combi sensors and voltage sensors. /5/

4.3 Control Cabinet

As mentioned in the introduction, control cabinets for different levels are manufactured. The following information is on level 3 outdoor control cabinet GAO3. A GAO3 level control cabinet is presented in Figure 18 and main principle of the control cabinet and controlled primary device are presented in single line diagram in Figure 19 next page.



Figure 18. Control Cabinet /8/

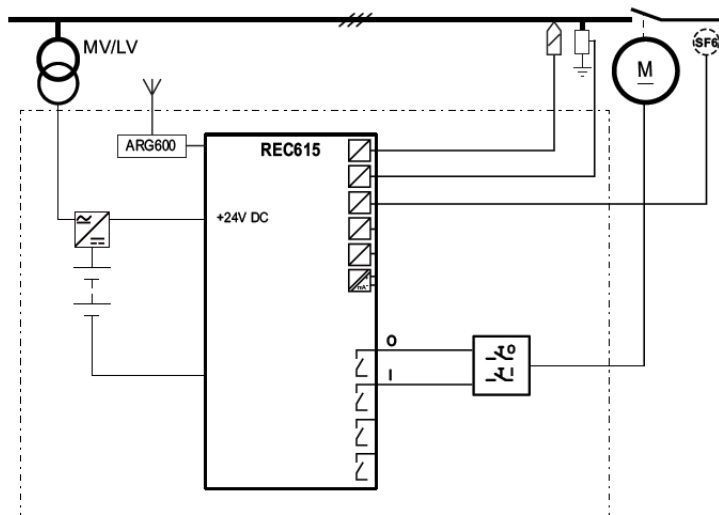


Figure 19. Principle of Control Cabinet & primary device solution. /8/

4.3.1 Features

Used hardware depends on the control cabinet model and customer specifications.

Below listed usual features for the GAO3 level control cabinet. /8/

- Enclosure IP 55
- Supply voltage 110-250 VAC/VDC
- Operational voltage (control circuit) 24 VDC
- Battery backup
- Charger/Battery condition surveillance
- Heater
- IED REC615

Optional features:

- Communication unit RER601/RER603
- Fuse & RCD (Residual-Current Device) protected socket outlet for service
- Service light inside

4.3.2 IED

REC615 is mentioned in brochures as an option for controlling SECTOS. REC615 contains integrated communication protocols as well as familiar protection functionality to the other Relion 615 -series devices. Other familiar features to Relion 615 –series are:

- Large LCD (Liquid Crystal Display) with SLD (Single Line Diagram)
- Local parametrization and control possibility thru push buttons and LCD
- Event logging and load profile
- Web-based parametrization tool
- Easily manageable setting groups
- Flexible auto-reclosing function
- Withdrawable-unit design

In addition to basic protection functions these models contain following features:

- Voltage presence indication
- Fault locator
- Automatic transfer switch
- Intermittent earth-fault detection
- Adaptable standard configuration for fast commissioning

REC615 also contains power quality analysis with logging of voltage dips and swells. Measurements can be implemented either with traditional instrument transformers or sensor technology. As an example of utilized quality analysis: advanced earth-fault detection can detect the development of earth-fault in the network before it causes an outage. Accurate FLIR (Fault Location, Isolation and Restoration) is provided to all types of network. FLIR decreases fault frequency and shortens the power outages. /13,18/

Communication protocol options for remote communication are: Modbus, IEC 60870-5-101/104, DNP3 level 2 and simultaneous support for high-speed messaging in the IEC 61850 protocol with GOOSE (Generic Object Oriented Substation Event). /13,18/

REC615 is designed for remote monitoring and control in medium voltage secondary distribution systems. The model is intended to use in urban areas where many objects are typically controlled by the same device and it is usually used for fault detection and protection in cable feeders. REC615 can control one circuit breaker and eight other objects. REC615 is available with three standard configurations A, B and C. The configuration and corresponding protection functionality is chosen according to measurement implementation and the needed amount of inputs. Possible measurement connections and binary IO connections can be seen in Table 1 next page. /13,18/

Table 1. REC615 number of physical connections. /13/

Configuration	Analog channels		Binary channels	
	Current	Voltage	Inputs	Outputs
A	4	3	8(14) ¹⁾	10(13) ¹⁾
B	4	6 ²⁾	12	10
C	3+1 ³⁾	3 ³⁾	8	10

- 1) With optional BIO0006 module
- 2) Support for phase voltage sensors or phase voltage transformer with the SIM0001 module
- 3) Support for three current sensors, three voltage sensors and one conventional lo input with the SIM0002 module

More precise possibilities for REC615 configuration and location (Slot ID) of different modules can be seen in Table 2 next page.

