Factory Acceptance Test (FAT) of protection relays

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BACHELOR'S THESIS

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Summary

This Bachelor's thesis was commissioned by ABB Power Generation in Vaasa, which designs and distributes automation controllers and electrical systems for gas, diesel, nuclear and water power plants.

The purpose of this thesis is to develop a standard Factory Acceptance Test procedure for protection systems in modular deliveries with Omicron, a software program with which it is possible to test generator protection relays. The standard test procedure is meant to operate automatically for as long as possible with as few parameter changes as possible although the projects differ. In addition to the standard test procedure, a manual with instructions is also to be made.

The procedure will be tested on Schneider Electric's protection relays VAMP 210, VAMP 265 and ABB's REG 670 since these relays are the most common ones in the automation controllers and the electrical systems. The idea with the procedure is to implement the most essential values related to the generator, current- and voltage scaling which then are tested with the relay. The result of the tests is a report which indicates if the relay is working properly.

The thesis will briefly describe the synchronous generator, the used test functions and the calculations. The thesis will also describe the test equipment such as Omicron, VAMP and ABB REG670. The used software programs will also be briefly described.

Language: English Key words: FAT, VAMP, REG, Omicron, generator protection

EXAMENSARBETE

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Abstrakt

Detta lärdomsprov gjordes åt ABB Power Generation som planerar och designar automationscentraler till diesel-, gas-, kärn- och vattenkraftverk.

Syftet med detta lärdomsprov är att undersöka och att implementera en standardtestprocedur i programmet Omicron, med vilken man ska kunna testa skyddsreläers skyddsfunktioner för, i detta fall, generatorer. Standardtestproceduren ska fungera automatiskt i så stor utsträckning som möjligt med så lite parameterändringar som möjligt även om ett annat projekt testas. Förutom standardproceduren ska också en manual framställas så att användaren kan läsa in sig på hur testprogrammet fungerar och ska användas.

Testandet kommer att utföras på Schneider Electrics skyddsreläer VAMP 210 och VAMP 265 samt ABB:s REG 670, eftersom dessa reläer är de mest förekommande i samband med produktionen av centralerna. Idén med detta testprogram är att man skriver in de mest väsentliga värdena på generatorn, ström- och spänningsskalning och får färdigt kalkylerade testvärden som sedan testas med ett skyddsrelä. Slutresultatet för testerna är en rapport som visar om reläet fungerar.

Lärdomsprovet kommer att kort allmänt gå in på synkrongeneratorn, testfunktioner som kommer att användas och uträkningar. Lärdomsprovet kommer också att ta upp fakta om rekvisitan som Omicron, VAMP och ABB REG670. Mjukvaruprogrammen som har använts kommer också att förklaras kort.

Språk: engelska Nyckelord: FAT, VAMP, REG, Omicron, skyddsrelä

OPINNÄYTETYÖ

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Tiivistelmä

Tämä opinnäyte työ on tehty ABB Power Generationille, joka suunnittelee automaatiokeskuksia diesel-, kaasu-, ydin-, ja vesivoimalaitoksiin.

Tehtävänä oli kehittää standardisoitu FAT- testausmenettelytapa Omicron ohjelmassa, jossa voidaan testaa suojareleitä. Menettelytavan on määrä toimia automaattisesti niin paljon kuin mahdollista, niin vähillä parametrimuutoksilla kuin mahdollista, vaikka kyseessä olisi minkälainen projekti tahansa. Menettelytavan lisäksi tulee tehdä käyttöohjekin.

Menettelytapa testataan Schneider-Electric:in VAMP 210-, VAMP 265- sekä ABB:n REG 670- releillä, koska nämä ovat yleisimmin käytettyjä projekteissa. Menetelmän idea on, että implementoidaan tärkeimmät arvot, koskien generaattoria, virta- ja jänniteskaalausta, joiden kanssa releet testataan. Lopputuloksena on raportti, josta saa selvää jos suojarele on käyttökelpoinen vai ei.

Opinnäytetyö tulee käsittelemään lyhyesti synkronointigeneraattoria, käytettyjä suojatoimintoja ja laskelmia. Käytetyt laitteet, kuten Omicron, VAMP ja ABB REG670 ja niiden käyttöohjelmat käsitellään myös tässä työssä.

Kieli: englanti Avainsanat: FAT, VAMP, REG, Omicron, suojarele

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Abbreviations

ABB	ASEA Brown Boveri
AVR	Automatic Voltage Regulator
CMC	Omicron CMC hardware
CT	Current Transformer
DC	Direct Current
DT	Definite Time
FAT	Factory Acceptance Test
IDMT	Inverse Definite Mean Time
PT	Potential Transformer, another expression for Voltage Transformer
VT	Voltage Transformer

1 Introduction

The subject of this Bachelor’s thesis is the development of a standard Factory Acceptance Test procedure to speed up the current approach of testing protection systems in automation control solutions for generators in diesel and gas power plants. This thesis will also describe protective relays for generators, their protective functions, how to set up the test equipment and how to calculate the test values that are used to test the actual operation of a protective relay. Furthermore it will also deal with Factory Acceptance Testing as a subject and why it is an important part of the production.

