Protection Relay Retrofit From SPACOM Relays to the Relion® Product Family Type Relays

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BACHELOR'S THESIS

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Abstract

The purpose of this bachelor thesis is to find a way for a relay change for a customer whose relays are getting old. In case where relays suddenly stop working, can the customer have losses in production. The scope of the work are the old SPAC relays and those will be replaced with new generation Relion relays.

The corresponding relays were found by analyzing the manuals of the relays. The goal of the thesis was to create a list for all the corresponding relays and configurations, as well as the complete installation manuals for each relay.

This bachelor thesis shows the steps of what to consider when replacing an old relay with a newer model. The configurations, different relay sizes between the new and the old and the material needed to perform the installation of a replacement relay are things that need to be taken into consideration. This thesis is based on the theory of distribution of electricity and relay protection. There already is a solution called the Relay retrofit program. This bachelor thesis is continuation to that work and covers more relay models.

Language: English Key words: SPACOM, Relion, Retrofit

EXAMENSARBETE

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Utbildning och ort: Elektroteknik, Vasa
Inriktningsalternativ: Elkraftsteknik
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Titel: Skyddsreläbyte av SPACOM-Reläer till produktfamiljen Relion®

Datum 18.5.2017 Sidantal 42

Abstrakt

Huvudtanken med detta examensarbete var att hitta en lösning för reläuppdatering till en kund vars reläer blir gamla. Kunden har inte råd att ha reläer som plötsligt slutar att fungera. Arbetet omfattar gamla SPAC-reläer som kommer att ersättas med den nya generationens Relion-reläer. Analysen för att hitta motsvarande reläer och konfigurationer gjordes genom att jämföra reläets manualer.

Syftet med detta examensarbete var att skapa en lista på alla motsvarande reläer och konfigurationer, samt att komplettera installationsmanualerna för varje relä.

Detta examensarbete visar stegvis vad man ska tänka på när man byter ett gammalt relä till en nyare relämodell. Konfigurationer, olika relästorlekar mellan det nya och det gamla samt material som behövs för att utföra installationen av det ersättande reläet, är saker som bör tas i beaktande vid reläbyte. Examensarbetet behandlar teorin om eldistribution och reläskydd. Det finns redan en lösning för ett antal reläer och detta examensarbete är en fortsättning och täcker flera relämodeller.

Språk: engelska Nyckelord: SPACOM, Relion, reläbyte

OPINNÄYTETYÖ

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Ohjaaja: Matts Nickull

Nimike: Suojareleiden päivitys SPACOM-sarjan releistä Relion®-tuoteperheen releisiin

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Päivämäärä 19.5.2017 Sivumäärä 42

Tiivistelmä

Tämän opinnäytetyön tarkoituksena oli löytää keinot releen vaihtamiseen asiakkaalle, jonka releet ovat vanhentumassa. Asiakkaalle voi koitua suuria ongelmia siitä, jos rele yhtäkkiä lopettaa toimintansa. Tämä työ kattaa kaikki vanhat SPAC-releet, jotka kuuluvat SPACOM-tuoteperheeseen. Nämä korvataan uuden sukupolven Relion-releillä. Vastaavat releet löydettiin analysoimalla releiden manuaaleja.

Työn päämääränä oli tehdä lista jokaiselle relemallille ja löytää tälle vastaava malli ja täydelliset kokoonpanokoodit. Tämän lisäksi jokaiselle releelle tehtiin oma asennusmanuaali.

Tämä opinnäytetyö esittelee työvaiheet, jotka täytyy ottaa huomioon kun korvataan vanha rele uudella. Releen kokoonpano, vanhojen ja uusien releiden kokoerot ja materiaali, joka tarvitaan asennusta tehtäessä, täytyy ottaa huomioon. Työ pohjautuu teoriaan sähkönjakelusta ja relesuojauksesta. Tämä työ on jatkoa jo valmiiksi tehdylle ratkaisulle ja tämä työ kattaa ison määrän uusia SPACOM-relemalleja.

Kieli: englanti Avainsanat: SPACOM, Relion, relevaihto

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1 Introduction

This thesis is a work for ABB, Medium Voltage Products in Vaasa, Finland. The goal is to create a system for customers who want to get an upgrade for their old relays. The scope will include all the ABB SPAC relays that belong to the SPACOM family and the newer generation Relion family of relays. This system will help sales to quickly find the corresponding newer relay models to offer as well as the configurations to go along with them. Then the next step will be to write a complete manual for installation. This includes the needed accessories as well as a systematic guide on how to install the new relays.

1.1 ABB

ABB (ASEA Brown Boveri) is a Swedish-Swiss multinational corporation that was a result from a merger in 1988 of the Swedish corporation Allmänna Svenska Elektriska Aktiebolaget (ASEA) and the Swiss company Brown, Boveri & Cie (BBC). ABB has approximately 132 000 employees and has operations in roughly 100 countries. (About ABB, 2017)

ABB's operations are organized into four global divisions. The divisions target specific industries and product categories.

Electrification products

Products and solutions suitable for multiple low and medium voltage electrical applications from residential home automation to industrial buildings, including modular substation packages, distribution automation products, switchgear, circuit breakers, measuring and sensing devices, control products, wiring accessories, and enclosures and cabling systems designed to ensure safety and reliability. Their customers are distributors, installers, panel builders, OEMs, system integrators, contractors, architects and end users. (About ABB, 2017)

Robotics and Motion

Robotics and Motion offerings include motors, generators, drives, mechanical power transmission, robotics, wind converters, solar inverters, voltage regulators, rectifiers, UPS systems, excitation systems, traction converters and fast DC chargers. Customers are manufacturers, OEMs in a variety of industries and utilities, process industry end users and transportation and infrastructure operators. (About ABB, 2017)

Industrial automation

Industrial automation offers products, systems and services designed to optimize the productivity of industrial processes. Solutions include turnkey engineering, control systems, measurement products, life cycle services, outsourced maintenance and industry specific products (e.g. electric propulsion for ships, mine hoists, turbochargers and pulp testing equipment). The customers are in process industries such as oil and gas, petrochemicals, mining, metals production, marine, pulp and paper and cement. (About ABB, 2017)

Power grids

Power Grids offers power and automation products, systems and service solutions across the generation, transmission and distribution value chain. Its portfolio includes transformers, high-voltage products, power transmission systems and grid integration and automation solutions to enable a stronger, smarter and greener grid. Power Grids have customers in power generation, transmission, distribution and other utilities. (About ABB, 2017)

1.2 Purpose

The SPACOM generation of relays are starting to be at the end of their life span. Although known for their reliability, electronic protective devices are subject to wear and tear. Harsh environmental and physical conditions such as varying temperature, humidity, pollution, interference etc. affect the aging of electronic components, which increases the likelihood of relay malfunction. ABB has sold and delivered approximately 40 000 SPAC relays around the world. The SPAC relays are a part of the SPACOM family and include three different series of relays. The SPAC 300, SPAC 500 and SPAC 600 series.

When switching the old relays to the newer generation Relion family relays, a system needs to be created for a smooth transition. It is important to have a cost effective solution for this process, both for the customers’ and company’s perspective. When ABB has a retrofitting solution, the work can be done much faster and with lower cost. In process industry or at a power plant where every minute counts in terms of stopping the production it is a major benefit when the installation can be done quickly.

There is a variety of different models and configurations of relays. It will be beneficial for the sales to easily find the corresponding relays and accessories for the customer. This will encourage the customer to be more willing to purchase newer equipment when the process is made simple.

