Development of templates for protective relays in design tool E³

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Abstract

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Title: *Development of templates for protective relays in design tool E^3*

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2 March 2014 32 pages 9 Appendices

This Bachelor's thesis work was done for ABB Power Generation Systems in Vaasa. The objective of this thesis work was to create ready-made templates in design tool E^3, containing all key schematics associated with a protection cubicle. As the design tool E^3 has only recently been taken into use by the entire staff at Power Generation, another objective was to try and find a unified layout for how the protection schematics could be drawn. The main focus was on generator protection relays, but also other types were evaluated. The resulting templates will be of use for both the design department and the sales department when negotiating with clients.

The results of this work were five separate protective relay templates, four of which were made for generator protection and one was for transformer protection. All of these templates were then distributed through the E^3 sub-circuit library to all users of the E^3 design tool within the Power Systems division.

Language: English

Key words: protective relay, E^3, template

Abstrakt

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Titel: *Development of templates for protective relays in design tool E^3*

2 mars 2014 32 sidor 9 Bilagor

Detta examensarbete gjordes åt ABB Power Generation Systems i Vasa. Målet var att skapa färdiga mallbottnar i planeringsverktyget E^3, innehållande alla relevanta samt viktiga elritningar tillhörande ett skyddsreläskåp. Eftersom planeringsverktyget E^3 först nyligen tagits i bruk av all personal vid Power Generation, så sattes det tid på att finna ett enhetligt sätt att rita skyddskretsscheman. Huvudsakligen sattes fokus på generatorskyddsrelän, även om andra alternativ undersöktes. De resulterande mallbottnarna skulle sedan komma i användning för både planeringsavdelningen samt för försäljningen då de förhandlar med kunder.

Resultatet för detta arbete blev fem olika skyddsrelämallbottnar, fyra specificerade för generatorskydd och en för transformatorskydd. Alla mallbottnar spreds via E^3:s ”sub-circuit” databas till alla användare av E^3-planeringsverktyget inom Power Systems divisionen.

Språk: engelska

Nyckelord: skyddsrelä, E^3, mallbotten

Tiivistelmä

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Nimike: *Development of templates for protective relays in design tool E^3*

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2. maaliskuuta 2014 32 sivua 9 Liitettä

Tämä opinnäytetyö tehtiin ABB Power Generation Systemsille Vaasassa. Työssä tehtävä oli luoda valmiita tyyppipiirejä E^3-suunnitteluohjelmaan, jotka sisältäisivät kaikki oleellisimmat kaaviot liittyen suojarelekaapin suunnitteluun. Koska E^3-suunnitteluohjelma on vasta äskettäin otettu käyttöön koko Power Generation henkilöstön voimin, ajatuksena oli myös yrittää yhtenäistää tapa, jolla suojauskaaviot piirretään. Pääpaino oli generaattorisuojareleissä, mutta myös muita suojareleitä tutkittiin. Valmiit tyyppipiirit tulisivat käyttöön suunnitteluosastolle sekä myyntiosastolle, kun neuvotteluja asiakkaiden kanssa käydään.

Opinnäytetyön lopputulos oli viisi erillistä suojareletyyppipiiriä, neljä generaattorisuojaukseen tarkoitettua ja yksi muuntajasuojaukseen. Kaikki tyyppipiirit jaetiin E^3 ”sub-circuit”-tietokannan kautta kaikille E^3-käyttäjille, jotka kuuluvat Power Systems divisioonaan.

Kieli: Englanti

Avainsanat: suojarele, E^3, tyyppipiiri

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Abbreviations

AC – Alternating Current

DC – Direct Current

CAD – Computer-Aided Design

CB – Circuit Breaker

CT – Current Transformer

I/O – Input/Output

IED – Intelligent Electronic Device

MCB – Miniature Circuit Breaker

SLD – Single Line Diagram

VT – Voltage Transformer

Preface

I would like to thank ABB Power Generation for the opportunity to do my Bachelor's thesis. I would also like to thank my supervisor Mikko Nevala at ABB and Roger Mäntylä at Novia University of Applied Sciences, as well as Sven Lindberg for all the help with the E^3 design tool.

2 March 2014

Axel Lindfors

Introduction

This Bachelor's thesis was made for ABB Oy, Power Generation unit in Vaasa. The objective with this work was to generate a library containing standardized templates of protective relays in design tool E^3.

1.1 Company

ABB is a worldwide, leading company in power and automation technologies. Headquartered in Switzerland, Zürich, the company operates in approximately 100 countries and employs about 150 000 people. About 7000, of the total 150 000 employees, work in Finland. ABB was the result of a merger made in 1988, between the Swedish company ASEA (Allmänna Svenska Aktiebolaget) and the Swiss company BBC (Brown Boveri & Cie) (The ABB Group 2013).

This thesis work has been carried out for ABB Oy, Power Generation unit. The Power Generation unit is a part of the Power Systems division and one of its offices is located in Strömberg Park, Vaasa. The unit in Vaasa offers turnkey electrical, automation, instrumentation and control systems to different power generation plants, e.g. hydro, gas and nuclear power plants.

1.2 Purpose

When the planning of different systems is being done in the Power Generation unit in Vaasa, the design tool that is used today is CAD-software E^3. With E^3 being a relatively new design tool at the unit there has not been a single standardized way of drawing protection schematics before, as the case has been with the previously used design tools AutoCAD and OPTI. In comparison with the other design tools earlier used at the Power Generation unit, E^3 provides the possibility of using libraries for both components and ready-made templates.

The main purpose of this work is to create a standardized set of schematics for all essential parts associated with protection design and planning. The main focus was on generator protective relays, but also other protection relays were evaluated. The templates will be device specific, which means that the templates will not be of a universal type. All the templates will be included in a library, which can then be accessed by all Power Systems E^3 users.

The benefits of creating ready-made templates like these are e.g. the facilitation of planning and design, but also the fact that this enables a transparent and standardized way of drawing schematics.

2 Protective relays

A protection relay is a device used in electrical applications for the protection of various units, e.g. transformers, motors, generators, electrical grids etc. The relay requires measurements for its operation, these measurements most commonly being current- and voltage measurements. As for the operation of the relay, the relay is configured inside an allowed range and if the relay detects that the magnitude of the incoming measurements are outside this range, the relay will operate. The operation consists generally of closing or opening of electrical contacts within the relay itself, which then leads to further action, for example the tripping of a circuit breaker. (El-Hawary 2000, pp. 267-270)

The protective relay protects units from different conditions that are not desirable, as these conditions can harm, or in the worst of cases damage the unit. Conditions that the relay monitors can be short circuits, overcurrent, over-/under frequency, reverse power flows, etc. (Ungrad & Winkler & Wiszniewski 1995, pp. 28-38)

2.1 History of protective relays

Protective relays have developed a lot since their first introduction. The relays are divided into three main groups according to their operating principle (Aura & Tonteri 1993, pp. 169-170):

- Electromagnetic relays
- Static relays
- Numerical protection

Electromagnetic relays were the first protective relays out on the market. The first relays were connected to the main circuit (primary circuit) and when the current in the main circuit reached the preset value, the relay tripped and via a bar opened the CB. Later on came models that could operate with CTs and VTs, which were more economical and had better tripping characteristics. Electromagnetic relays have a lot of moving parts, thus requiring a substantial amount of maintenance.

Figure 1. Electromechanical overcurrent relay (China Relay 2013)

In the middle of the 1960s static protective relays became ever more common as the relay of choice for protection applications. Static relays are based on semiconductors (transistors and diodes), and can provide a significantly faster and more accurate operation than the electromechanical relay. The use of electronics instead of a mechanical design enables the possibility of having several protection functions implemented in one relay instead of just one function per relay.

Figure 2. Static directional overcurrent relay (ABB 2011)

In the 1980s the next generation of protective relays, numerical protection relays, started to emerge. These relays incorporated digital technology in the same way as the static relays, but also microprocessors, which were a relatively new invention at the time. The microprocessor in these protective relays made them very flexible and versatile, e.g. even more protection functions could be packed into a single relay. The microprocessor technology also enables the use of logical functions, which can be of use in applications demanding blocking of other signals as well as in other tasks demanding programming. The numerical relays are the main choice of relays when designing a power plant today, although one can find older types of relays in power plants that have not been upgraded or as backup protection (Mörsky 1993, pp. 21-28).

Figure 3. Numerical generator protective relay REG670 (ABB 2007)

2.2 The purpose and tasks of protective relays

The main objective of a protective relay is to minimize the impact of faults, i.e. the protective relay does not prevent a fault. Therefore it is not only critical that the relay detects the fault quickly, but also that the protection IED uses this fault detection to, e.g, trip a circuit breaker. It is, however, important that the protection operates selectively, meaning that it isolates the correct unit from the electrical power system. The reliability regarding the operation of a protective IED is of most importance. The device has to work consistently in every fault situation and be consistent in the tripping signals.

As earlier established, a protective IED takes voltage and current as input measurements. A fault affects these measurements in a distinct manner. As a result of the changes to the input measurements during a fault, the impedance and power change simultaneously compared to the normal operating condition. In some cases even the frequency can be affected. This means that the relay, by metering one of the above stated units, has to determine if there is a fault in the power system. In all of the measurement values that the relay monitors there can be fault harmonics and transients, which stresses that the protection IED has to be able to filter out the unnecessary information.

For the correct operation of a protection IED, an area of protection is defined for the device, which the protection IED then monitors and operates in. Typical protection areas are generators, motors, busbars etc. These areas then extend to breaker which border these areas in different segments. An example of this can be found in figure 4. (Ungrad et alia 1995, pp. 3-5).

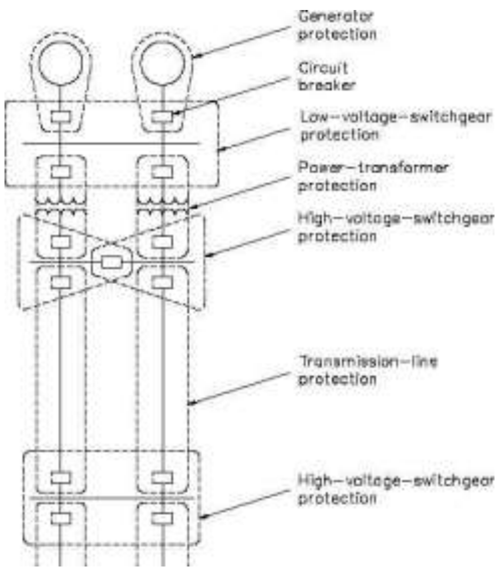

Figure 4. Overlapping protection zones (Tpub.com)

2.3 Technical aspects of protective relays

Most protective relays use direct current (DC voltage) as their power supply. The use of DC voltage in protection applications is based on the need to have a reliable power source, which will not be affected by faults in the power grid. While supply outages indeed being a possibility when using alternating current (AC), the DC voltage can be stored and used during faults if the situation requires that. The protective relay does not generate any signals to e.g. trip circuit breakers or send contact information to other devices; therefore it is vital that the DC system operates faultlessly. The DC system consists generally of one (or more) bank of storage batteries, a battery charger and a DC distribution board.