Table 2. Location of different modules in REC615. /13/

Main unit	Slot ID	Content	Module ID	Details
Plug-in unit	-	HMI	DIS0011 DIS0015	Small (5 rows depending on the selected language, 20 characters)
			DIS0012 DIS0014 DIS0016	Large (10 rows depending on the selected language, 20 characters)
	X100	Auxiliary power/ BO module	PSM0003	24...60 V DC 2 normally-open PO contacts 1 change-over SO contact 1 normally-open SO contact 2 double-pole PO contacts with TCS 1 dedicated internal fault output contact
	X110	BI/O module	BIO0005	With configurations A,B and C: 8 binary inputs 4 SO contacts
	X120	AI module	AIM0013	With configuration A: 4 phase current inputs (1/5 A) 3 phase voltage inputs (60...210 V) 1 residual current input (0.2/1 A ¹⁾)
		AI/BI module	AIM0017	With configuration B: 4 binary inputs 4 phase current inputs (1/5 A) 1 residual current input (0.2/1 A ¹⁾)
	Empty			Not equipped in configuration C.
Case	X130	Optional BI/O module	BIO0006	With configuration A: 6 binary inputs 3 SO contacts
		Sensor input module	SIM0001 ²⁾	With configuration B: 6 phase voltage sensor inputs
			SIM0002	With configuration C: 3 combi sensor inputs (three-phase current and voltage) 1 residual current input (0.2/1 A ¹⁾)
	X000	Optional communication module		See the technical manual for details about different type of communication modules.

- 1) The 0.2/1 A input is normally used in applications requiring sensitive earth-fault protection and featuring core-balance current transformers
- 2) By default, the *Voltage input type* parameter of SIM0001 is set to "CVD sensor". The parameter can be set to "Voltage Transformer", if necessary.

The locations of different slots are presented in Figure 20 next page.

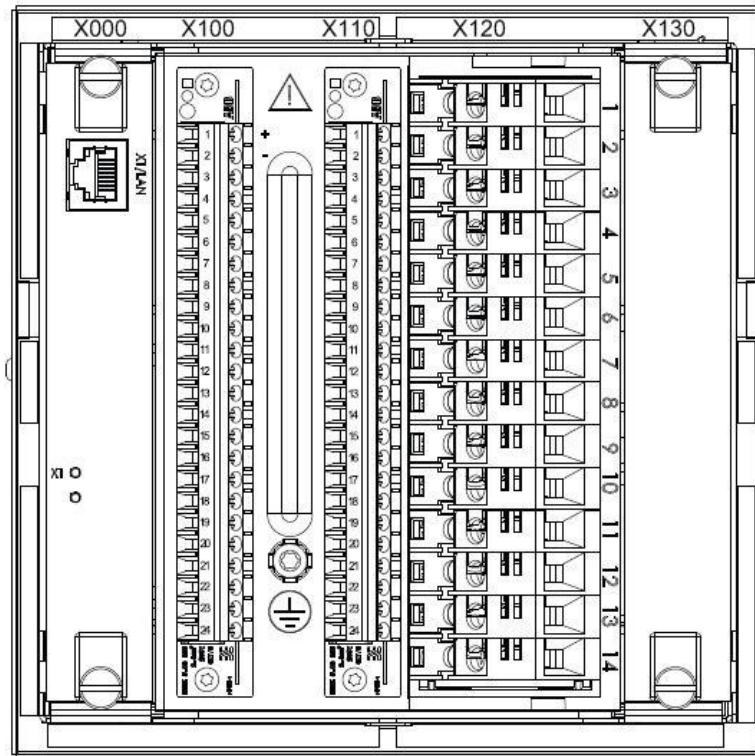


Figure 20. Positioning of Relion 615 –series relay slots/connections. /13/

The outfit of different modules in slot X000 varies depending on wanted communication features and in X130 depending from on the configuration. Possible communication modules (X100) are presented in Figure 21. /16/