2 Distribution of electricity

Transmission- and distribution networks are used for transmitting electrical power from production to consumption. The purpose of the transmission network is to enable reliable transmission of high powers on large areas. The distribution network is a local electric grid, which distributes electricity to consumers. In Finland, the consumption of electrical energy and the production of electricity (except hydropower), is focused in the Southern Finland. Nuclear power plants and the bigger condensing power plants are located in the south-west. The biggest consumers of electricity are various types of industries and bigger residential areas. (Hietalahti, 2013)

Fingrid is the grid owner in Finland and is in charge of electricity transmission. The grid is the frame grid for the distribution of electricity. Big power plants and local distribution networks are connected to the grid. The grid consists of 400 kV, 220 kV and 110 kV power lines as well as 111 electrical substations. The grid serves both electrical consumers and producers and enables the market for both parties as well as the market outside of Finnish border. (Hietalahti, 2013)

Figure 1. Power transmission grid in Finland. (Fingrid, 2012)

The production of electrical energy and consumption needs to be in balance at all times. This is the responsibility of the holder of the grid. Fingrid monitors and controls the relations between consumption and production, maintenance, building, development and promote the electrical market. (Hietalahti, 2013)

The transmission and distribution of electricity implements nowadays a three-phase alternating current system that has displaced the DC systems. A DC current system is also implemented today in longer high voltage transmission lines, where DC current has shown to be a cost effective solution for energy transmission and especially power control. Good examples of this are the sea cable DC current systems between Finland and Estonia as well as Finland and Sweden. The principal structure of electrical transmission- and distribution system is represented in Figure 2. (Hietalahti, 2013)

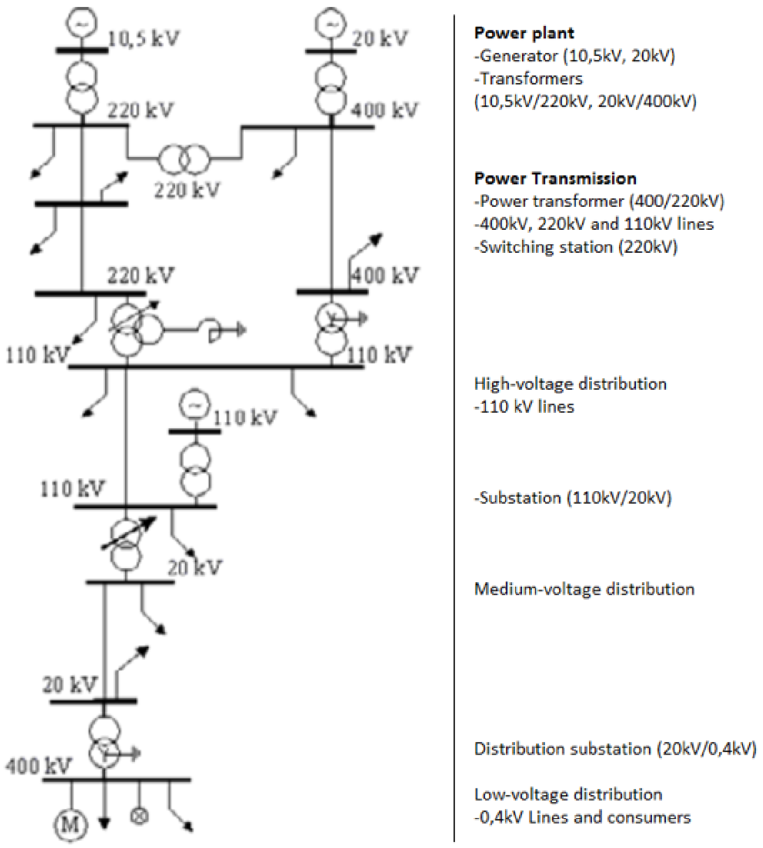

Figure 2. The principal structure of electrical transmission- and distribution system. (Korpinen)

2.1 Electricity network operators

Distribution system operators in the European Union internal electricity market are responsible for providing and operating low, medium and high voltage networks for regional distribution of electricity and of supplying lower level distribution systems and connecting customers directly. (European Union Emission Trading Scheme, 2017)

As stated before, the grid in Finland consists of 400 kV, 220 kV and 110 kV power lines, separate 110 kV regional networks and 0.4/70 kV distribution networks controlled by local electricity companies. Some of the local electricity companies also controls 110 kV power lines. (Energy authority, 2017)

Electricity network operations in Finland requires permission by the Energy authority. The network operators are obliged to maintain and improve their grid, connecting electricity and production sites and to distribute electricity. The network operators are responsible for the condition of the grid and quality of the electricity supplied to the customers. (Energy authority, 2017)

Distribution network operator licenses for the grid is given for certain responsibility areas where the network operator has exclusive rights to build the distribution network. Location of a customer cannot influence the transfer prices. The transfer price can not be influenced either by from what distributor the customer chooses to buy electricity from. (Energy authority, 2017)

The prices of the transfer services of electricity varies between different network holders, but customers cannot choose from different network holders. The transfer price is determined by the amount of electrical power transferred, how much power is needed and the voltage level. (Energy authority, 2017)

2.2 Network structures

When building network structures, three main types are used: radial network, ring network and looped network. All of them have their unique benefits and downsides. When comparing the three, their technical and economical features have to be taken into consideration. Those features are cost effectiveness, reliability and the ability to add spare inputs and protect the grid. (ABB, 2000)

Radial network

The advantage of radial networks is the clear structure of them. They are simple to use and protect. Downsides in a radial network are the downtime during maintenance and that it does not support the possibility of securing. The radial network is typically used at medium- to low voltages. (ABB, 2000)

Ring network

Networks with higher voltages are usually built as ring networks. Benefits over the radial networks are that the ring network have secured feeder, a better voltage stability and smaller power losses. The downside is the fact that it is harder to use and relay protection gets more complicated. (ABB, 2000)

Looped network

A looped network is similar to the ring network but it contains middling connections inside the rings. This enables to get even better securing to feeders, better voltage stability and smaller power losses. This means more complicated use and more expensive relay protection systems. In Finland 400 kV and 220 kV networks are looped, so that voltage stability can be maximized and power losses minimized. (ABB, 2000)

2.3 Substation

Substations are key installations in the power grid that facilitate the efficient transmission and distribution of electricity. They control power flows, connect power stations to the grid and link transmission and distribution networks as well as final consumers. (ABB, 2013)

A substation that is feeding a medium voltage grid transforms bigger voltages, usually 110 kV to lower 20 kV. The substation is the most important single block in the electric distribution grid. Substation works as a versatile distribution center for the grid that contains the main part of the grids relay protection and automation among other things. The main reason for building substations is maintaining quality in electricity distribution. (Lakervi & Partanen, 2008)

Substations comprises of a high-voltage switchgear plant, one or more main transformers, medium-voltage switchgear plant and the auxiliary voltage system with the support use of its functions. Air insulated switchgears are used in low populated areas. In more populated areas high- or medium voltage plants are often SF_6 gas-insulated because of aesthetics and to save space. (Lakervi & Partanen, 2008)

In addition to radial wiring there can be many different wires in a high-voltage switchgear plant. This enables substations to have additional feeder directions and depending on the busbar type the possibility to substitute the separation threshold in the rings or the use as a looped network. Busbar solutions and circuit breakers at switchgear plants offers different options for feeder changes. For example under high loads connecting wires, coupling changes between substations are possible if exceptional coupling situations are taken into consideration in the network design. (Lakervi & Partanen, 2008)

Transformers are the most expensive components in substations. The rated power of the transformers affect the short-circuit currents in medium-voltage networks. The bigger the rated power, the smaller impedance and bigger short-circuit current. Typically the main transformer sizes are between 10 MVA and 40 MVA. In a normal setting a transformer can not be used at its rated current, because a part of the conversion capacity has to be reserved as reserve power if other substations have faults. In backup supply situations the transformers overload possibilities can be exploited, if the temperature is low. (Lakervi & Partanen, 2008)

The main transformer has diverse protection. The main protectors are differential relays and overcurrent relays. The differential protection detects internal faults in the transformer, such as short circuits and earth-faults. Also a gas relay with a flow trigger is an important part in transformer protection. The gas relay works for most major internal faults in the transformer. The main transformers upper voltage coil has a coil switch and its job is to keep the lower voltage sides voltage constant, at for example 20.5 kV. (Lakervi & Partanen, 2008)

Medium-voltage switchgear plant forms an electrical feeder route from the main transformer to the medium-voltage outgoing feeders. One transformers busbar system is either a one single busbar or a double busbar system. The main busbar works as a collecting busbar and each of its outgoing feeders have a circuit breaker and isolators on both sides of it. (Lakervi & Partanen, 2008)

Figure 3. 400 kV/110 kV/20 kV Electrical substation in Ulvila, Finland. (Fingrid)

3 Relay protection

A relay protection system has to be selective, quick, reliable and it has to work in unusual operating conditions. A selective protection system works in a way that it separates a faulty component from the rest of the grid. This minimizes the drawbacks. It also means that all the components in the grid are protected with a relay. The status of the grid varies, so does the short circuit currents, which is why there can be errors in the measurements. When the grid needs to be secured, the parameters has to be set by certain standards. When the relay is wanted to deliver a trip signal to the breaker, the value is set so that for example the short circuit current is multiplied by a number lower than one. This makes sure that the relay works. When the relay is not wanted to trip, the value is set higher than one. (Haarla & Elovaara, 2011)

Reliability in protection means two things. Security of protection, means that the relay does not send a trigger signal when there are no faults. Dependability of protection, means that the relay will work when a fault actually happens. (Haarla & Elovaara, 2011)

3.1 Grid protection

The protection of devices in the grid happens by a combination of measuring transformers, protection relays and circuit breakers. According to standard SFS 60050-448 (SFS, 2002) the concept of protection system is precisely specified to include protection equipment, measuring transformers, wirings, tripping circuit, power and possibly even a data transmission system and reclosing automation but no circuit breakers. Conduits and fiber optics do data transmission inside the station. In some cases even between two stations the relays are connected via data transmission connection. Cooperation between the different components is needed for the protection to work and the faulty parts can be separated from the main grid. (Haarla & Elovaara, 2011)

According to standard SFS-IEC 60050-448 (SFS, 2002) protection is detecting unusual conditions in the system, for the faults to be cleared and unusual events to stop. Protection relay is a measuring relay, that is a part of the whole protection equipment system. (Haarla & Elovaara, 2011)

When a short circuit or earth fault occurs, the faulty part of the network has to be separated from the system, for it not to cause danger and so that the short circuit current does not damage the devices. When the protection disconnects the faulty part, power transmission may continue in the other parts of the network. The short circuit- and earth fault currents are often so high, that the faulty part has to be disconnected quickly. If the short circuit or earth fault is not disconnected from the network, the consequences may be dangerous to humans and/or animals. Also it may result in equipment breaking. (Haarla & Elovaara, 2011)

Reasons why a faulty component has to be separated from the grid:

- The thermal effect of a short-circuit current can be dangerous to people or animals. It can also destroy equipment and cause fires.