As mentioned earlier, the DC system nowadays powers the protective relay outputs. These outputs are most commonly being used for tripping circuits for CBs, but there are other outputs that are used for sending position information to the automation system and to inform other protective IEDs. Most protective relays today have digital inputs for interlocking signals originating from other protective IEDs. The use of interlocking has soared since the introduction of microprocessor-based protection IEDs. (Blackburn & Domin 2006, pp. 539-540)

2.4 Measuring transformers

When using numeric and static protection relays, instrument transformers, also known as measuring transformers, are used. The instrument transformers step down the current or voltage of the main circuit (primary) to a more sensible value (secondary), e.g. in CTs from 500A to 5A. The benefit of such a solution is that you do not have to dimension the relay inputs to handle the main circuit currents or voltages and you isolate the primary circuit from the secondary. Another benefit is that you can have the relay(s) placed far away from the protected unit, for example in a cubicle in a control room (Mörsky 1992, pp. 85-100).

The primary winding and secondary winding values come in many different varieties, although there are standardized guidelines regarding the instrument transformer levels. For instance the rated primary currents for CTs are standardized by the IEC standard 187.

Rated secondary currents for CTs are 1A, 2A or 5A, of which 1A and 5A are the most commonly used.

For VTs the rated voltage of the primary winding is usually the rated voltage of the power system (I.e. phase-to-phase connected). For phase-to-earth measurements the rated voltage of the VT is 1/√3 of the power system rated voltage. The standardized secondary voltages are 100, 110, 200 and 220V, and for earth-to-phase measurements the secondary voltage is 1/√3 of the standardized voltages. For the measurement of a "broken-delta" arrangement, the voltages will be a third of the standardized voltages, e.g. 100/3V (Ungrad et alia 1995, pp. 55-58).

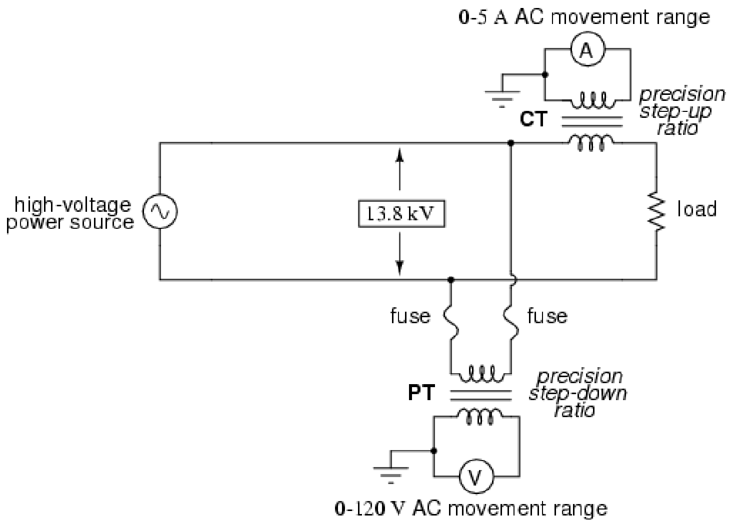

Figure 5. CT and VT connected in a circuit (All About Circuits 2012)

2.5 Protection functions in protective relays

As already established, protective relays are used for the limitation of damage to the protected object. The protection in modern microprocessor-based relays (numerical relays) is often done by implementing specific protection functions. Numerical relays nowadays are by most manufacturers designed for the protection of a specific unit, e.g. one protection IED will be used for the protection of a generator while another protection IED will be used for a transformer. The protection functions available in different protection IEDs can vary depending on the type. However, there are also block protection IEDs on the market (e.g. generator-transformer block protection).

The size of the protected unit often determines the amount of used protection functions. Big units (generators, transformers, substations etc.) are vital to the electrical power system and if these units fail the cost both in repairs and outages can be enormous. Listed down below are some protection functions commonly used in generator protection IEDs. (El-Hawary 2000, p. 270-273)

2.5.1 Differential protection

Differential protection is mainly used to detect short circuits between stator windings of synchronous generators, but also for earth fault detection. A fault such as a short circuit between phases can generate large damages in the generator, as a consequence of the large fault currents. The damage is not only limited to the generator (windings, stator core etc.). Also components such as the turbine and the shaft between the generator and the turbine can get damaged due to the current forces. Critical for the protection of the generator, but also for the stability of other generators in the vicinity, is that the fault clearance time has to be as fast and sensitive as possible.

The operation of the differential protection is based on Kirschoff's current law. The law states that the sum of current flowing into a node is equal to current flowing out of that node. This means that with identical CTs on both sides of a generator, comparisons can be made to see if the currents in fact are the same. A differential protection scheme can be seen in figure 6. (ABB 2013).

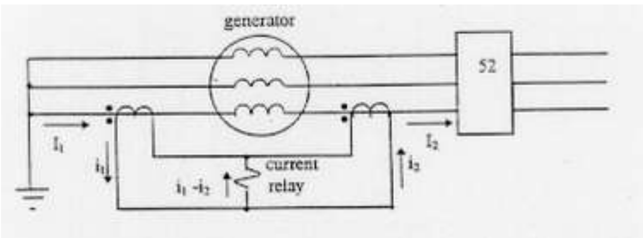

Figure 6. Operating principle of the differential protection (El-Hawary 2000)

2.5.2 Pole-slipping protection

In normal operation a synchronous generator is in synch with the rest of the power system, but a long power system fault near the generator can cause the generator to accelerate and loose synchronism. The result of a pole-slip is an oscillation of power, which can threaten the power system stability but also put the generator under a great deal of mechanical stress. Also an insufficient excitation of the generator can risk the synchronous operation of the generator, therefore it can also operate as a backup protection for the under-excitation protection function.

The pole-slipping protection should localize the fault, i.e. if the fault is in the generator, it should trip the generator and isolate it from the network. If the fault is external, originating from outside the plant, then the protection should isolate the faulty network. (Ungrad et alia 1995, pp. 219 – 220)

2.5.3 Overload protection

The thermal overload protection protects the generator from effectively overheating. The causes for overheating can be many, but a fault that can occur is an excessive reactive power load. Thermal overloads are particularly serious as they cannot proceed for a long time, before they start damaging the generator, which makes a fast operation of the protection vital. (ABB 2013)

There are various ways of implementing the overload protection, one of which is to use resistance thermometers for the generator. Temperatures are measured on the generator windings, while another measurement can be made for example on the coolant medium (air, oil etc.). (Ungrad et alia 1995, p. 222)

2.5.4 Negative phase sequence protection

The task of the negative sequence protection is to protect the generator against asymmetrical load. When a synchronous generator is subjected to an asymmetrical load, there will be a negative phase component in the stator current. This is an issue due to the fact that a proportionally small unbalanced load can distort the waveform of both the current and the voltage. This then leads to a heavy heating of the rotor core iron and can in worst cases cause generator vibrations (Ungrad et alia 1995, p. 223).

2.5.5 Reverse power protection

The reverse power protection function has the objective of preventing the damage to the prime-mover (turbine). When a turbine does not get supplied with energy (e.g. steam, water, gas etc.), the generator starts to act as motor. This is not desirable as particularly in steam and diesel engine power plants this can cause major damages to the gen-set (diesel) but also to the surroundings.

The protection operates by monitoring the direction of the power flow. The protection needs to be very sensitive as the range of settings is between 1-5% of nominal power. (Ungrad et alia 1995, pp. 227-228)

2.5.6 Single line diagram

A single line diagram (SLD), also known as one line diagram, is a way of describing an electrical power system. While generally all electrical power systems are in reality three-phase systems, the SLD simplifies the system to only be drawn with one line instead of three. This is useful when getting to grips with the layout of the power system and when looking at the power flows in the system. The main components of the power system are most commonly displayed in the SLD, these being: Generators, transformers, circuit breakers, bus bars, conductors etc.

When looking at the SLD from a protection point of view, only the protected unit(s) is displayed, together with the equipment connected with the protection of the unit. The equipment that is most commonly seen in protection SLDs are CTs, VTs, CBs, protective IEDs and the protection functions. A protective SLD can be found in figure 7.

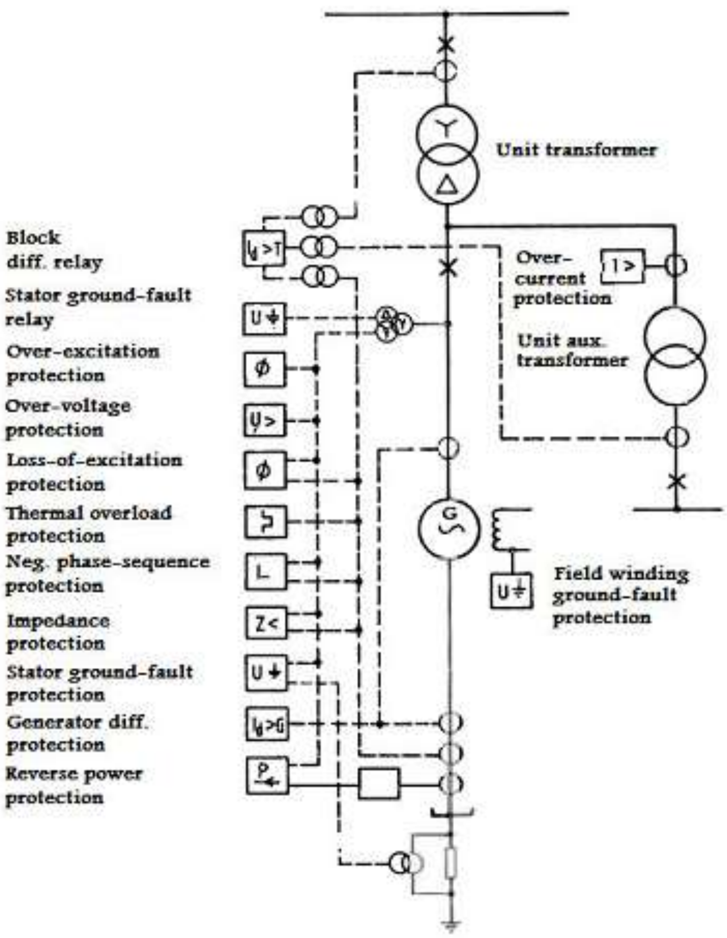

Figure 7. SLD over measurements and protection functions for a generator-transformer block (Stien 1986, p.4)

2.6 Protection philosophy

When designing the protection of a given unit, there are some important factors that need to be taken into account. The first, and most important, is to fulfill safety demands concerning people safety and equipment safety. With that factor dealt with, then other factors such as technical and economic aspects may be taken into account. Other considerations that also affect the design of the protection are for example, the importance of the protected unit and the probability of a certain fault.