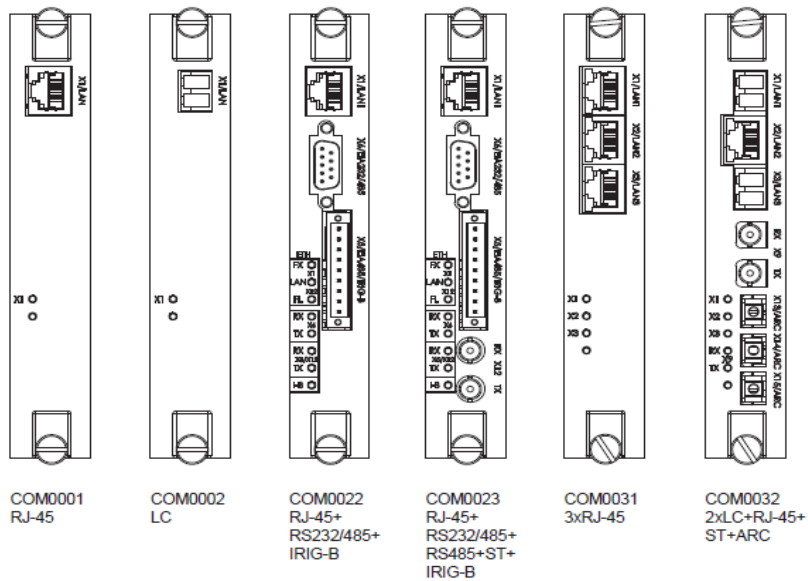


Figure 21. Communication module options. /13/

Possible SIM/BIO modules for Slot X130 presented in Figure 22. On the left SIM0002 and on the right SIM0001. BIO0006 has a similar looking connection interface to SIM0001.

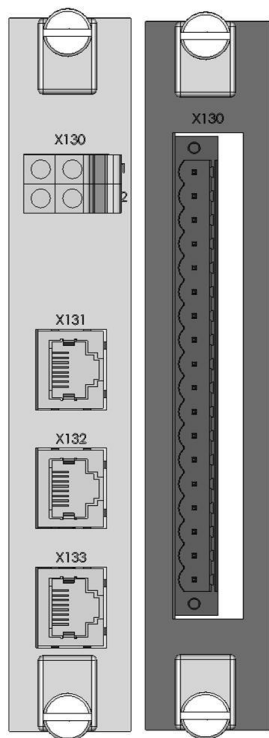


Figure 22. Module options for Slot X130. /11/

Connection diagrams for REC615 can be found in Appendix 1. /12/

4.3.3 Wireless gateway RER601 and RER603

Applications

RER601 and RER603 both offer high quality connectivity for the IEC 60870-5-10* protocols. They can be used for various monitoring and control application in different sites from industrial use to unmanned substations in the distribution network, such as individual control cabinet. Differences between these two models can be seen in Table 3 next page. /6/

Table 3. Features of RER601 and RER603 /6/

	RER601	RER603
Serial interfaces	2	2
Ethernet ports	1	1
GPRS module	Inbuild secure VPN connection	Inbuild secure VPN connection
Binary inputs/outputs	None	8/2
Dimensions	45 x 175 x 108 mm	45 x 175 x 108 mm

RER601 shown in Figure 23.



Figure 23. Wireless gateway RER601. /6/

Connectivity

Both RER601 and RER603 have end to end VPN which offers a safe wireless connection between the monitored and controlled object and the control center over the GSM/GPRS network. Owing to VPN tunneling any public mobile network can be used for connection and both dynamic and fixed IP addresses are supported.

The connection protocol RER601 and RER603 used for communication between RMUs and other devices is IEC 60870-5-101. Both RER601 and RER603 have a built in protocol convertor between IEC60870-5-101 and IEC60870-5-104 protocols which provides opportunity to attach both conventional and modern TCP/IP-based control systems together. In the transparent mode communication is supported with many protocols including DNP3. /6/

A solution example is presented in Figure 24, RER 601 and 603 are branded Viola products.