- The current in the ground during an earth-fault can cause harm to people and other living creatures.
- During an earth-fault the potential of a substation can rise dangerously high.
- In a 400 kV grid a long lasting short-circuit and earth-faults can cause the loss of stability in a power system. When the short circuit is close to a generator, the speed of the generator rises during the fault, because a voltage drop causes the transfer ability to be lower than during a normal situation. The longer the fault time and the smaller the voltage is during a fault and the closer the fault is to the generator, it is more likely that the generator is unable to recover to synchronous operation after the fault. The loss of one generator does not cause harm to the grid. However, a long fault time may result in the release of several big generators, which may crash the grid. In Finland the generators has to fill technical system requirements that require that the generator has to withstand a 250 ms long voltage drop close to the generator without the generator losing stability and being released off the grid (Fingrid 2007). For protection this means that, if it is wanted to keep the generators in the grid, the fault has to be triggered faster than 250 ms. The normal short-circuit and earth-fault triggering time in a 400 kV grid can be at maximum 100 ms.
- The voltage drops caused by an earth-fault or a short-circuit will spread to a wide area. The production of many factories cannot withstand a long voltage drop and they are separated from the grid and it will cause costs.
- Earth-faults can induce disturbance voltage to other electrical circuits. (Haarla & Elovaara, 2011)

3.2 Protection relays

A protection relay is a device that monitors the state of a power line, and can stop the flow of electricity when it detects an error in the electric network. This happens in order to prevent any further damage to equipment. (Vaasa University of Applied Sciences, 2014)

Protection relays used to be electro-mechanical devices, but today’s relays are embedded devices, which operate with digital data. Today’s protection relays behaves as the earlier electro-mechanical relays in many ways. The analog information about the power lines, such as the instantaneous magnitude and phase of the alternating current and voltage, are processed with digital algorithms. (Vaasa University of Applied Sciences, 2014)

A modern protection relay performs a variety of different protection functions, so that each function takes a set of input values and produces a number of Boolean output signals. A given function performs a given algorithm on the input values periodically, and when a given set of trigger conditions for the function are met, the function is started. If the trigger conditions remain true for a given time, the function is tripped, causing an output signal called trip to be asserted. If there is no delay between the start and trip states, the function is called instantaneous. For example, instantaneous overcurrent protection will trip immediately when the value of current exceeds a limit that was set. (Vaasa University of Applied Sciences, 2014)

A function can be blocked with an input signal called block. In this state, the function operates otherwise normally, except its trip output signal is blocked and will not start. The function may still enter the tripped state, so that immediately when the block signal is disserted, the function asserts its trip signal. The trigger conditions can be considered as fixed mathematical relations evaluated on them. (Vaasa University of Applied Sciences, 2014)

After a protection function has entered the started state, it may require another set of conditions to hold for a given duration in order to cause the relay to return to its initial state. Once the function enters the tripped state, it must be cleared in order to return it to the initial state. (Vaasa University of Applied Sciences, 2014)

A protection relay receives a number of analog input signals, typically fed by instrument transformers, and a number of binary input signals, which may be connected to for example a switch. The relay produces a number of binary output signals, so that some of them are typically used to command a circuit breaker. Such device is used to physically stop the flow of electricity when needed. (Vaasa University of Applied Sciences, 2014)

3.2.1 Overcurrent relays

Overcurrent relays work when the current exceeds the limit that has been set to it. It does not detect the direction of the current. It is not the best option for looped networks because the current may come from any direction. Overcurrent relays nowadays have two steps. One for definite time retardant and the other one can be chosen from standard time- or reverse time retardant. Definite time- delay overcurrent relay starts when the measured current exceeds the set value and trips when the set time limit runs out. The relay reverts when the current goes below the set value again. This type of relay can be used for protecting transformers, reactors, capacitors or generators. Inverse overcurrent relay slows down in reverse in relation to the current, meaning that the relay trips much faster when the current is higher. This type of relay is used in looped networks. How steep the curve is can be chosen from ready standard curves. The tripping times for the graphs according to the IEC-standard 60255-3 can be solved with the following formula:

$$t_{TRIP} = \frac{k \times \beta}{(\frac{I}{I >})^{\alpha} - 1}$$

Where I is the fault current, I> is the set start current for the relay. α and β are factors chosen from the table. The values depend on the steepness of the graph that is wanted. The parameter k is chosen from the curves in the graph, when a very inverse graph is chosen. (Haarla & Elovaara, 2011)

Table 1. Table for slope of the time/current.

Slope of the time/ current curve set	α	β
Normal inverse	0.02	0.14
Very inverse	1.0	13.5
Extremely inverse	2.0	80.0
Long-time inverse	1.0	120.0

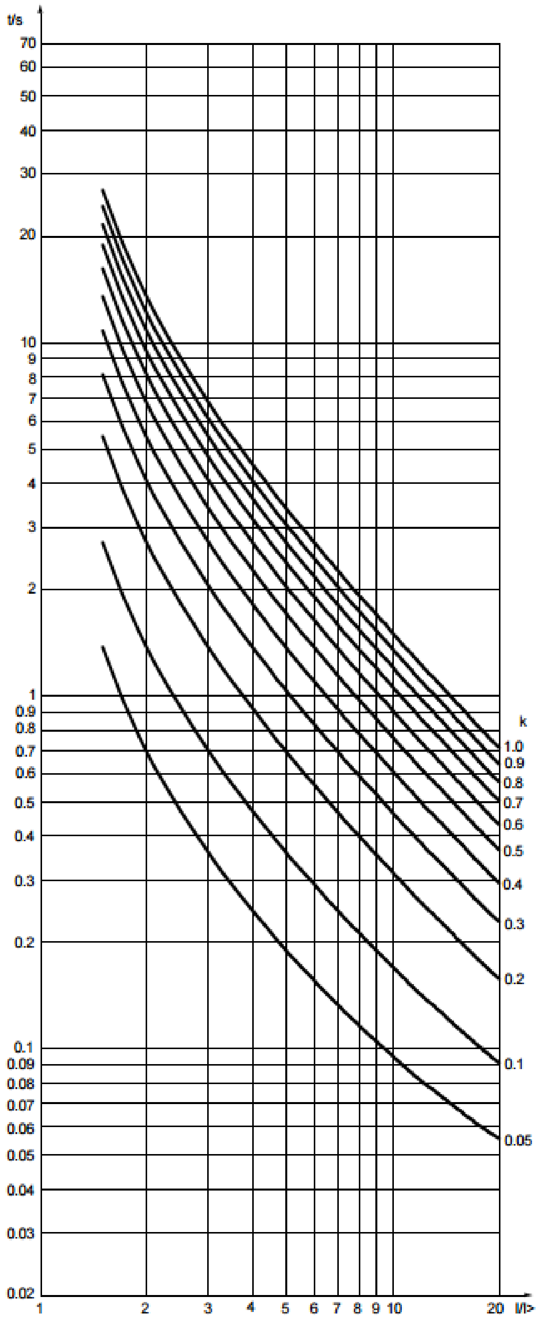

Figure 4. Very inverse-time characteristics of the overcurrent and earth-fault unit SPCJ 4D29. (SPAC 310C users manual)

3.2.2 Earth-fault protection relays

Earth-fault protection relays are overcurrent relays connected to the secondary coil of a transformer. It measures the total current of the phases and works in a case of earth fault. Earth-fault protection relays does not recognize the direction of the current. A sensitive earth fault-protection relay has low current settings and high retardants. Rough earth-fault protection relay settings are calculated by short-circuit current calculations and a short retardant is used. The current settings are higher than on a sensitive earth-fault protection relay. Earth-fault protection relays are also used as ground contact protection for transformers. There they work as provisional protection for other faults in the network. (Haarla & Elovaara, 2011)