With all the protection considerations taken into account, there are some requirements that are usually set for a protection IED, these being:

- Selectivity
- Sensitivity
- Speed
- Reliability

It is said that a protection IED operates selectively if it can distinguish a faulty part of a system. An example of this can be seen in figure 8, where the preferred CB to trip would be the first one upstream of the fault. One of the most common ways of ensuring absolute selectivity nowadays is to implement a differential protection, which only detects and operates on faults within the IED's own protection zone.

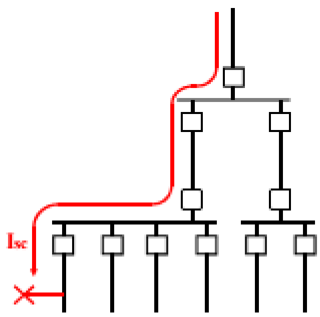

Figure 8. Flow of current after a short circuit

The sensitivity of a protection IED is of utmost importance, as many faults in the electrical power system can in terms of fault values be relatively small. However, the protection device may not be too sensitive, as this can generate unwanted operations resulting from inrush currents etc. As a consequence of these two factors the resulting sensitivity is often a compromise between normal operation mode and fault clearance.

Large fault currents caused by short circuits need to be cleared as fast as possible before the current causes damage to the protected unit. Slow and non-responsive fault clearance may also cause fluctuations, which then can evolve into an electrical grid stability issue. The speed of a protection IED can be divided into two categories: firstly the operation time of the protection function, i.e. how fast the relay detects a fault. The second factor is how fast the protective IED changes state and trips the desired CB.

The reliability of the protection used is vital. When looking at protective relays there are two fault situations that can occur, a false operation and a failure-to-operate situation. When looking at the two situations, it can be said that a fault of the type failure-to-operate generally causes greater damage to the protected unit. The malfunction of a protection IED often originates from factors not connected to the IED itself. Instead incorrect set-up of the relay, measurement errors and wrong protection functions are often the root of the problem. To minimize the risk of failure-to-operate faults, back-up protections are used. Often with protective relays the back-up protection is executed with another protective relay, effectively working in parallel with the main protection. The back-up protection can often in these cases be simpler in its design, partially due to economic aspects, but also for its task as a back-up protection. (ELKRAFTSSYSTEM 1, 2012, cha.11)

3. E3 series

E^3 is a software created for drawing and designing of electrical and fluid applications, targeted to a wide range of industries including automotive, power, machinery etc. The E^3 series utilizes an object-orientated database and the tool is based on the Windows-operating system. The tool consists of many different modules which all have different purposes and can provide the end user with different uses. The complete information relay is being dealt with by a joint database, also known as ECAD. A screenshot of the graphical user interface can be seen in figure 9. (CCS Group 2012)

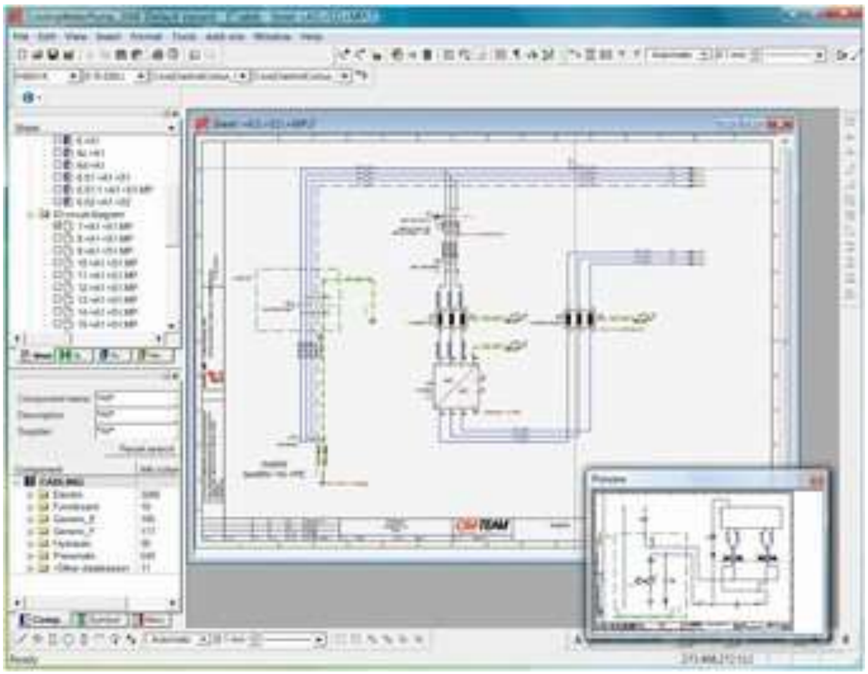

Figure 9. Graphical user interface of E^3 (CCS Group 2012)

3.1 The developers

The E^3 series tool was originally developed by the CIM-Team Corporation in Germany. The company was founded in 1987 and has always had its focus on CAD software for electrical and fluid applications. In 2001 CIM-Team introduced their first version of E^3. In 2006 the Japanese company Zuken acquired CIM-Team and their E^3 design tool, and the name change of CIM-Team to Zuken happened in 2009. In Scandinavia the E^3 products are licensed by CCS Group.

The tool is ideal for designing separate parts of a possibly complex project in one project environment. This makes E^3 useful in many different fields, e.g. in electrical power engineering, automation industry, hydraulics industry etc. (CCS Group 2012)

3.2 Modules

There are several different modules that you can use in the E^3 environment. The most important modules for power system electrical engineering applications are:

- E^3 Schematic
- E^3 Panel.

3.2.1 E3 schematic

The E^3 Schematic module is the core of all E^3 modules and is used for the designing and documenting of electrical control systems. With the schematics drawn it is possible to generate terminal lists, apparatus lists, cable lists and connection tables, which will facilitate the manufacturing of the design. All these documents can then be exported to Microsoft Excel for easy editing etc.

The E^3 system library, where all electrical components are located, is easily accessible and modifiable, e.g. for your own specialized components. The Schematic module has a lot of functions, such as preventing the designing of short circuits, automatic connections, text and object links etc. (Zuken 2012)

3.2.2 E3 panel

The E^3 Panel module is a seamless part of the E^3 Schematics module, which makes it easy to see and place connection in cabinets etc. As the two modules work together it is effortless to pick a component and use it in both modules. As both are updated at the same time, a change made in either one will be updated automatically in the other module. There is also a possibility of ‘auto-routing’, which will connect the wires for you, precisely as the connections have been made in the schematics module. (Zuken Inc. 2012)

4 Designing of the standardized template

The job description for this work was to generate standardized templates of protection devices, which would give a good foundation when designing new protection systems. As a consequence, following the design of the template, there was a need to get a library containing the most commonly used protection IEDs, but also protection IEDs that are going to be used in the future.

The main focus of this work was to generate templates for generator protective relays, but also a transformer protection relay was included. The E^3 module that was used in this specific work was the E^3 Schematic module (see chapter 3.2.1).

4.1 Choice of protective relays

The first part of the work was to examine and evaluate the protective relays with which hardware specifications would be included. As seen in chapters 2.1 and 2.2, protective relays are nowadays highly complex devices and the right hardware specifications are a vital part when assuring a proper functionality.

As a starting point old projects were consulted to examine which relays have been used before. The result of this was a list containing all the generator protective relays used in the Scandinavian hydro power plant projects carried out by ABB. Recurring protective IEDs in the projects were examined, and then placed on a shortlist as possible devices to be utilized in the templates. Some thought was also given to the future as most of the protective relays used in the Scandinavian projects were of the older ABB 500-series, which as of today have been upgraded to the ABB 600-series. After evaluating the previous projects and the future, the decision was made to focus entirely on ABB protective relays and to use a back-up relay protection configuration (see chapter 2.6).

Further investigations were made into the economic aspects of the protection IEDs used in the templates. The idea was to create co mbinations that would suit economically different applications and different protection unit sizes. This was important particularly when looking at the cost difference between the top end models and the lighter models, as the cost difference between the cheapest and the most expensive can be fivefold.

With these things in mind, the protective relays that were chosen to be made into E^3 protection templates were:

- 2 x REG670 + Injection unit REX060
- 2 x REG630
- 2 x REG650
- 2 x REM543
- RET670 & REF610 (Transformer Protection).

Looking at the chosen protective relays the REG670 represents the top end model and the REG630 (REM543) represents the lighter model in the generator protection case. The REM543 is a relatively old model and as mentioned before it is replaced with the 600-series. However, it is still used quite a lot in the Finnish hydro power plants and therefore it was decided to make a template out of it as well. The RET and REF used in the transformer protection were chosen so that the RET acts as a main relay and REF as a backup in case of a failure in the main protection relay (see chapter 2.6).

As for the hardware specifications the general idea was to make them all as complete models, i.e. “top-of-the-range” models, as possible. The protective relays were therefore equipped with the maximum amount of I/O components (see chapter 2.3) supported by the device. As a result, the time spent on modifying the templates should be minimized, when comparing the time it takes to add new components to the project and then the time it takes to remove them.

The choice of analogue inputs and the allocation of CT and VT inputs (see chapter 2.3) are explained in depth in chapter 4.2.1.

4.2 Designing and drawing of the schematics

The idea of the standardized template is to open it as a file and by modifying it adapt it to the specific project. The other main point is to try and unify the way of drawing these protection schematics.

Protection control systems, consist of several different segments (covered in the upcoming chapters), which means that the template has to contain all those segments as schematics. The schematics have to be easily modifiable, easy to understand and also they have to follow a logical order. This means that particular attention is necessary when designing the schematics.