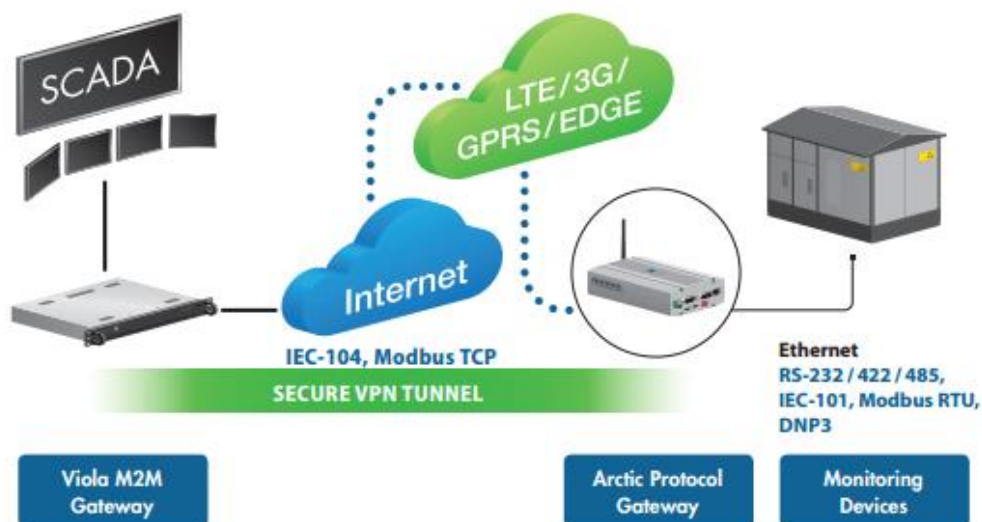


Figure 24. Communication solution example. /33/

5 FACTORY TESTING DEVELOPMENT

The original purpose of the thesis was to develop modular test station for control cabinets. The need for test specifications however superseded the original objective when it was decided that the test specifications are created as a part of this thesis work. Existing testing instructions and information acquired from testing at its current state were compared to various standards regarding the testing of control cabinets in order to create the new test specifications. Besides test specification the comparison of suitable hardware for the test station was made. More specific report on the performed work and appendices including the created test specifications and compared hardware are not included in this publication. The following subchapters describe at a surface level what the current situation in testing was, what the basic needs for test specifications are and which standards were used as a base for the test specifications.

5.1 Quality management systems

The basic need for testing and recording of the results can be found in customer satisfaction and quality. ISO 9001 describes process guidelines for entire organizations and all processes from the view of quality. In this thesis only processes concerning testing are mentioned.

ISO 9001 Chapter 1 defines requirements for quality management systems which organizations can utilize to prove their capability to manufacture and deliver customer satisfying products. Besides customer specifications the product must also meet the requirements for specific product defined by the law and the authorities. The ISO9001 standard and the described requirements are international applying for all organizations regardless of their type, size or products they manufacture.

ISO 9001 Chapter 7 gives guidelines and describes needed processes for implementation of the product from planning to manufacturing. Product related requirements are determined to organizations according to customer needs, law and regulations concerning the product and its use. Processes for product verification, measurement, inspection, testing, tracking, etc. are also defined.

ISO 9001 Chapter 8 describes more specifically how processes described above shall be implemented and how product information shall be traced, designed features verified and results recorded during manufacturing. Different options for deviating products are also defined and actions to correct those given.

ISO9001 Chapter 4 describes how recorded information shall be stored and maintained. /31/

5.2 Factory Testing Today

Factory testing today takes place according to the inspection form. The inspection form is created manually according to project information. Inspections are performed in the following order and contain mentioned procedures.