3.2.3 Voltage protection relays

Over- and under voltage relays work when the voltage goes over or under the allowed values of the network. Voltage relays are used most often as supplements for shunt device voltage adjustment. Some three branch wires have a 400/110 kV transformer connected as a separate branch along the wire and the actual wire has no circuit breakers at all at the transformer branch. The transformer has two circuit breakers on both sides. If this type of 400 kV three-branch wire circuit breakers open and the wire is connected to the network only through the 400/110 kV transformer, its voltage rises due to the wires no-load reactive power. This type of situation is normalized and the over-voltage relay sends a tripping signal to the transformers breaker. (Haarla & Elovaara, 2011)

4 ABB relays

In the 1960’s Strömberg Oy established a department for control technology and electronics at their Pitäjänmäki factory in Helsinki. The purpose of the new department was to develop control electronics for the company’s main products within various application areas. Oiva Laakso was the head of the new department and when he left the company, Aarre Toivanen was appointed as his successor. As the operation expanded into several application areas, many new product families based on electronics were invented. (Wiklund, 2011)

The early two main product groups included excitation and voltage control equipment for AC generators and control equipment for paper machine drives. In addition a third product family, mains or battery supplied voltage regulators, was developed. The most important products within this family were light control equipment. The development of electronics continued and in 1970 Strömberg introduced their own computer, named Strömberg 1000, for control of industrial processes. (Wiklund, 2011)

Thyristor-based regulators were manufactured at the Pitäjänmäki factory and these needed various protection functions. These functions done for separate plug-in modules, e.g. overvoltage modules were inserted into the regulator racks. Erkki Laurinmäki, director of the project department in Helsinki, got the idea to use these as separate utility protective relays. At that time, Toivo Jokinen was the development director and he made the first specification for a static protective relay for stand-alone utility applications. The task of carrying the development was given to an expert in electronics, Christian von Alfthan and he developed the first relay prototype in 1965. (Wiklund, 2011)

Figure 5. Year 1965 prototype for the static or electronic protective relay.

4.1 Complete family of protective relays

In the 1970's came the need of having a static protective relay available for every application. The electronic designs were developed at the same time as new circuits become available. In 1971 a new measuring technique for static protective relays was introduced and in 1972 the first integrated feeder protection package was introduced. The package included three-phase overcurrent protection, directional earth-fault protection and autoreclosing. (Wiklund, 2011)

Figure 6. Complete feeder protection package model 1972.

The DC/DC converter was developed and integrated into the relays for the auxiliary voltage supply to the electronics. Before, the auxiliary voltage for the electronics had been stabilized using resistors, zener diodes and LC filters, which meant that the electronics were directly connected to the station battery. (Wiklund, 2011)

The DC/DC converters reduced the power consumption and there was no galvanic coupling between the electronics and the station DC battery. As a result, the electronics no longer had to be isolated on a 2 kV level from the mechanical parts of the relay. A further development step of the DC/DC converter came in 1975 when the PWM (Pulse Width Modulation) technique was introduced into the supply units of the relay family. This meant that the relays were provided with self-regulated DC/DC supply units allowing a wide auxiliary voltage range. (Wiklund, 2011)

The first digital static relays were introduced to the market in 1974 and in 1976 came the first approvals for offshore applications of the relays. The development of complete protection systems continued and in 1977 the first generator protection panel with an integrated testing system was commissioned. (Wiklund, 2011)

The family of static protective relay was quite complete at the end of the decade. In general, each relay covered one particular protection function. Complete protection schemes were built by combining the necessary relays and, in many cases, assembled into cabinets at the factory. (Wiklund, 2011)

Figure 7. Generator protection panel with integrated testing system at Metsäbotnia, Kaskinen, Finland.

4.2 Microprocessors into the protective relays

During the 1970´s the microprocessors had been taken into use in military and space applications, but also in more consumer oriented products. In Vaasa, the design engineers of the Strömberg Electronics Group proposed to their management that the group would try to base the relay design on microprocessors. At first, they did not get the support for the idea, but did not give up on it. In 1980, a prototype was secretly developed and the design engineers tested it at home during holidays. The testing results showed that the idea was very doable. The engineers involved in the development work were Seppo Pettissalo and Henrik Sundell together with Tapio Hakola, the application specialist, who was especially involved later when the first product was developed. (Wiklund, 2011)

Kurt Kämpe became manager of the Electronics Group and after talking to Seppo Pettissalo and Henrik Sundell, he learned about their secret development of a microprocessor relay prototype. The group then presented the prototype to the Strömberg top management and explained the new opportunities. The management was convinced of the ideas and the

Electronics Group got all the investments and support it needed for the further development. In the end of February 1982 the first microprocessor relay, the multifunction and multipurpose relay SPAJ 3M5 J3 were shipped. This was the first microprocessor protective relay for distribution applications on the market and the Electronics Group in Vaasa was about four years ahead of the competition. The internal software was very well structured and the hardware utilization was optimized.

Figure 8. The first microprocessor based protective relay SPAJ 3M_J3.

The relay had two-stage overcurrent protection and thermal overload protection with possibilities to set different time characteristics for the stator and rotor of a protected machine. Additional functions were warning for thermal overload and the possibility to connect an external temperature sensor to compensate for changes in the ambient temperature of the protected object. It also had the built-in self-supervision. (Wiklund, 2011)

Until then, the microprocessor relays were not capable of serial data communication. In 1985 Strömberg introduced the SPACOM secondary equipment family, where all the units were able to communicate over a fiber optic serial bus. In addition to the protective relays, the feeder protection unit and a voltage relay, the launch also included the central communication unit. (Wiklund, 2011)

4.3 Combination of protection and control

After the SPACOM family had been introduced, the planning started to include also circuit breaker control and position indications into the same package with the feeder protection. This would make the switchgear panel layouts more simple. Also the signals would be transferred over the fiber optic communication bus and that would reduce the control wiring. This was supported by the Strömberg Control development and the first deliveries were done in 1984. In 1987 the combined protection and control unit was introduced, the SPAC feeder terminal, and the same year the first customer delivery was made to Örnsköldsvik in Sweden. The delivery included switchgear with more than 50 units of SPAC feeder terminals and the Strömberg Control systems at the substation for local control and in the remote control center as the SCADA system. In this delivery, the protection and control were combined in the same unit and in full cooperation with both the local and the remote control systems. (Wiklund, 2011)

Figure 9. Earlier SPACOM products

4.4 SPACOM series

SPACOM series relays are microprocessor based products for protection, measuring, reporting, controlling and supervision. SPACOM includes secondary equipment in the substation level of distribution automation. (ABB Substation Automation Oy, 1999)

The SPACOM product range consists of protection, measuring and control relays. The relays are for feeder, motor, generator, substation, transformer and capacitor bank protection. The relays annunciator systems are analog input systems and on-off input systems. The relays have the capability of working as data communicators and reporting units. They can do event logging and protocol conversion. (ABB Substation Automation Oy, 1999)

4.4.1 SPAC feeder terminals

SPAC feeder terminals are protection and bay control in the same package. They have a simplified cubicle lay-out. This means that they are standardized and the cubicle has less wiring. There is no need for auxiliary relays or signal marshalling. Also the panel and station lay-outs are simplified. Therefore there is less bay-to-bay wiring and the relay is easy to test at the factory. The reliability is improved since there are less connection points in the cubicles and no auxiliary relays outside the package. The flexibility is increased with easy modification of the schemes. (ABB Substation Automation Oy, 1999)

The SPAC feeder terminals have full range of protection functions. They control circuit breakers and disconnectors remotely and locally. The local position indications are remote and local. The relays have programmable bay related interlocking. They are capable of feeder auto reclosing and they have freely programmable inputs for alarms and logics. The measurement functions in various combinations are for current and voltage, active and reactive power and energy which is counted by pulses or calculated. (ABB Substation Automation Oy, 1999)

Figure 10. SPAC 533C.