When designing these templates, one complete template was first made and then, by modifying the first template, the rest was created. This was done to ensure that all of the templates had the same basic design and look. The first one that was made into a template was the REG670 including the injection unit REX060.

In the following subchapters there will be an overview of the design and the drawing process.

4.2.1 Single line diagram

As mentioned in chapter 2.5.6, the SLD is very useful and gives anyone working with electrical power systems a quick simplified overview of the electrical power system.

The placement of the CTs and VTs was based on a standard layout of an electrical power system. Although many projects might deviate from the SLD presented, it was designed as a good foundation to start a project from. This meant that in the generator protection SLD seven CTs and three VTs were used. In the transformer protection SLD, nine CTs and three VTs were used. Some of the measurement transformers did actually do the same type of measurements but, for the flexibility of choice and to allocate enough measurement transformers, this was the pre ferred option.

In addition to the measurement transformers, the protective relays and their analogue inputs and protection functions were also included in the protective SLD. The protective relays were drawn as E^3 fields into which the protective functions and analogue input specifications were displayed. The amount of analogue inputs used and the allocation of them were determined by the protection functions of each separate protective relay.

The circuit breakers and disconnectors were placed upstream seen from the generator, before the medium voltage bus bar.

Two different protection SLDs were designed for this work, one for the generator protection case, which can be seen in appendix 1, and one for the transformer protection case, which can be seen in appendix 2.

4.2.2 Protection matrix

The protection matrix is essentially a way of describing inputs, outputs and protection functions of a protective relay. There are many ways of doing these protection matrices. One AutoCAD example can be seen in figure 10.

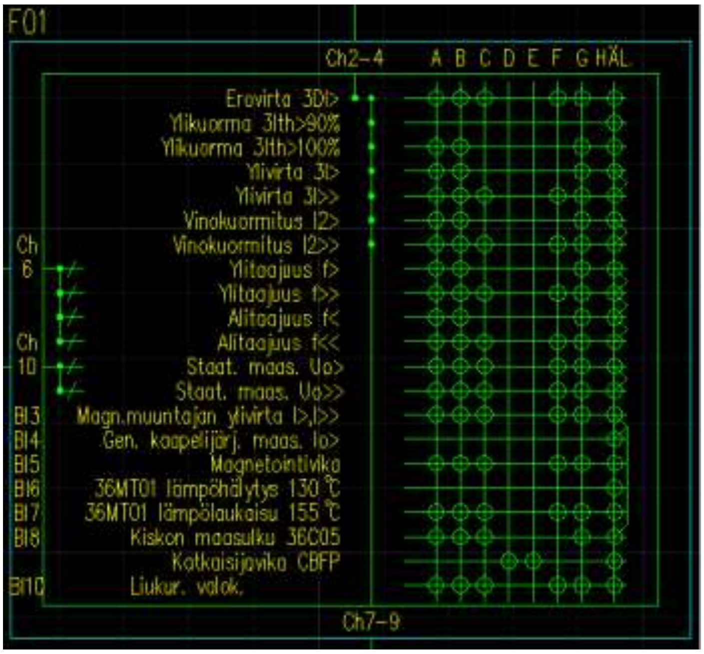

Figure 10. Protection matrix example

Many of the ABB projects examined for this work included the protection matrix within the same drawing as the SLD. However, there was no space to put the protection matrix in this project on the SLD sheet, so the decision was made to move it to a separate sheet. The protection matrix for one relay was then divided into two separate sheets, one containing the analogue inputs and protection functions and the other one containing the digital I/Os. To facilitate navigation when configuring the relay, a column was added in the first matrix containing the protection function name used in the relay.

The protection matrix was designed as a table to facilitate the modification and the interpretation and also to enable the use of a referencing system (see chapter 4.3). So for example there is a good overview of the inputs and there is a clear understanding of where they are coupled and for what task they are intended. As mentioned earlier there is an extensive referencing system that provides fast navigation within the project to facilitate the navigation between sheets to the correct analogue and digital inputs.

The protection matrix featuring the analogue inputs can be seen in appendix 3.

4.2.3 Supply circuits

As established in chapter 2.3, the protective relay is generally working with DC. However, in some protection systems there can be situations where AC is required. In the making of these templates the decision was made to use AC for cubicle lighting and also for an electrical outlet.

The DC supply was divided into separate circuits, one for every protective relay or device associated with the protective system. This was done by MCBs to facilitate for example maintenance or repair work done within the cubicle.

The source of the power supply for all the different components will not come from within the cubicle, instead the supply of DC and AC will come from a separate source.

An example of the supply circuits for the REG670 case can be found in appendix 4.

4.2.4 Measurement circuits

The measurement circuits display the analogue inputs and to which measurement transformers they are connected.

When designing the measurement circuits for these templates the basic idea was to try and display both the measurement transformers and the analogue inputs in the same sheet. This layout is transparent and easy to interpret when assembling or testing the cubicle. Further the schematics were made so one analogue input-card (usually containing 9-12 inputs) was displayed on one page. Some of the relays had two analogue input cards, which meant that they were placed on subsequent sheets.

The measurement circuits also included connection boxes, as they can be present in some power plants as junction boxes between the measurement transformer and the protective IED. There were also wire markings made in advance for the cables that will go between the connection terminals and measurement transformers.

Some voltage measurement transformer designs (open-delta configuration) took quite a lot of space and this meant that they had to be moved to another sheet. The signals were then referenced back to the measurements sheet and coupled with the corresponding protective relay voltage input.

A schematic of a measurement circuit can be found in appendix 5.

4.2.5 Tripping circuits

The tripping circuits describe and display the contacts in the protective relay that, when ordered shut, send a trip signal to a coil on a CB.

As the templates that were designed were to be a broader design, not only the main generator/transformer-breaker was drawn into the sheets as a field, but also other CBs were included. E.g. the subsequent upstream CBs were also included in the sheets, as they are breakers that would probably get a trip signal if a larger fault occurred.

The way of drawing the tripping circuits, as well as other circuits, in the ABB Power Systems division is to have the current flow from top to bottom. This had to be taken into account when designing the layout of the schematics. Noteworthy is also that for the correct functionality of certain contacts, the connecting wire between two contacts had to be drawn with a graphical line and not as a signal (wire).

The result of how the tripping circuit designs turned out can be found in appendix 6.

4.2.6 Digital inputs/outputs

As mentioned in chapter 2.3, the digital inputs/outputs are mainly used for the sending of information to the automation system and for interlocking between devices (see chapter 2.3). This elaborates in sending or receiving notifications from other components/devices in direct or indirect operation with the protective IEDs.

As the relays had various numbers of inputs and outputs depending on the model of the protective relay, the number of digital I/O sheets differed from one template to another quite radically. The digital inputs and outputs were displayed as they appear on the I/O-cards at the back of the protective relay, i.e. all inputs belonging to an input-card were on the same sheet. The same principle was adopted with the digital outputs.

The connection terminals associated with either the digital inputs or digital outputs were placed successively, in terms of numbering and placement in the cubicle, to enable the use of bridging between the terminals thus reducing the use of excess wire. All the digital inputs and outputs are connected between connection terminals so that easy changes can be made if changes of components or signal routes are required.

One digital input card from a REG670 can be seen in appendix 7.

4.2.7 Layout

The layout schematic displays how different components and devices are placed in a cubicle and how the cubicle itself is designed.

For these templates an ABB MNS type cubicle was used, with the cubicle description text on the top left and top right side of the cubicle. The templates were designed with multiple views of the cubicle, i.e. there was a front door view, back of front door view, front view of the inside and a side view of the cubicle.

E^3 has layouts for all components in its database and also for some components there are backplane layouts available. An example of a front facing layout of a REG630 can be seen in figure 11 and a backplane layout of the same REG630 can be found in figure 12.

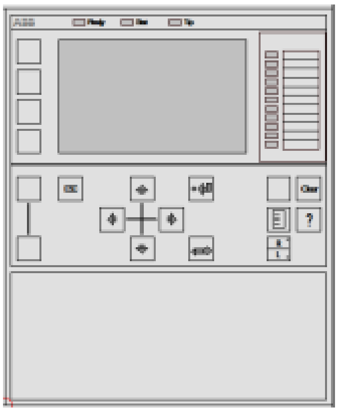

Figure 11. Front layout of ABB's protective relay REG630

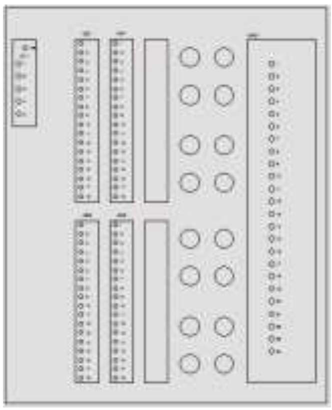

Figure 12. Backplane layout of ABB's protective relay REG630

The connection terminals in the layout schematic, and in the entire template, are designed to be grouped together according to their device names, this to enable bridging of the connection terminals and to isolate different circuits from one another, e.g. tripping circuits from signal circuits. The inside of the cubicle is equipped with extra DIN-rails with future expansion of protection devices and connection terminals in mind.

The layout schematic made for the REG670 template can be seen in appendix 8.

4.2.8 Reference tables

For IEDs in design tool E^3 there is something called reference tables. These tables make references to a component (often cards or modules) in the project and particularly to the symbols used from that specific component. It shows i.e. the placement of a symbol used from a device in the project.

Since the protective relays in this project had a lot of different input and output modules (cards), this added a couple of sheets to the template. In figure 13 there is an example of what a reference table of a power supply module from a REG670 looks like in E^3.

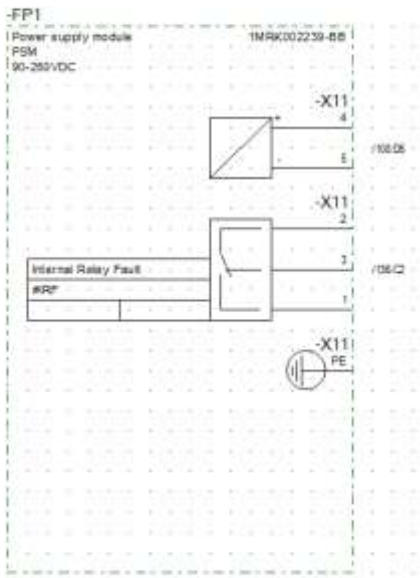

Figure 13. Reference table of a Power Supply Module

4.2.9 Lists and tables

In E^3 the generation of connection terminal tables, parts lists etc. is very easy once all the connection terminals and devices are set up properly.