1.1 Commissioner

ABB, Asea Brown Boveri, is the result of a merger between a Swedish company, named ASEA (Allmänna Svenska Elektriska Aktiebolaget), and a Swiss company named Brown Boveri. Both ASEA and Brown Boveri were established at the end of the 19th century. In 1988 ASEA and Brown Boveri merged and became ABB, which is today a global leader in power and automation technologies. ABB has got over 150 000 employees and is operating in about 100 countries worldwide. About 5 000 of the employees are working in Finland at about 30 different locations. ABB’s turnover in Finland is about 2.3 billion euro. About 184 000 euro is used yearly for research and development.

ABB Power Generation, the commissioner of this thesis, is a department which is part of the division Power Systems. The department Power Generation and Power Systems as well, are located in Strömberg Park, Vaasa. The Power Generation department designs and delivers electrical, automation, instrument and supervision control systems for power plants such as nuclear, diesel, gas and water power plants.

1.2 Purpose

The commissioner needed a standard FAT procedure for their modular deliveries, where the user is able to test protection systems for generators automatically, for as long as possible, to free the user from the task of setting up and testing each function one by one manually. This would give some kind of routine to follow, in order to eliminate the risk of forgetting to test a certain protective function. The procedure will be made with the software program Omicron, including hardware from the same manufacturer. The FAT procedure should work for the testing of protective relays such as VAMP 210, VAMP 265, ABB REG 650 and ABB REG 670, which are the most common relays to be used in the automation systems.

Part of the thesis is also to create a user manual which will guide the user in how to set up the test and in how to test the protective relays' protective functions in a reliable and safe approach.

The newly developed procedure should result in optimization of time and in obtaining a test result, a test document, which can guarantee the customer that their system is equipped with a safe and working protection system.

2 Generator and generator protection

Producing power with a generator has got its risks. Sometimes faults might appear, both in the distribution network and near the generator. In such cases protective relays come in handy. Nor do they only work as measuring devices; they also protect the generator itself. But knowing that a protective relay for generators protects generators does not clarify to the reader of any specific functions at all. For this thesis different protective relays were used for the same purpose but still the differences are notable. That is why this chapter is going to give the reader an overview of what a protection relay actually is and how its functions work and are used in real life cases. To give a wider perspective, the beginning of this chapter will explain how a generator works. Only synchronous generator types will be described because their most usual area of use is as power plant generators.

2.1 Synchronous generators and their attributes

Synchronous generators are electrical machines, but instead of consuming power from the network an auxiliary power source, such as turbines or engines, is rotating the generator’s rotor and when synchronous speed is achieved it is possible to connect the generator to the network and produce power (Alfredsson 2012, p.90).

The synchronous generator is built up of two different parts: a non-moving part called stator and a rotating part called rotor, which has got a certain number of poles (usually two or four), which are rotating inside the stator. Both the stator and the rotor have got windings. The stator windings are placed in slots which are carved in the stator. The rotor windings are wrapped around the rotor and work as magnetic windings. A DC source, e.g. a DC generator, feeds direct current to the synchronous generator’s rotor windings which are magnetized, and when the rotor in the synchronous generator is made to spin, a sinus wave voltage is induced in the stator windings, from where the electric grid is fed (Alfredsson, 2012, p. 80, p. 130).

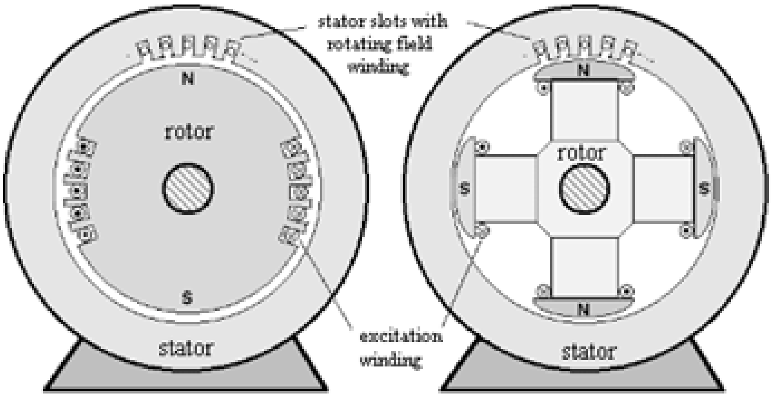


Figure 1. Sectional picture of two synchronous generators with different kinds of rotors(Wind Energy 5, Electrical Engineering basics, 1998).