4.5 Relion family

The Relion® product family offers the widest range of products for protection, control, measurement and supervision of power systems for IEC and ANSI applications. The new generation Relion product family was introduced in 2009. Already in 2011 over one million units had been shipped since the start. To ensure interoperable and future-proof solutions, Relion products have been designed to implement the core values of the IEC 61850 standard. Whatever the customer may need, the Relion family has a solution. There are ready-to-use products for standard solutions or the products can be tailored to meet any application need with a multitude of configuration possibilities. (ABB, 2015)

Application	Type	500	670	650	630	620	615	611	610	605
Feeder protection	REF				■	■	■	■	■	■
Bay control	REC		■	■			■			
Transformer protection	RET		■	■	■	■	■			
Line distance protection	REL		■	■						
Line differential protection	RED		■	■			■			
Motor protection	REM				■	■	■	■	■	■
Generator protection	REG		■	■	■		■			
Busbar protection	REB	■	■	■				■		
Capacitor bank protection	REV						■			
Wide area protection	RES		■							
Breaker protection	REQ			■						
Voltage protection	REU						■	■	■	
Current protection	REJ									■/■
Load-shedding	PML				■					
Feeder automation	RER					■	■			
Railway application	RER		■							

Figure 11. Relion family product offerings. (ABB, 2015)

4.5.1 Relion 615 series

The 615 series of relays provides a number of standard configurations and is the ideal choice for a great variety of applications within distribution protection and control. The series highlights include:

- Compact and versatile solution for utility and industrial power distribution systems with integration of protection, control, monitoring and supervision in one relay.
- Wide application coverage – feeder, transformer, motor, line differential, voltage, capacitor bank as well as generator and interconnection protection and control.
- Extensive range of protection and control functionality, either with sensors or conventional instrument transformers.
- Extensive earth-fault protection portfolio with unique multifrequency admittance-based protection for higher sensitivity and selectivity.
- Advanced and fast fault location of short circuits and earth faults.
- Three-channel arc-fault protection to increase personal safety.
- Withdrawable plug-in unit design for swift installation and testing.
- Ready-made standard configurations for fast and easy setup with tailoring capabilities.
- IEC 61850 Edition 2 and Edition 1 support, including HSR and PRP, GOOSE messaging and IEC 61850-9-2 LE for less wiring and supervised communication.
- IEEE 1588 V2 for high-accuracy time synchronization and maximum benefit of substation-level Ethernet communication.
- Large graphical display for showing customizable SLDs, accessible either locally or through a web browser-based HMI.
- Extensive life cycle services, including training, customer support, maintenance and modernization. (ABB, 2017)

Figure 12. REF615.

4.5.2 Relion 620 series

The 620 series relays provides the following standard configurations and features:

- Standard configurations for several applications.
- Ethernet and serial communication.
- The relays are ready after setting the application-specific protection parameters.
- Control of circuit breakers via the relays’ HMI or a remote control system.
- Customizable single line mimic diagrams in the local HMI.
- Patented plug-in design speeds up installation, maintenance and testing and allows the cases to be installed and wired before delivery of the plug-in units.
- Compact design allowing excellent suitability for new and retrofit installations.
- High performance GOOSE messaging.
- Advanced earth fault/ground fault protection, including transient protection to detect faults in any cable and overhead network (REF620 ANSI/IEC).
- Three-channel arc-fault protection to increase personal safety (REF620 ANSI/IEC, REM620 ANSI/IEC and RET620 ANSI/IEC).
- Six setting groups.

- Cable fault detection (REF620 ANSI).
- Web-browser base user interface. (ABB, 2017)

Figure 13. REF620.

5 Methods and excecution

This bachelor thesis work is a continuation to an existing relay retrofit solution and is done in similar steps. Some of the material can be used for this extension, such as cover plates and cable markings. In PCM600, however the automatic parameter transfer will not work for SPAC relays, because the PCM600 extension was done exclusively for the previous retrofit solution. Therefore, the parameters have to be manually set.

5.1 Finding the corresponding relays

Ideally, the relay switch should be as cost effective as possible. For that reason, the first choice for retrofitting SPACOM relays would be the Relion 615 models. In some cases, the Relion 615 does not have enough of inputs and outputs. In those cases the replacing relays are Relion 620 series relays. The SPAC relays are all motor- or feeder protection relays. The REF relays will replace the feeder relays and REM relays will then replace the two motor protection relays that are in the scope.

ABB relays have specific order codes designed to them and are specified by the features that the relays have. The PST – Product Selection Tool is a web application that creates the order code by the user’s choices. With the help of this web application the order code for relay replacement can be obtained, after the replacing relay model is decided. The order code will be used as reference that will help find the corresponding relay when a relay switch is needed.

The Relion order code to replace each individual SPAC relay is dependent on the features that the SPAC relay has. One Relion model can perform a variety of different functions. Relion relays are built with different standard configurations depending on customer needs. The features considered in the retrofitting are the standard configuration and the amount of analog and binary inputs and outputs. All the other factors are case specific.

5.1.1 Product Selection Tool

The Product selection tool is designed to support order code creation for ABB Distribution Automation IEC products with emphasis on but not exclusively for Relion Product Family. The Product Selection Tool can be accessed by anyone on the internet.

Due to the modular nature of the product there are restrictions to order code selection. Selection of any available order code character may result other codes to be unavailable.

PST automatically guides users to create valid order codes. Unavailable selections are dimmed and cannot be selected. By filling out every selection in order, starting from the top, the order code will then show on the line.

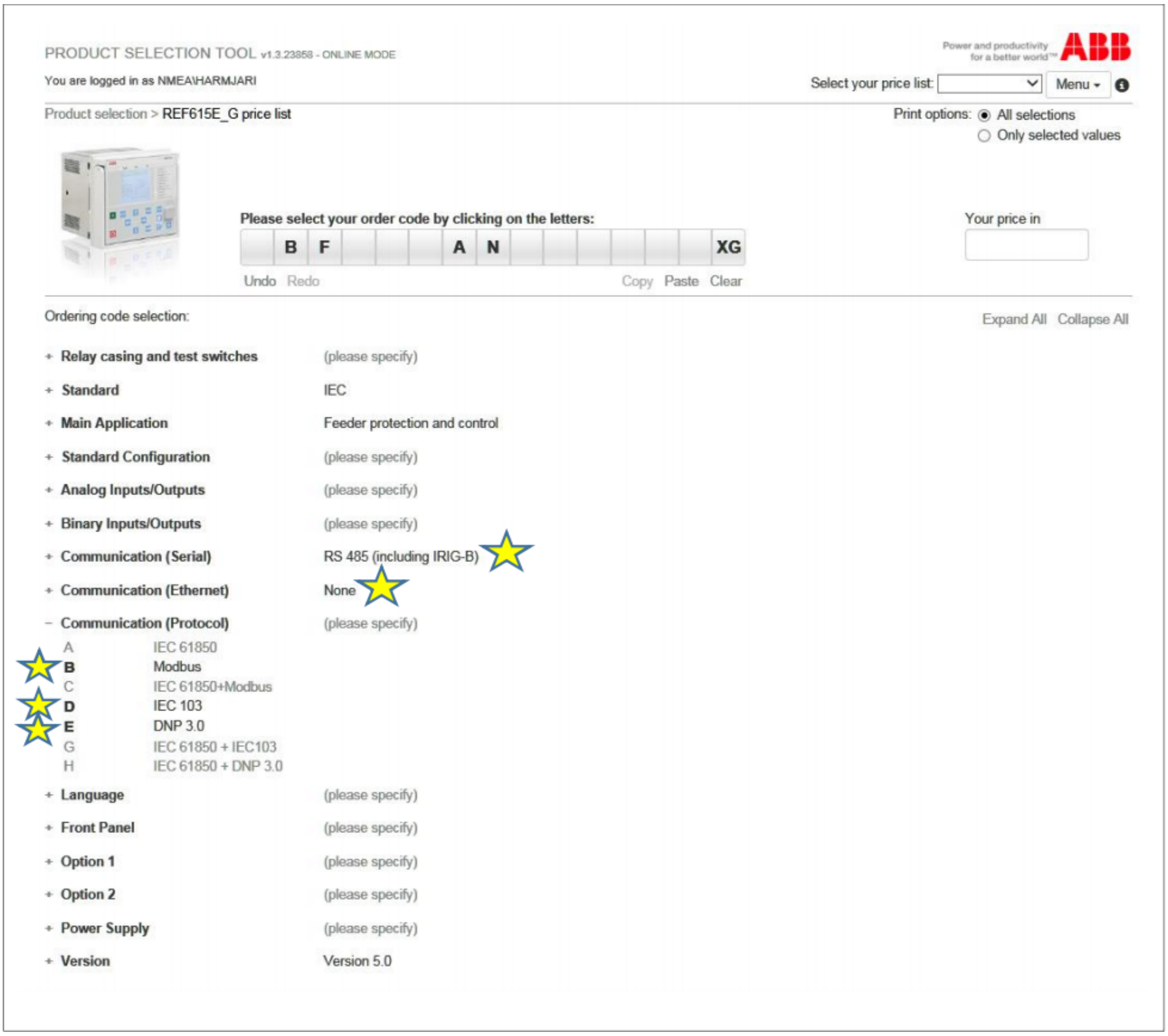

Figure 14. The view in Product selection tool.

5.2 Changing the relay

The relay change was the main goal of this bachelor thesis. This part of the thesis addresses the writing of a manual for each individual relay in the scope. Every relay needs its own manual because the connections, protection functions and accessories needed are different. These factors will also affect the installation. The relay change is more complicated than just removing the old relay and installing a new one. There are some things to consider such as different inputs/outputs as well as the different physical size between the relays.