The connection terminals in this work were divided into categories depending on in which segment they were in use. This meant that five different categories of connection terminals were created. See the list down below.

- X1 (No. 100 and onwards) : AC Voltage
- X2 (No. 200 and onwards) : DC Voltage – auxiliary
- X3 (No. 300 and onwards) : AC Voltage – measurements
- X4 (No. 400 and onwards) : I/O – Signaling
- X5 (No. 500 and onwards) : Tripping circuits

There were two types of connection terminals used in this project. For signaling and supply circuits Phoenix Contact terminals UT 2.5-MT-P/P were used and for the heavy duty circuits (supply and measurements) connection terminals URTK/S-BEN6 by the same manufacturer were used.

When generating the parts list of the template, it is important to make sure that all the devices that are used are assigned to the right assembly (figure 14).

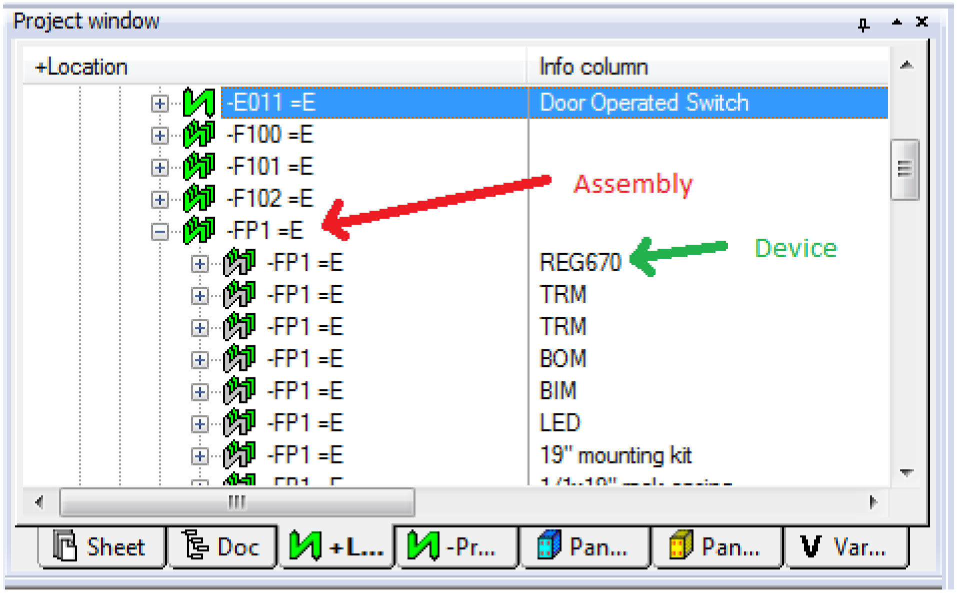

Figure 14. Description of assembly and device in design tool E^3

An E^3 terminal table showing the X1 connection terminals can be found in appendix 9.

4.3 Referencing of the inputs

The referencing system of signals in E^3 enables the user to “jump” between schematics, instead of opening a new drawing every time, e.g. when trying to cross reference two separate drawings or follow a wire from one drawing to another.

In this template the invisible signal reference symbols (figure 15) and reference system were used to facilitate the navigation between sheets, and ordinary signal referencing was used for basic signal referencing. In the referencing system used for navigation, the protection matrix contains the analogue and digital inputs as text and to make it easier for the designer to jump to the actual symbols, a reference system was implemented.

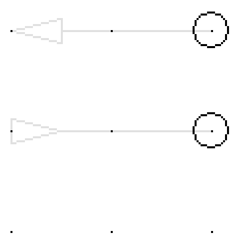

Figure 15. Invisible signal reference symbols

To create this the invisible signal (figure 15) reference in E^3 was utilized, but instead of connecting a signal to it, it was only used as a link between the protection matrix and the inputs. This creates a green signal reference text in the shape of XXX.YZ. The Xs tell the sheet number, Ys the row and Zs the column of the linked signal reference. When moving between the sheets in E^3, the corresponding signal reference symbol gets surrounded by a purple-coloured box to highlight it. The reference "jumping" also works when printing the schematics into a PDF-format, although the highlighting function does not. A figure describing the referencing system used in this project can be found in figure 16.

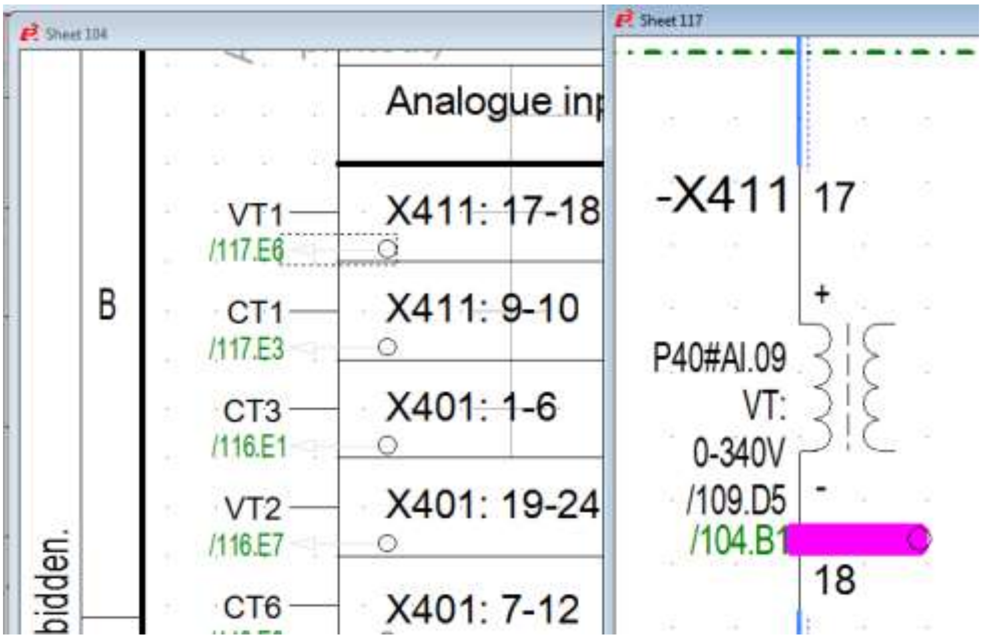

Figure 16. Operating principle of the referencing system in E^3

5 Results

The main task of this Bachelor’s thesis was to create a standardized template for protective relays in design tool E^3. Special attention was paid to the single line diagram and protection matrix, as so far there has been no single standard way of drawing these schematics before.

The result of this work was five templates made of protection relays, four of which were targeted for generator protection and one which was targeted for transformer protection. These five templates were then included in ABB Power Systems’ E^3 template library.

There were a lot of minor tasks involved in this work, and the biggest of them was to make the measurement circuits as easy to interpret as possible. As seen in appendix 6, the solution that in the end was adopted was that all the inputs relating to a card would be displayed on a single sheet instead of being spread out on several different sheets.

The protection matrix was chosen to be designed as a table format, because it should be easy to modify and easy to understand. The fact that the matrix should include everything related to the protective relay made the choice easier, as there is a lot of information being displayed in a protection matrix. The final version of an analogue signal protection matrix can be found in appendix 3.

The main idea of the SLD was that they would be designed in such a way that the first glimpse of the SLD would give the observer an extensive understanding of the system and the protections implemented. The protection SLD for a REG670 generator protective relay can be found in appendix 1. The corresponding SLD for a RET670 transformer protective relay can be found in appendix 2.

6 Discussion

Before I started with this project I had been working as a summer trainee at the Power Generation unit in Vaasa. During that period of time I came into contact with the E^3 design tool and understood what it was used for.

In the beginning of the work I had to study a lot of protective relay manuals and also try to get used to working with E^3 as it is a very broad design tool. I also acquainted myself also with old AutoCAD drawings, trying to understand the way drawings had been made in this unit before.

A lot of the time in the beginning was spent on the drawing of sample schematics, which then were sent to be checked and approved. The first template took quite a while to be finish. However, as the general idea was first to generate one template and by modifying that generate the others, the rest of the templates became ready much faster.

The work with this project is over from my point of view and the templates made in this work are now used by the marketing team and the design engineers in the Power Generation unit. Although my work is done, there is most probably a need to develop more templates as these are just the most common ones used in ABB’s projects.

I would imagine that in the future there could be a couple of changes made to the templates if deemed necessary. One idea would be to extend the referencing system to the SLD, and not only to the protection matrix. Creating universal templates for protection relays might not be impossible, although it would require a lot of time setting up everything in E^3.

During this work carried out for ABB Power Generation I have learned a lot about protection relays, but also about the design tool E^3 and the way of drawing schematics in this unit of ABB. I have also gained a better understanding of the protection of electrical power systems and in particular an in-depth understanding of the generator protection.