5.2.1 Visual Inspection

- Device positioning and marking
- Identification and marking of terminal blocks
- Wiring connection tightness check on random basis
- Earthing; connectors, usage of contact plates
- Logging of founded deficiencies
- Tightness of wiring contacts and terminal block connectors

5.2.2 Wiring Inspection (“Ringing” According Wiring Diagrams)

- Wiring
- Jumpers
- Operation of fuses and their auxiliary contacts
- Separation of L (Line) and N (Neutral) in main circuit
- Separation of + (positive pole in DC (Direct Current) -circuit) and – (negative pole in DC –circuit) in auxiliary circuits
- Resistive components; measurement of resistances

5.2.3 Isolation Resistance Test

- Every terminal block and connector (which in normal state is separated from ground) against ground were tested.

5.2.4 Functional Tests

- Functional tests vary according to project information, optional accessories and different control cabinet models.
- Designed features are tested extensively.

5.3 Control Cabinet Testing and Related Standards

Product related regulations can be found in the product related standards. For control cabinets many related standards can be found. As the cabinet operates on low voltage (under 1000 V), primary device control cabinet controls are connected to

high voltage (over 1000 V) overhead-lines and the product can be seen as an auxiliary and control circuit for a primary device. Based on standards listed below the creation of test specifications was done.

- IEC60947-1 Low-voltage switchgear and controlgear
- IEC61439-1 Low-voltage switchgear and controlgear assemblies
- IEC62271-1 High-voltage switchgear and controlgear
- IEC61008-1 Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses

5.4 Creation of Test Specification

After comparing standards mentioned in Chapter 5.3 test specification was created. The idea in comparison was to find “worst-case” terms for testing. The test specifications describe which tests and inspections shall be performed but it does not make statement how to do those. The idea in the creation of test specifications was to create a basic frame which would be suitable for all control cabinets. Tests and inspections to be performed are described, high and low limits given to measurements which are repeated. Options for different testing methods are given in the cases where different standards varied from each other.

5.4.1 Defined Inspection Order

The following order was decided after comparing different standards. The defined order or subjects within each inspection do not essentially differ from existing inspection practice but specifies the maximum resistance to the continuity of protective circuits. Circuits which include a resistive component are mentioned separately in the inspection order compared to existing practice.

1. Visual inspection
2. Protection against electric shock and integrity of protective circuits
3. Circuits including resistor or resistive component (measurements)
4. Wiring inspection
5. Dielectric properties
6. Functional tests

5.4.2 Differences Between Used Standards

Wiring inspection, dielectric properties, functional tests and continuity of protective bonding were the ones which differed from each other depending on the standard.

Continuity of protective bonding

IEC 62271-1 describe visual inspection to be sufficient for checking protective circuits or alternatively high current test to be done. From these options visual inspection was not seen as secure enough from the view of test result surveillance and current test described in standards were not seen as a reasonable option. The solution was found from IEC 61439-0 where resistance is defined to be measured between earthed parts and main earthing and the maximum resistance was given.

/24,25,26/

Wiring inspection

IEC 62271-1 describes wiring to be checked according to wiring diagram whereas IEC 61439-1 describes that depending on the complexity of assembly it may be necessary to proceed with wiring inspection. Wiring inspections were defined according to IEC 62271-1. /25,26/

Dielectric properties

IEC 62271-1 defines that an auxiliary and control circuit shall be tested with power frequency method with voltage of 1 kV and duration of 1 s whereas IEC 61439-1 allows dielectric properties for assemblies to be proceed with the insulation resistance method with 500 V and insulation resistance must at least be $1000\Omega/V$ from the supply voltage in reference to earth. Both options were mentioned in the test specifications. /25,26/

Functional tests

IEC 62271-1 defines functional tests to be done with lower (85%) and upper (110%) limits of the nominal supply voltage whereas IEC 61439-1 describes that depending on the complexity of assembly it may be necessary to carry out an electrical function test. Functional tests were defined according to IEC 62271-1. On models where an RCD protected socket outlet is installed, functioning time and injected current were adopted from IEC 61008-1. /23,25,26/

6 CONCLUSIONS

Even though I had some basic knowledge from these control cabinets as an assembler during my career in ABB, in retrospect the extent of this thesis was oversized to be accomplished within the time of few months these thesis work usually takes. Also the fact that production systems do not produce automatically needed information for testing was a problem from the view of testing automation. My knowledge concerning database managing would have been a major problem if the process for gathering information would have been a task for me to develop. However, I am quite pleased that the important base document for testing was finished during the making of this thesis. I was also pleased that information from potential devices was found and one device obtained based on the compared results.