The process starts from identifying the need for a relay change and identifying where the problem is and inspecting the upcoming installation. Then ABB chooses the material needed for the project and makes an offer to the customer. After this the work can be started by preparing the settings and going through the as-built installation documents. Finally at the site after the relay change begins the commissioning.

Figure 15. The relay retrofit process.

5.2.1 Connection tables

Connection tables are needed for every single relay and the replacing relay. The connections have to be correctly installed and engineered, because the goal is to get the new relay working exactly like the old one. The corresponding inputs and outputs are decided by comparing the connection diagrams of both relays. The chosen connections are based on the default connections that the relays have. The default connections for the inputs and outputs can be found in the relay manuals. Every manual has a list of the terminal numbers and connections, which show how the relay should be connected.

Terminal numbers:

Terminal block	Terminal number	Function
X0	1-2	Current I_{L1}, 5A
	1-3	Current I_{L1}, 1A
	4-5	Current I_{L2}, 5A
	4-6	Current I_{L2}, 1A
	7-8	Current I_{L3}, 5A
	7-9	Current I_{L3}, 1A
	25-26	Neutral current I_0, 5A in SPAC 310 C or 1A in SPAC 312 C
	25-27	Neutral current I_0, 1A in SPAC 310 C or 0.2A in SPAC 312 C
	61-62	Auxiliary power supply. Positive voltage should be connected to terminal 61
	63	Protective earth
	65-66	Open output, as a default also I>, I>>, I_0> and I_0>> tripping signal
	85-86	Close output
X1	1-2-3	Self-supervision (IRF) signalling output. When auxiliary power is connected and the device is operating properly the contact 2-3 is closed
	4-5	Signal output 3. E.g. I> alarm, I>> alarm, I_0> alarm, I_0>> alarm (programmable), as a default alarm for I> or I>> trip
	6-7	Signal output 2. E.g. I> start or alarm, I>> start or alarm, I_0> start or alarm, I_0>> start or alarm (programmable), as a default no signal is connected
	8-9	Signal output 1. E.g. I> start, I>> start, I_0> start, I_0>> start (programmable), as a default I> start
	10-11	Input channel 9
X2	1-5	Input channel 4
	2-5	Input channel 5
	3-5	Input channel 6
	4-5	Input channel 7 or energy pulse counter
	6-7	Input channel 8 or blocking for protection
	8-14	Input channel 1, open status. E.g. when a circuit breaker is open there must be a voltage connected to this input
	9-14	Input channel 1, closed status. E.g. when a circuit breaker is closed there must be a voltage connected to this input
	10-14	Input channel 2, open status
	11-14	Input channel 2, closed status
	12-14	Input channel 3, open status
	13-14	Input channel 3, closed status
X3	1-2	mA input for the measurement of active power
	3-4	mA input for the measurement of reactive power

Figure 16. The terminal number list for SPAC 310C. (SPAC 310C users manual)

Table 12: Default connections for binary outputs

Binary output	Description
X100-PO1	Close circuit breaker
X100-PO2	Circuit breaker failure protection trip to upstream breaker
X100-PO3	Open circuit breaker/trip coil 1
X100-PO4	Open circuit breaker/trip coil 2
X100-SO1	General start indication
X100-SO2	General operate indication

Figure 17. Default connections for binary outputs REF615. (REF615 application manual)

It is nearly impossible to construct a full connection table for a relay. The relays have many functionalities and customers who have the relays in use will have different connections, because they may need different kind of protection. This is why the on-site engineers have to look at the as-built drawings, which show the connections in use. Finally, the new relay connections with the help of the connection table and relay manuals can be planned.

SPAC310C		REF615	
Terminal Block	Terminal Number		
X0	1	X120: 8	IL1/N
	4	X120: 10	IL2/N
	7	X120: 12	IL3/N
	2-3	X120:7	IL1
	5-6	X120:9	IL2
	8-9	X120:11	IL3
	25	X120:13	Io/N
	26,27	X120:14	Io
	61	X100:1	aux+
	62	X100:2	aux-
	63	GND	
	65	X100:16	CB Open-
	66	X100:15	CB Open+
	85	X100:6	CB Close-
	86	X100:7	CB Close+

Figure 18. Connection table for SPAC 310C to the REF615.

5.2.2 The old relay

The manual will have a list of tools and accessories needed when arriving to a relay switch site. Also the switchgear pictures and as-built drawings have to be obtained. The first step when coming to a site to perform a relay switch is to look at the as-built drawings, which show the connections and the protection functions that are in use. Then the parameters can be downloaded with the Relay engineering tool CAP505 from the old relay. Before extracting the relay from the switchgear, the power to the relay has to be disconnected. When using the same cables, a wire marking set can be used. With the help of the wire marking set, the wires are marked with the terminal and port where the cable needs to be connected in the new relay. The cables are marked according to the existing installation and then compared to the connection tables. This will help to avoid confusion with the cables. There are many different cables, that need to be connected and marking them will make the installation easier. After the markings are done, the relay can be disconnected and removed. Another option would be to use a new cable set which will have the markings already on them. Using new cables is a good option when the old cables in use are old and damaged. Sometimes the existing cables can even be too short.

The old and new relays come in different sizes so this means that the hole needs to be covered with a plate that fits a Relion relay into it. The SPACOM relays are wider and Relion relays are higher in general. This means that the hole needs to be extended upwards and the width gets covered by the plate. The SPAC310C relay has 226 mm in width and the height is 162 mm. The hole needs to be extended 15 mm upwards since the height of the Relion relays is 177 mm. Depth in these relay switches will not be an issue because the SPACOM dimensions are deeper compared to the Relion relays.

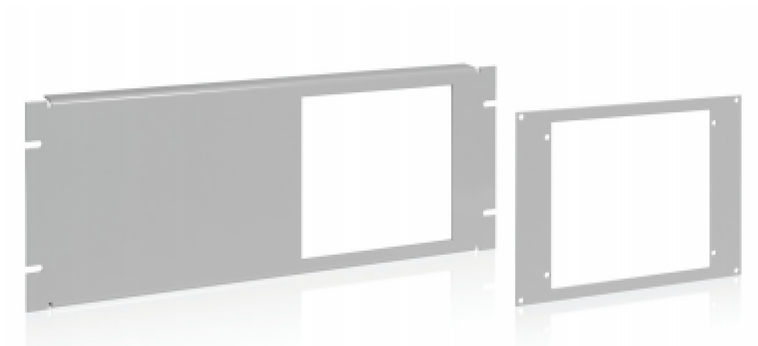

Figure 19. Cover plates for REF615 and SPAC 310C change.

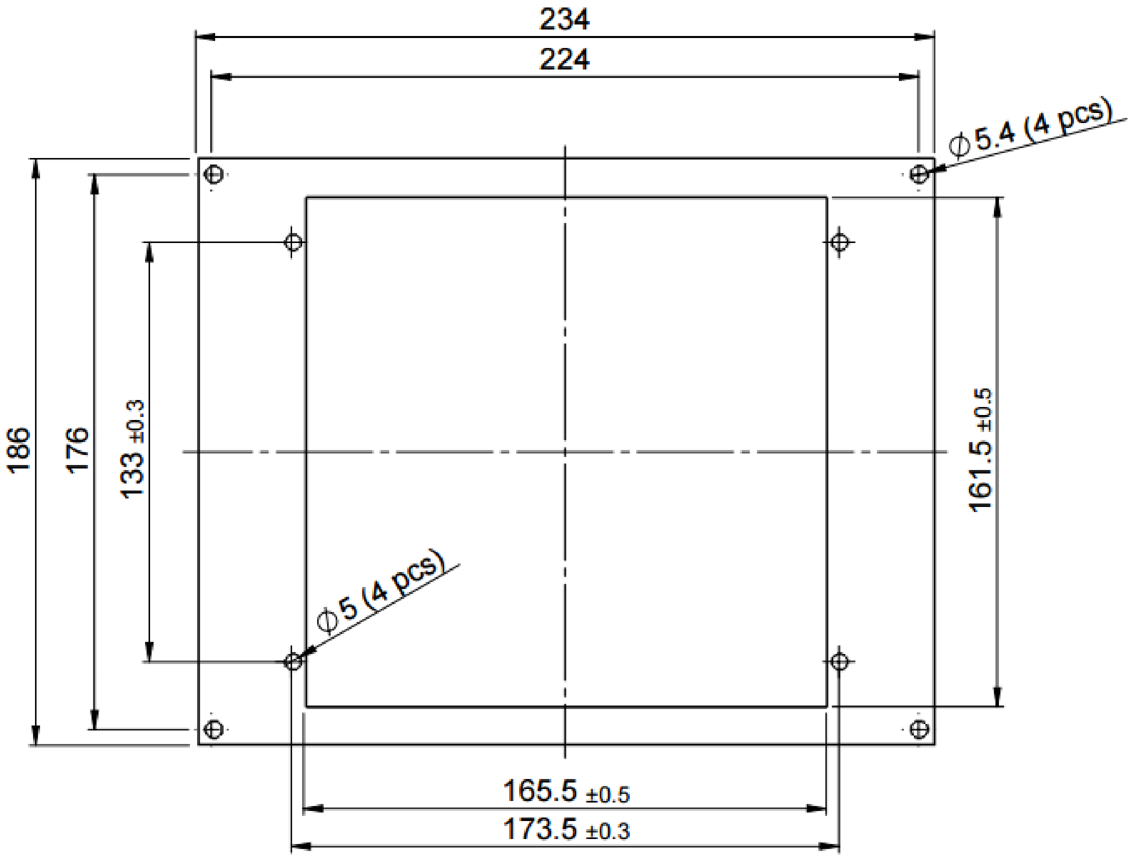

Figure 20. Dimensional drawing for REF615 cover plate for change from SPAC 310C.