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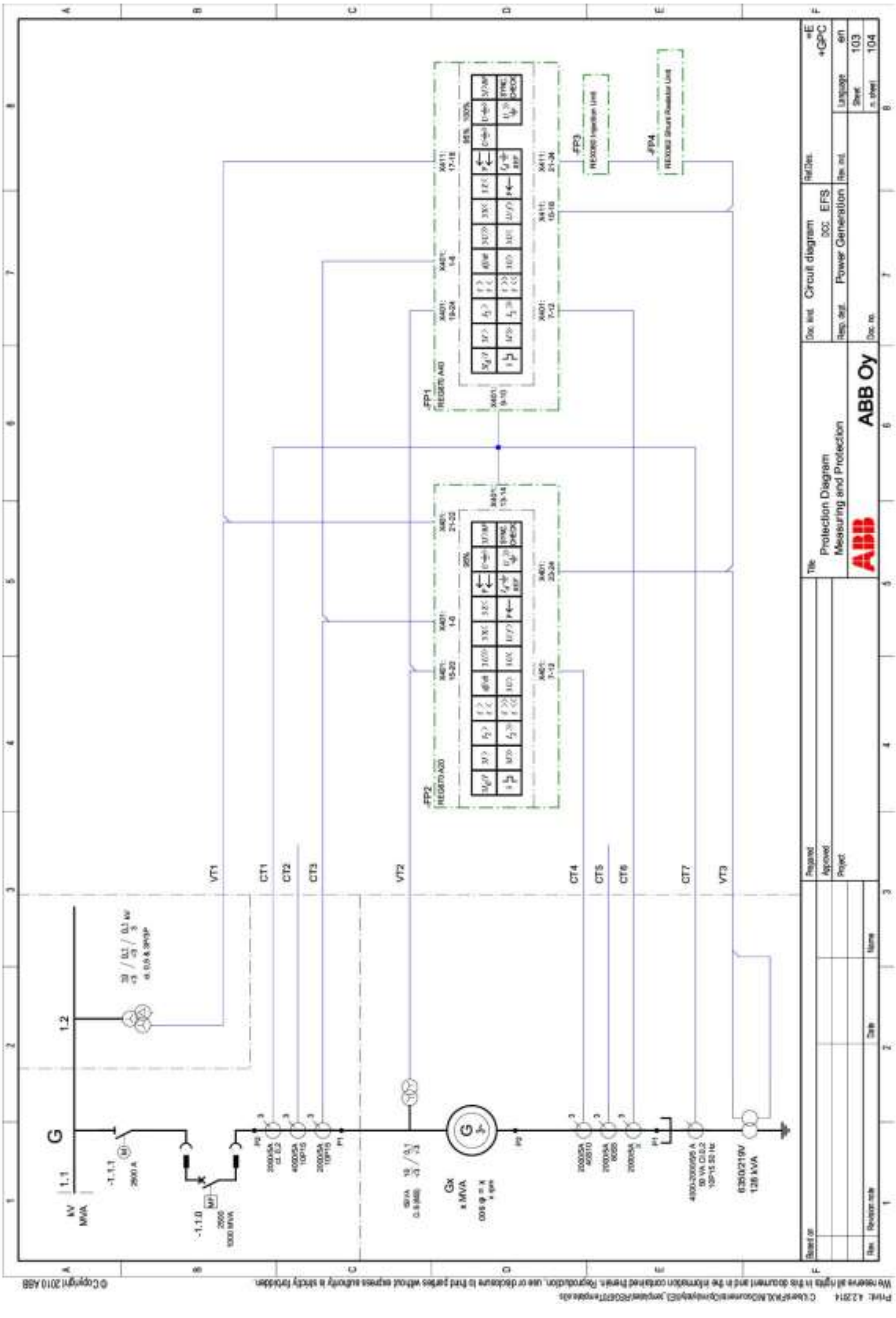
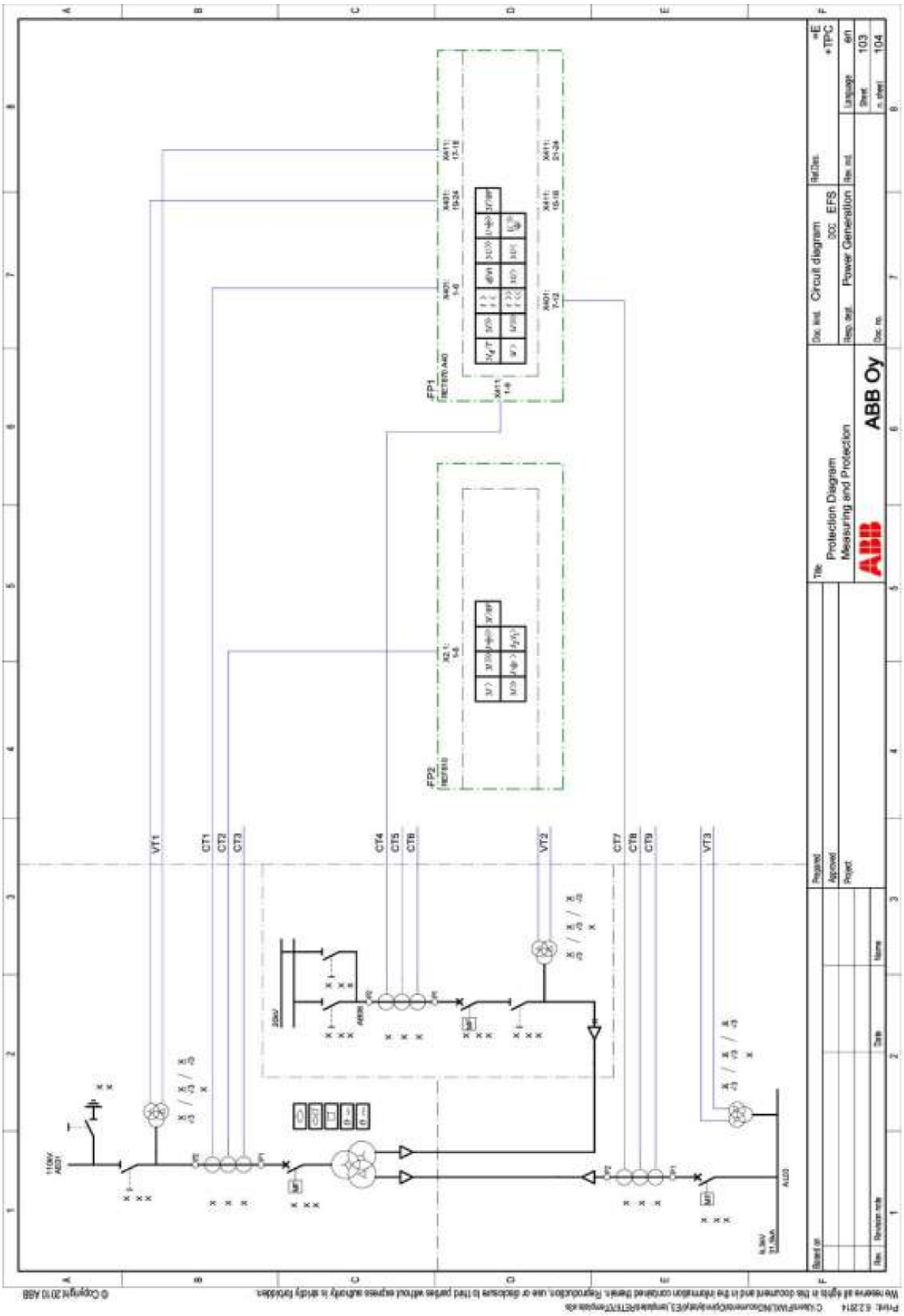
APPENDIX 1



Protection Diagram
Measuring and Protection
ABB Oy
Circuit diagram
Power Generation
VT1
CT1
CT2
CT3
VT2
CT4
CT5
CT6
CT7
VT3

APPENDIX 2



Protection Diagram
Measuring and Protection
ABB Oy
Circuit diagram
Power Generation

APPENDIX 3

FP1
REG 670 A40

	Analogue inputs	Protection functions	Identification	Trip	Breaker closing control	CT1	CT3	CT4	CT7	VT1	VT2	VT3	A	B	C	D	E	Alarm	Info	Note
VT1	X411: 17-18	Generator differential protection	GENDIF																	
CT1	X411: 9-10	3-Phase overload protection 90%	TRPTTR																	
CT3	X401: 1-6	Overload protection 100%	TRPTTR																	
VT2	X401: 19-24	Stator overcurrent protection	OC4PTOC																	
CT6	X401: 7-12	Stator overcurrent protection	OC4PTOC																	
CT7	X411: 9-10	Negative sequence overcurrent protection	NS4PTOC																	
VT3	X411: 15-16	Negative sequence overcurrent protection	NS4PTOC																	
VT3	X411: 21-24	Over frequency protection Under frequency protection	SAPTOF SAPTUF																	
		Over frequency protection Under frequency protection	SAPTOF SAPTUF																	
		Rate-of-change frequency protection	SAPFRC																	
		Overvoltage protection	UV2PTUV																	
		Overvoltage protection	UV2PTUV																	
		Undervoltage protection	OV2PTOV																	
		3-Phase Under reactance protection	ZDMRDIR																	
		Overexcitation protection	OEXPVPH																	
		Under impedance protection	ZMHPDIS																	
		Reverse power protection, low stage	GUPPDUP																	
		Reverse power protection, high stage	GUPPDUP																	
		Restricted earth fault protection	REFPDIF																	
		Stator 95% earth fault protection	ROTIPHIZ																	
		Stator 100% earth fault prot., low stage	STTIPHIZ																	
		Stator 100% earth fault prot., high stage	STTIPHIZ																	
		Circuit breaker failure protection	CCRBRF																	
		Synchrocheck	SESRSYN																	

Power supply

Current measurements: CT1, CT3, CT4, CT7 — Voltage measurements: VT1, VT2, VT3 — Blocking: A, B, C, D, E