I also got a good view how automated test stations work in the IED factory and good experience applying standards to the production.

I hope that the report I wrote to my supervisor about my thesis work helps to develop the processes, which were problematic concerning automated testing, towards the right direction.

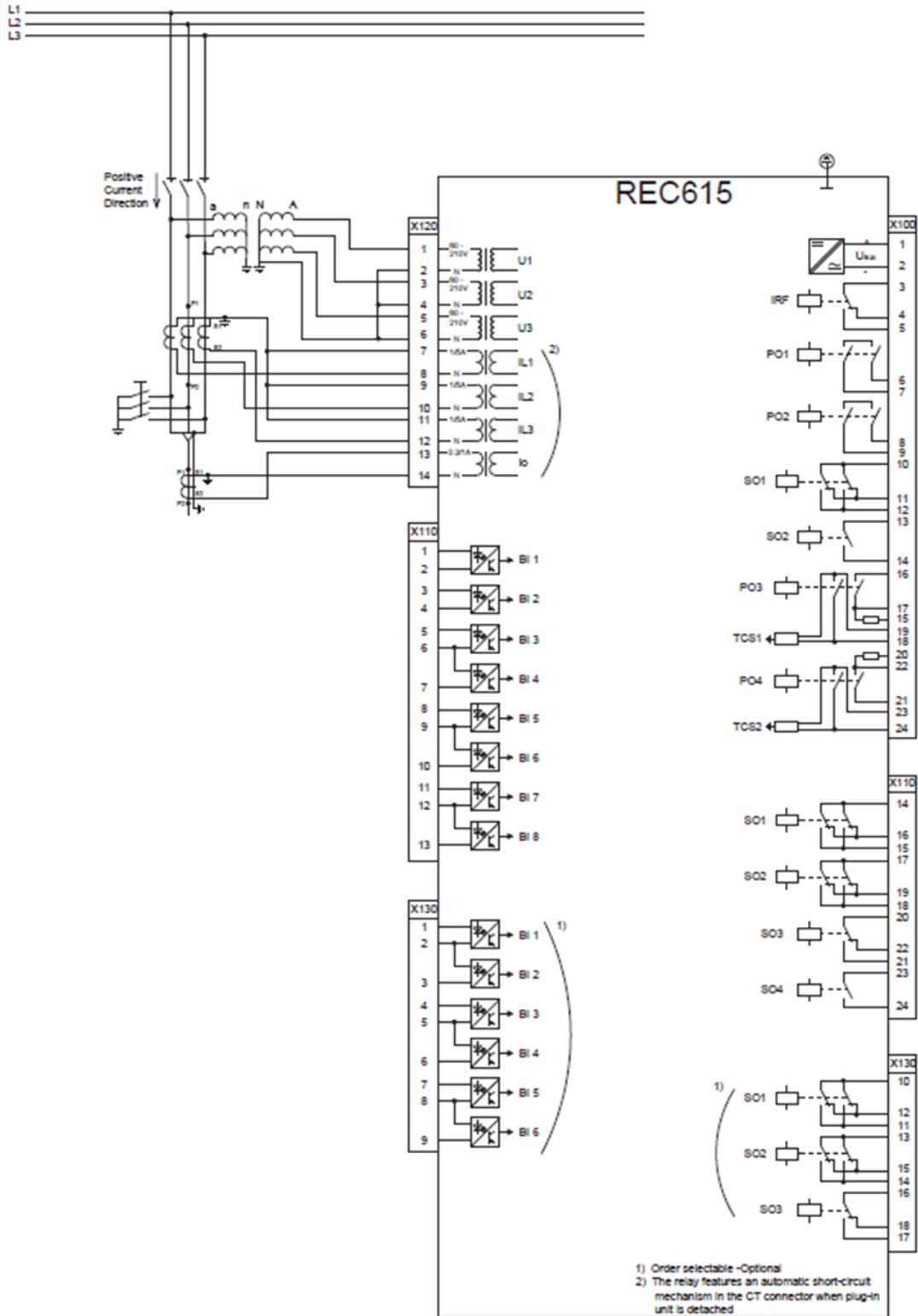
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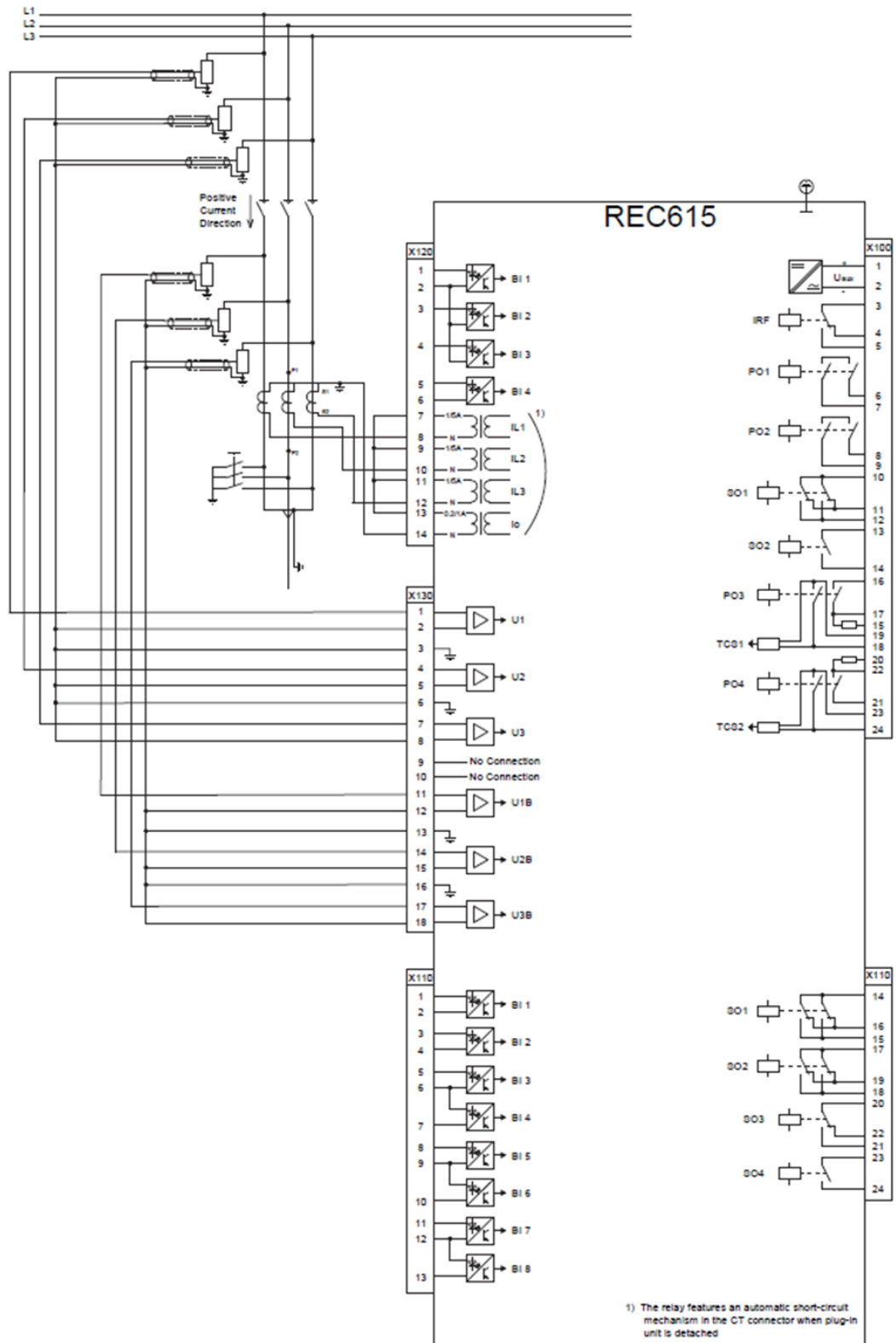
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REC615 Wiring diagram, standard configuration A



REC615 Wiring diagram, standard configuration B



REC615 Wiring diagram, standard configuration C