5.2.3 New relay

When the cover plates are in place and the hole in the switchgear door is done, the new relay can be installed. The already marked cables can be connected to the relay. The marked cables can be connected to the ports easily, since the markings show the exact port where they should be connected. Now the power can be turned on and a laptop with PCM600 software can be connected to the relay. Parameters taken from the old relay can now be installed to the new relay with the software.

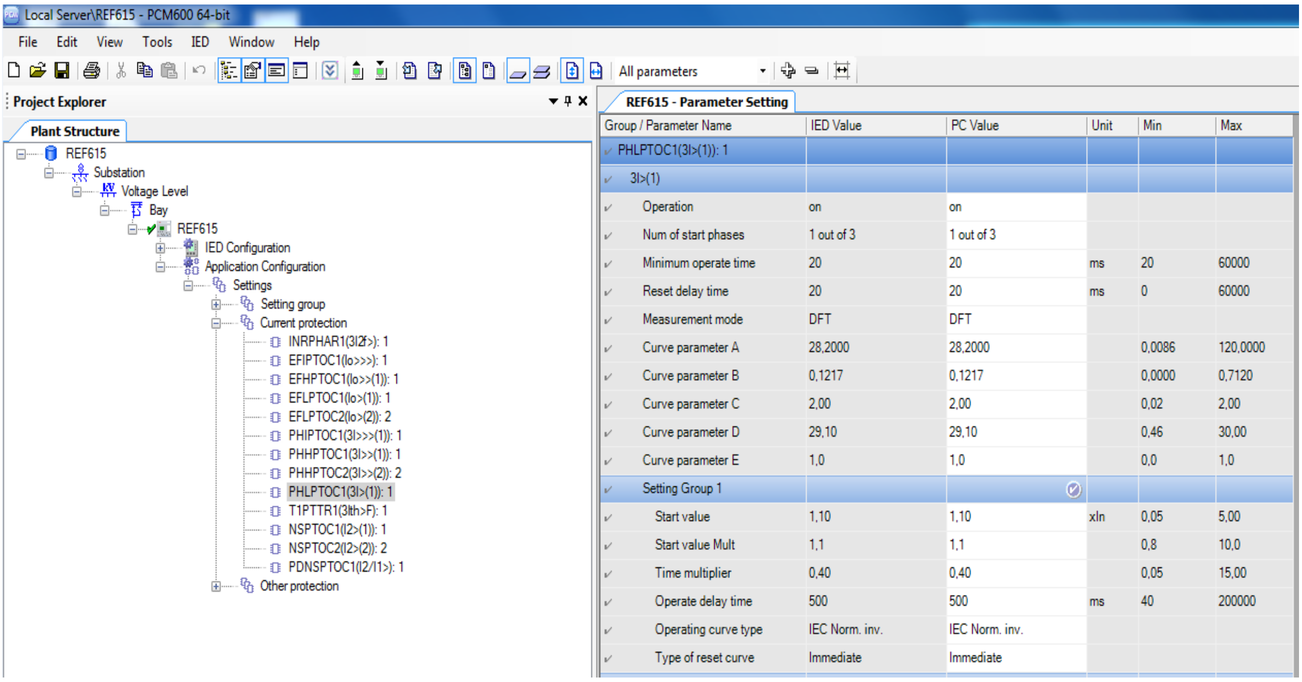

Figure 21. The view in PCM600.

5.3 Relay testing

After the replacing of the relay, the new relay functionalities have to be tested before commissioning. The relay tests will show if the protection functionalities work the same way with the new relay. This will also show if the connections work correctly.

The relays chosen for the tests in this project were SPAC 310C, SPAC 320C and the replacement relays REF615 and REM615. The SPAC 310C is a feeder protection relay and SPAC 320 a motor protection relay

The SPAC310C has a SPCJ 4D29 overcurrent and earth-fault relay module. The overcurrent protection was tested according to the normal inverse graph. The parameters that were used were 1.1 · In, which means that the relay sends a trip signal when the current exceeds 1.1 A.

Table 2. Test results for REF615 and SPAC 310C.

REF615		SPAC310C	
Current(A)	Trip(s)	Current(A)	Trip(s)
2	4,688	2	4,431
4	2,149	4	2,116
6	1,634	6	1,61
8	1,39	8	1,388

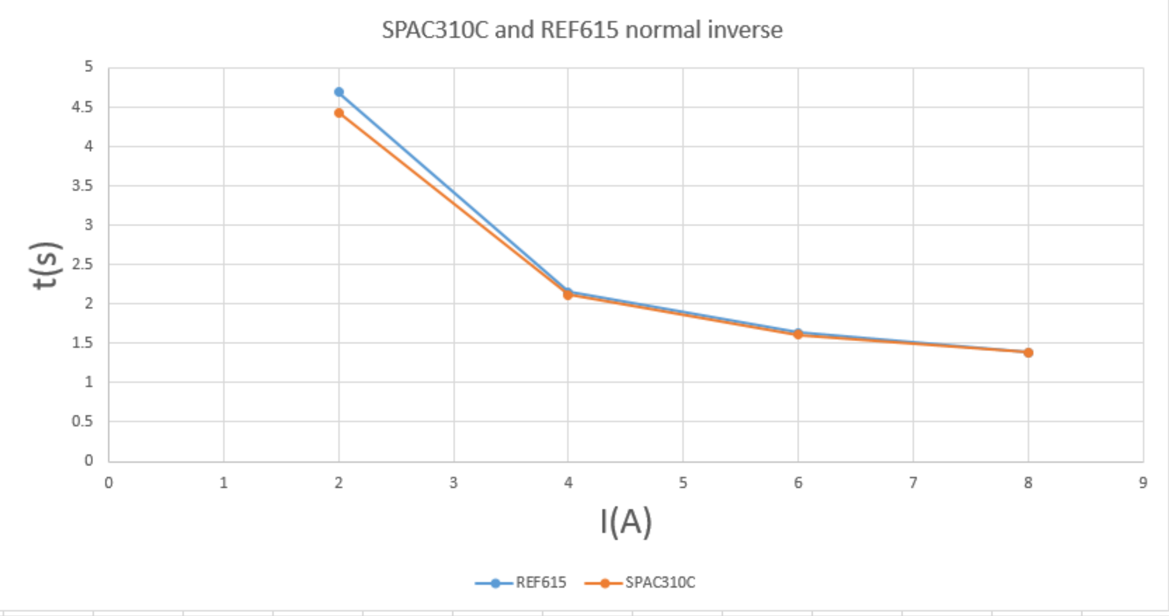

Figure 22. Test results for REF615 and SPAC 310C.

SPAC320C relay has a SPCJ 4D34 Motor protection relay module. The main protection functionality of the module is a thermal overload unit. The protection was tested according to trip curves with no prior load ("cold curve"). Current limit was set to 0.5 A and t6x was at five and p 50% (See Figure 23.).