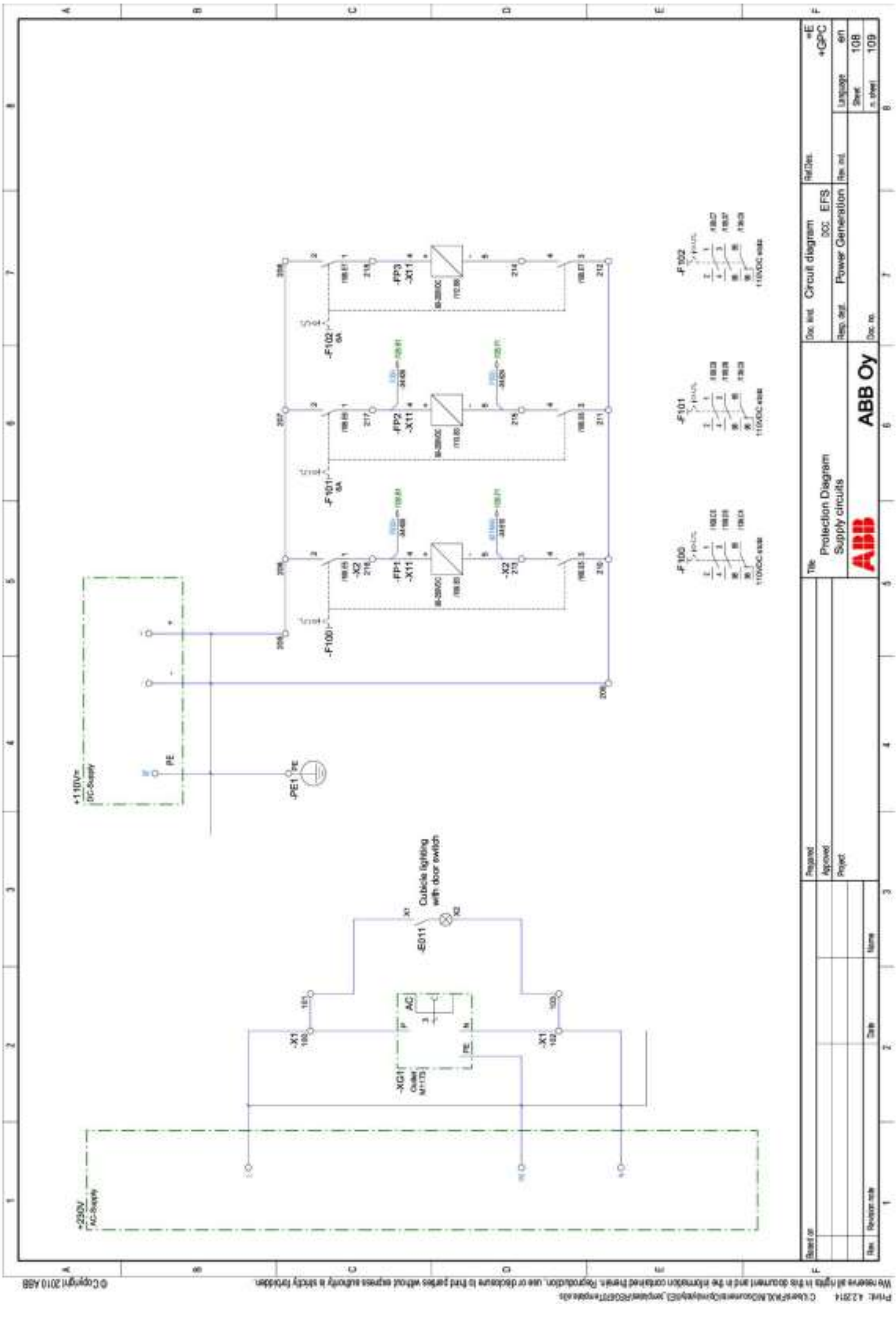
Note: A= B= C= D= E=

× = Output
○ = Input

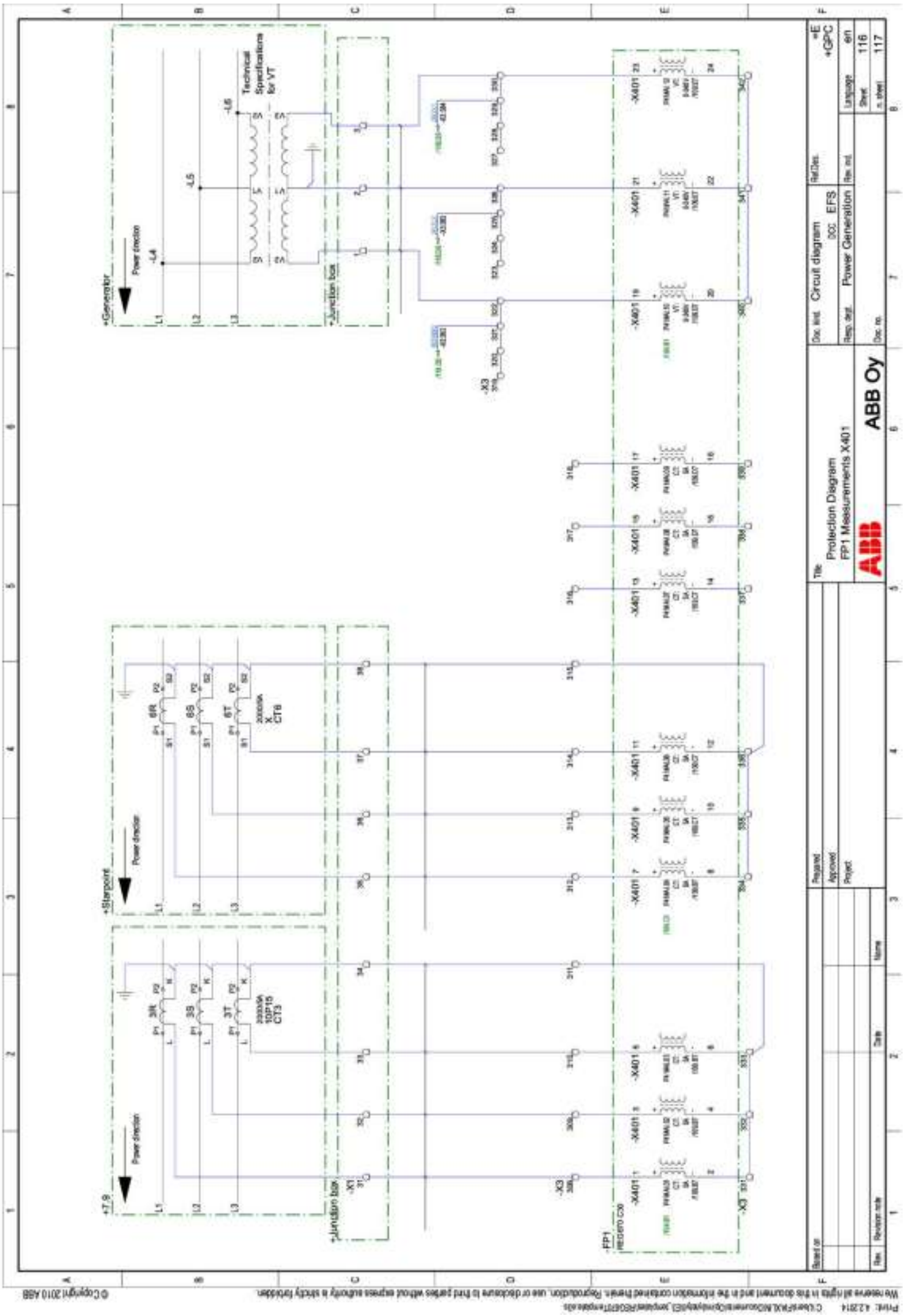
Title	Protection Diagram REG 670 C30 Protection Matrix
Doc. kind	Circuit diagram
DCC	EFS
Resp. dept.	Power Generation
	ABB Oy
Ref.Des.	=E +GPC
Language	en
Sheet	104
n. sheet	105

Based on / Prepared / Approved / Project / Rev. / Revision note / Date / Name / Doc. no. / Rev. ind.

APPENDIX 4

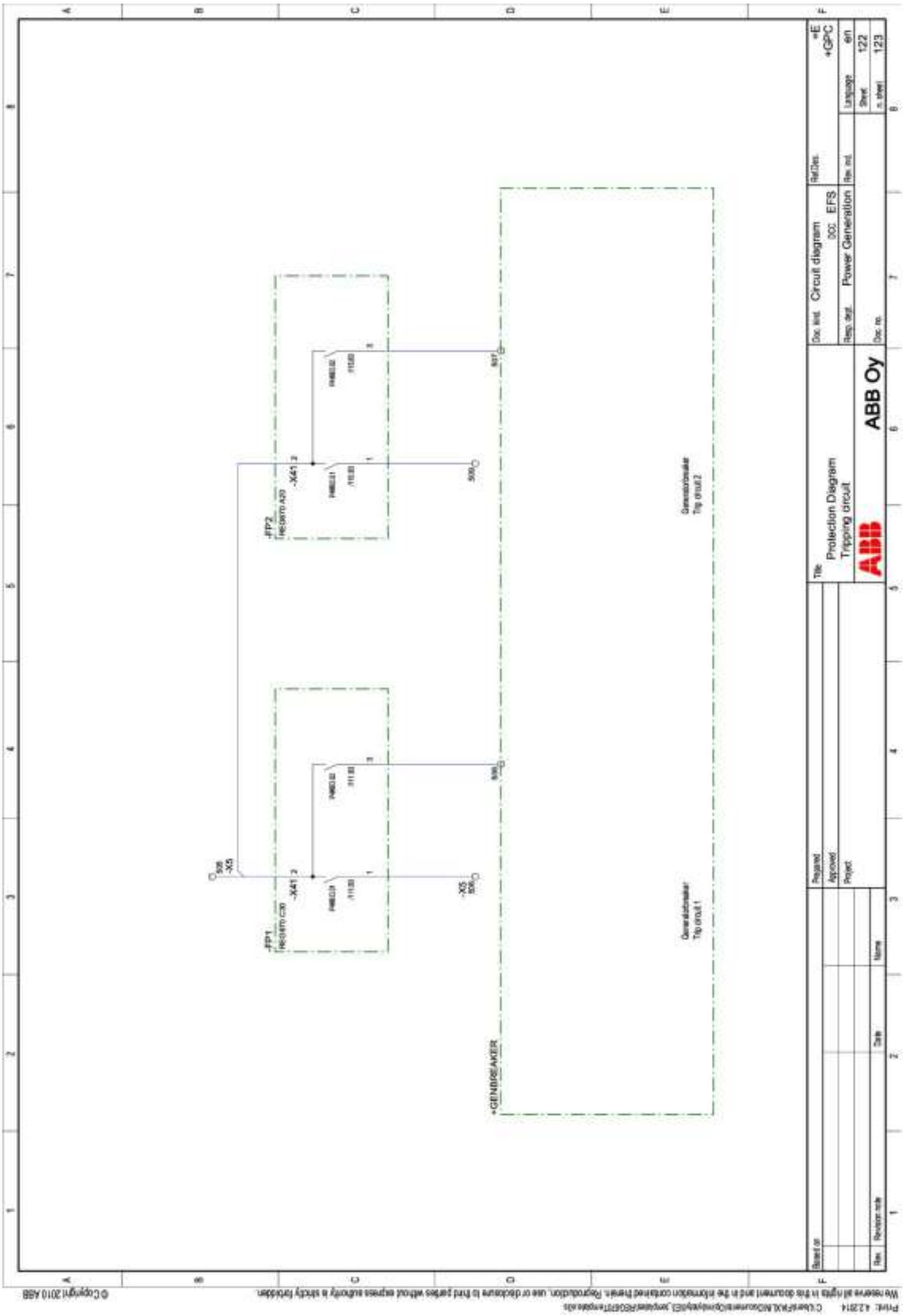

Protection Diagram
Supply circuits
ABB Oy
Circuit diagram
Power Generation
Cubicle lighting with door switch
+110V=
DC-Supply
+230V~
AC-Supply
© Copyright 2010 ABB

APPENDIX 5



Protection Diagram
FP1 Measurements X401
ABB Oy
Circuit diagram
Power Generation

APPENDIX 6



Circuit diagram
Protection Diagram
Tripping circuit
Power Generation
ABB Oy
EFS
+E
+GPC
en
122
123
-FP1
-FP2
-X41
+GENBREAKER
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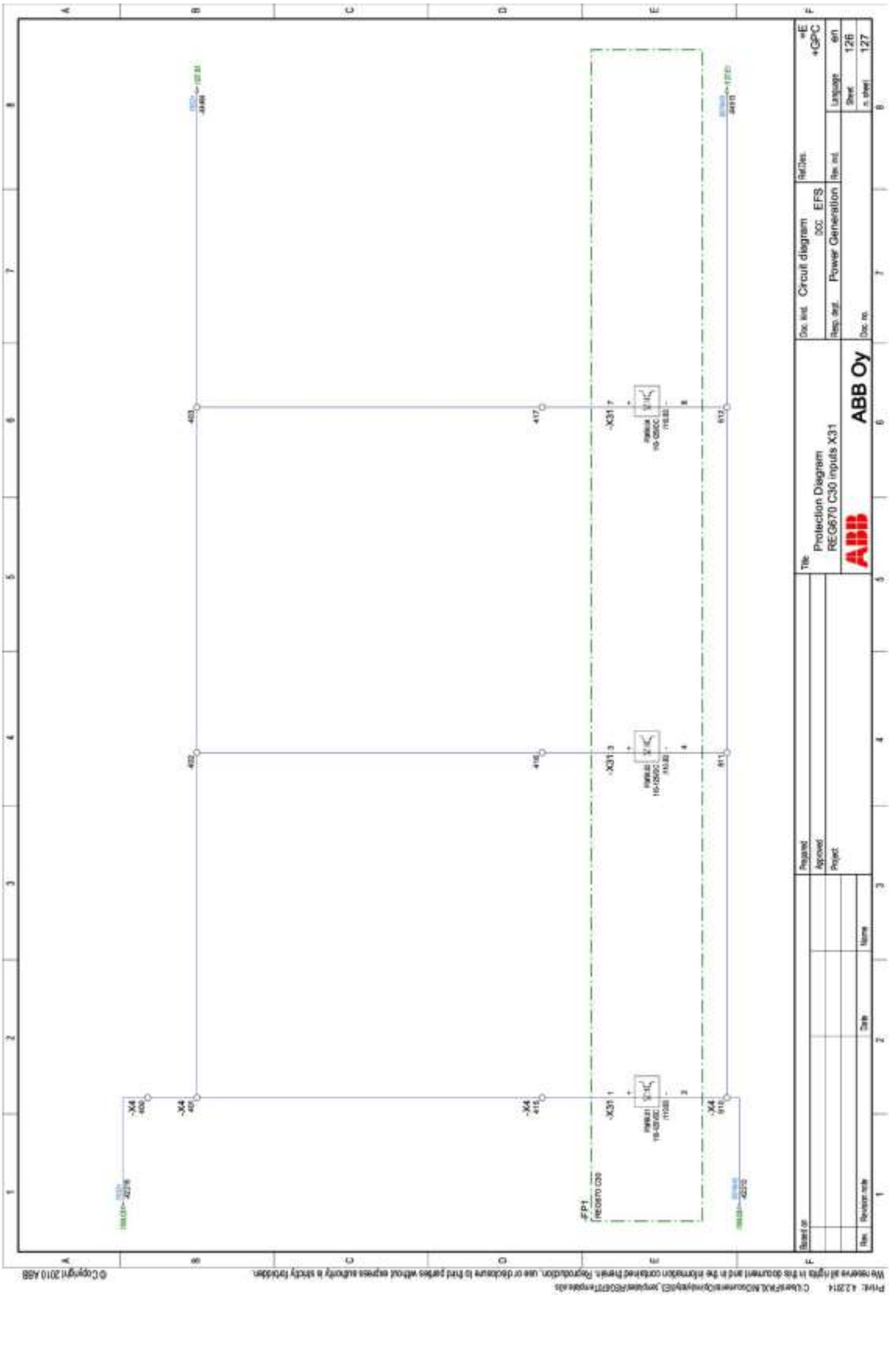
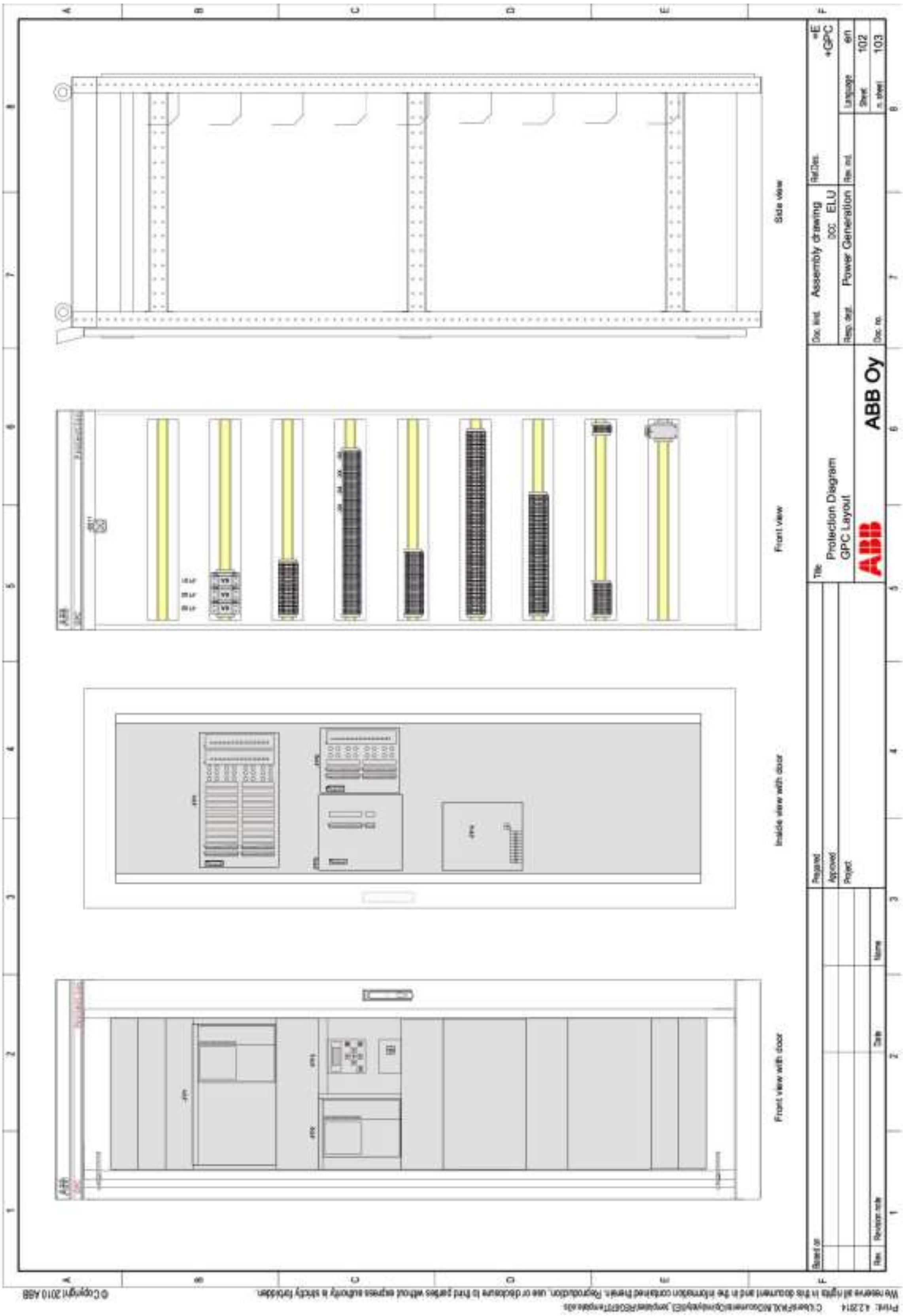
APPENDIX 7



Protection Diagram
REG670 C30 inputs X31
ABB Oy
Circuit diagram
EFS
Power Generation

APPENDIX 8



Side view
Front view
Inside view with door
Front view with door
Protection Diagram
GPC Layout
ABB Oy
Assembly drawing
ELU
Power Generation
+E
+GPC
en
102
103
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APPENDIX 9

=E
+GPC

Signal	Cable type	Core	Cable designations	Target External: Device designation	Pin	Terminal type	Terminal strip	Target Internal: Device designation	Pin	Core	Cable designations	Cable type	Placement in schematics
						UT 2.5-MT-P/P	200	=E +GPC -FP3	-X81:5				/120.B4
						UT 2.5-MT-P/P	201	=E +GPC -FP3	-X81:6				/120.B4
						UT 2.5-MT-P/P	202	=E +GPC -FP3	-X81:7				/120.D4
						UT 2.5-MT-P/P	203	=E +GPC -FP3	-X81:4				/120.D7
						UT 2.5-MT-P/P	204	=E +GPC -FP3	-X81:2				/120.D8
						UT 2.5-MT-P/P	205						/108.C5
						UT 2.5-MT-P/P	206	=E +GPC -F100	:2				/108.C5
F22+						UT 2.5-MT-P/P	207	=E +GPC -F101	:2				/108.C8
F22+						UT 2.5-MT-P/P	208	=E +GPC -F102	:2				/108.C7
						UT 2.5-MT-P/P	209						/108.E4
						UT 2.5-MT-P/P	210	=E +GPC -F100	:3				/108.E5
						UT 2.5-MT-P/P	211	=E +GPC -F101	:3				/108.E6
						UT 2.5-MT-P/P	212	=E +GPC -F102	:3				/108.E7
						UT 2.5-MT-P/P	213	=E +GPC -X4 =E +GPC -FP1	:510 -X11:5				/108.D5
F25-				=E +GPC -F102	:4	UT 2.5-MT-P/P	214	=E +GPC -FP3	-X11:5				/108.D7
F033				=E +GPC -F101	:4	UT 2.5-MT-P/P	215	=E +GPC -FP2 =E +GPC -X4	-X11:5 :526				/108.D6
F832+						UT 2.5-MT-P/P	216	=E +GPC -FP1 =E +GPC -X4	-X11:4 :400				/108.C5
F25+						UT 2.5-MT-P/P	217	=E +GPC -X4 =E +GPC -FP2	:429 -X11:4				/108.C8
F25-				=E +GPC -F102	:1	UT 2.5-MT-P/P	218	=E +GPC -FP3	-X11:4				/108.C7

Based on			Prepared	Title	Doc. kind		RefDes.	=E +GPC
			Approved	Terminal table -X2		DCC EMA		
			Project		Resp. dept.	Power Generation	Rev. ind.	Language en
Rev.	Revision note	Date	Name	ABB — ABB Oy	Doc. no.			Sheet 138
								n. sheet 139

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