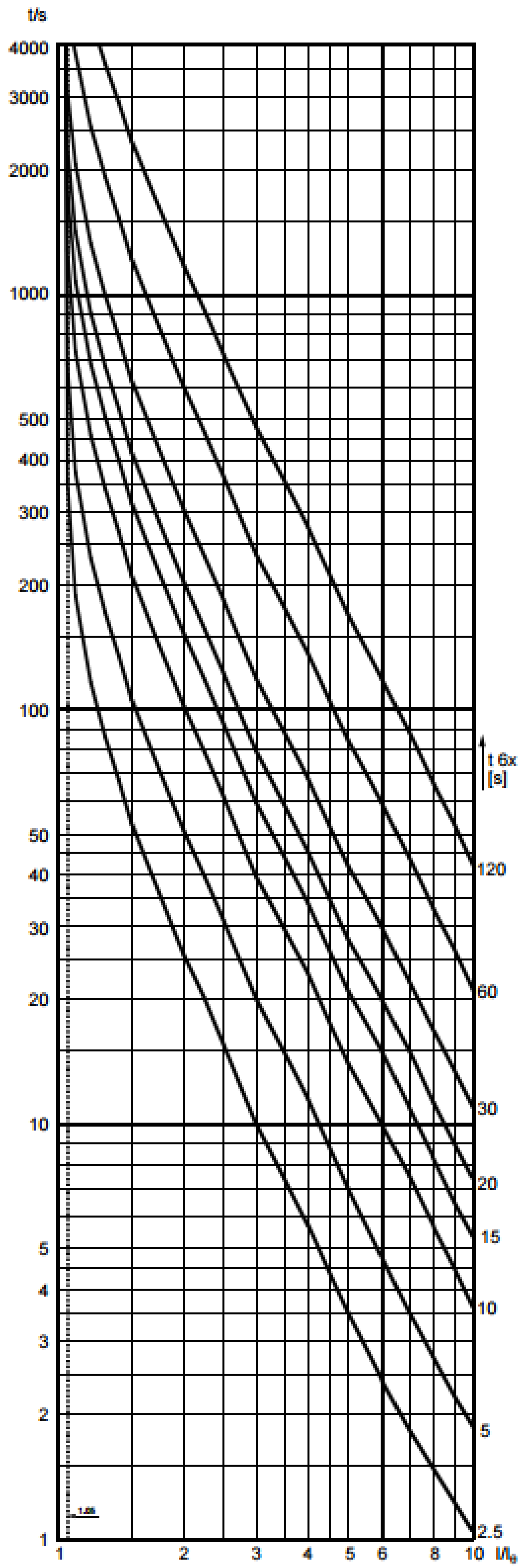

Figure 23. Trip curve for the thermal unit without prior load ("cold curve") p = 20…100 %. (SPAC310C user's manual)

Table 3. Test results for SPAC320C and REM615.

SPAC320C		REM615	
Current(A)	Trip(s)	Current(A)	Trip(s)
1.5	18.61	1.5	18.07
2	11.45	2	10.6
2.5	7.327	2.5	6.9
3	4.86	3	4.603

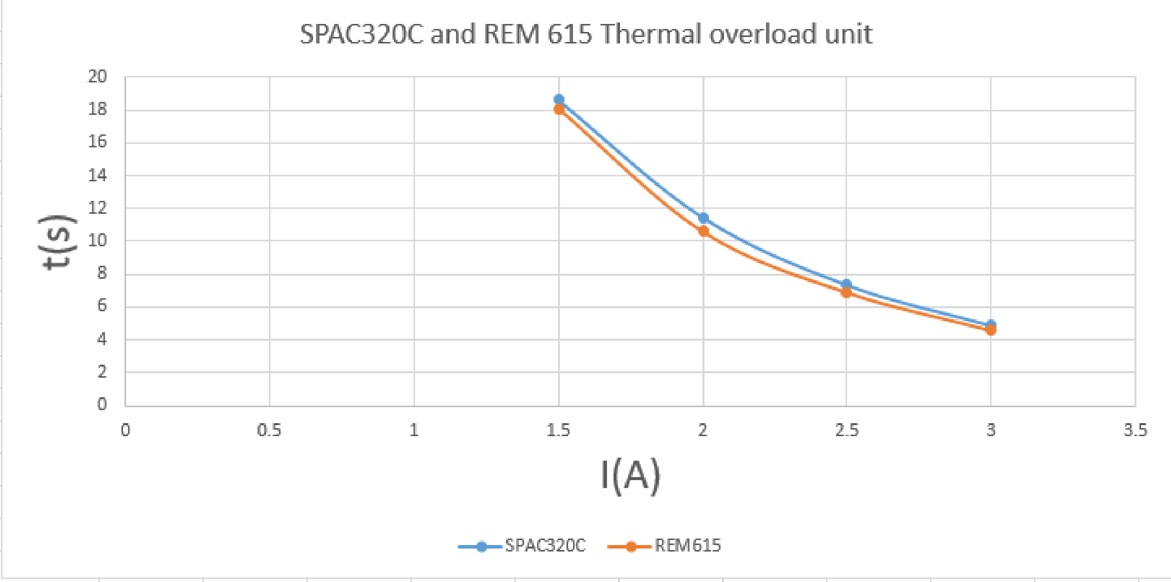

Figure 24. Test results for REM615 and SPAC 320C.

The results show that the protection works like it is supposed to. There is more deviation in the results with longer tripping times. Small deviations are normal and the testing gear cannot be completely accurate.

5.3.1 Omicron test equipment

The Omicron CMC256-6 is used as test equipment for the relay testing in this work. The CMC 256plus is the first choice for applications that require very high accuracy. This unit is not only an excellent test set for protection devices of all kinds, but also a universal calibration tool. Its high precision allows the calibration of a wide range of measuring devices, including electricity meters of class 0.2S, measuring transducers, power quality measurement devices and phasor measurement units (PMU). Its unique accuracy and flexibility make the CMC 256plus ideal for protection and measurement equipment manufacturers for research and development, production and type testing. (Omicron)

Key features include:

- Protection test set and universal calibrator in one device.
- Testing of all relay generations. Electromechanical, static, numerical, IEC 61850.
- Highly accurate test signals. For meter testing: The sources are the reference, no additional reference meters are required.
- Continuous synchronized outputs.
- Test universe software with manual and automated testing functionality.
- Front panel control.
- 10-channel analog measurement and transient recording functionality.
- Reliable and robust. (Omicron)

6 Results

Finding a solution for replacing the aging SPACOM relays was the main goal of this thesis. The first part of that was the making of the excel list. The excel sheet is a complete list of all the SPAC relays and variations. The list shows the corresponding Relion family relay, the order code for that relay and what material is needed for the relay switch. The sellers can use this list as a tool to make an offer with the right material quickly.

The corresponding relays and configurations is a part of the retrofit process, but also other things need to be considered. When performing a relay switch, the new relay does not go in to its place directly because the new relays are often different size compared to the old relays. ABB uses a cutting tool to make the hole big enough for the new relay and a cover plate to cover the extra space that the old relay may leave.

Another problem with the installation is the different connections between the relays. This problem was solved by creating connection tables for every SPAC relay showing the connections between the old and new relay. The connection tables are there to help on-site engineers with the relay switch. On site, the cables might be difficult to connect to the right ports only by looking at the connection tables. For installation ABB uses wire marking sets which show the right ports and pins where the cable should be connected.

The step-by-step manual was the other part of the result. It has a list of material needed for installation and what things should be considered before the relay switch. The first step when coming to the site, is downloading the parameters from the old relay and the removal of the old device. After this comes the preparations for new relay installation, such as the cutting of the hole and installing a cover plate. When the new relay is installed, the final step is testing and commissioning.

In this thesis work, the manuals were done for SPAC 310C and SPAC 320C relays. These manuals will work as templates for possible expansions in the future for the other SPAC relay manuals. The manual table of contents are as follows:

1. Prerequisites and check lists for the site work

    1.1. Needed engineering related documents

    1.2. Needed tools at the site

2. Removing the old device

2.1. Setting up the communication and reading the parameters from old device

2.2. Marking the wires

3. Mechanical installation of the new device

4. Configuration of the new device

5. Final actions

7 Discussion

This bachelor thesis work showed the development of ABB relays during a long period. The SPACOM relays, which were already introduced in the 1970's, had some advanced technology. That technology is still being used today because of its reliability of the SPACOM relays. But eventually due to wear and tear switching the relays become a mandatory step. This thesis work was done to find a way to make this change quickly and cost effectively.

The new generation of Relion relays showed to be valid options in replacing the SPACOM relays. The Relion product family has a wide range of functions and one unit can have the same functions as many different SPACOM relays.

The parameters of the relays in this project between the old relays and new relays work a bit differently. Those parameters were chosen as similar as possible so that both of them would work the same way. The main concern was on the functionality of the relays and the tests proved it successful. Functionality meaning the connecting of the relays as well as the protection. The testing was done with old relays that have been out of use for a long time. When a relay gets old the outputs of the relay wears out. This might have caused variation in the test results. This only goes to show the importance of switching to newer relays. The new relays did work similarly with given parameters and the protection functionalities worked how they are supposed to.

This thesis work and results have proven the need of relay change for old relays that have been used for a long time. If the relay gets old and measurements are not accurate, in worst cases it may cause damage to the grid. Also the results showed that the new generation will cover the needs of the application that the old relay have had, as well as the possibility of added functionalities of the new generation Relion relays.

This bachelor thesis work gave the opportunity to research a wide variety of relays, both old and new. This was a good way of learning the functionality of a relay from the aspect of how the relay has developed during time.

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