If the rotor axis is brought mechanical power, the mechanical power starts accelerating the rotor. There will be a small lagging between the rotor and the magnetic flux in the stator, which makes the current in the stator winding increase and power is emitted to the network (Alfredsson, 2012, p. 90).

The most important connections when generating power are:

Active power $P = \sqrt{3} \times U \times I \times cos\varphi$ (equation 1)

Reactive power $Q = \sqrt{3} \times U \times I \times sin\varphi$ (equation 2)

Apparent power $S = \sqrt{3} \times U \times I$ (equation 3)

There are also trigonometrical connections:

$$cos\varphi = \frac{P}{S} \quad \text{(equation 4)}$$

$$sin\varphi = \frac{Q}{S} \quad \text{(equation 5)}$$

The symbol φ (phi) represents the angle between the rotor and the lagging magnetic flux in the stator (Viitala, 2012, p.1003).

2.2 What is a protective relay?

A protective relay is practically a microprocessor implemented to monitor a certain part of a power system e.g. generators, transformers, power lines etc. in order to detect if any kind of abnormal conditions occur in the power system. In case of an error, the relay should send a trip impulse which should, directly or indirectly, break the power distribution to the protected object to avoid damages. It is essential that corrections of this kind take place quickly since response times of a few milliseconds are usually required. The response should cause as little disruption as possible to the power system (Öhlén, 2012, p. 349; Horowitz & Phadke, 1996, p. 1; Blackburn, 1994, p. 1).

When a fault occurs in the power system, current and voltage will change in a way that is characteristic of the fault. Because of this, power and impedance will change as well compared from their normal values. Even the frequency might change under abnormal conditions. The relay’s task is to measure one or several of these magnitudes and determine if the condition is abnormal. The reference with which the relay compares the condition is the user’s implemented settings (Öhlén, 2012, pp. 350-351).

2.3 Generator protective relay

A generator produces active power to a power distribution network. The amount of power the generator can produce is restricted by its ratings. Still the generator does not always stay within its restrictions. This is where the generator protective relay should act to prevent any damage to the generator (Öhlén, 2012, pp. 377-378).

A generator protective relay is not connected directly to a generator. The relay is connected to voltage transformers (VT or PT) and current transformers (CT), which transform the power system’s currents and voltages to lower magnitudes. They also serve as galvanic isolation between the power system and relays. The transformers’ secondary windings are standardized to simplify usage of relays made by different manufacturers. An example of a VT rating would be 11000/120 volts phase-to-phase, and for a CT 800/1 ampere or /5 ampere which is more common in the United States. The primary values can be calculated to secondary values, and vice versa, with these equations:

$$I_{secondary} \times \frac{800}{1} = I_{primary} \qquad \text{(equation 6)}$$

$$U_{secondary} \times \frac{11000}{120} = U_{primary} \qquad \text{(equation 7)}$$

(Horowitz & Phadke, 1996, pp. 51-59, p. 66; Viitala, 2012, p. 1008)

It is important to notice that the voltage and currents might be in a much greater magnitude than the nominal under abnormal conditions and therefore the VTs and CTs should be designed to tolerate a much higher voltage and currents than the nominal values (Horowitz & Phadke, 1996, p. 51).

3 Protective functions

This chapter briefly describes protective functions, how they work, including important equations, and what kind of errors trigger the relay. Only the protective functions used in a certain standard, developed by ABB, will be described since the test program itself is based on these functions. The functions are categorized in two categories to separate the more commonly implemented protective functions from the less commonly implemented functions. The protections are described according to how they work in VAMP 210, VAMP 265 and ABB REG 670.

3.1 Standard protective functions

Settings for the relay are taken from a standard. The standard includes functions which are more often used in gas and diesel power plants and the values are also standard values, i.e. it does not matter what the nominal ratings for the generator are since the settings are expressed in percent and per unit.

Some of the functions are implemented more commonly in the protective relay. These functions are called "Standard functions", since they are implemented as standard functions in the relay and are separated from a few other protective functions that are not implemented as standard in the relay. This category will be described further in chapter 3.2.

3.1.1 Over-current, *I*>

The over-current protection protects the generator against short-circuit failures and heavy overloads. The function works by measuring the fundamental frequency component for each of the phases. The function starts operating whenever one of the phases' current exceeds the user's pick-up setting for a particular stage, and a start signal is issued. When the fault lasts longer than the operation delay, the relay sends a trip signal. There are usually three stages, expressed *I*>, *I*>> and *I*>>>, and they are separately adjustable. The lowest stage can be configured for the inverse time operation characteristic (IDMT), which means that the relay operates faster, the higher the input current is (VAMP Ltd., 2011a, p. 53).

The over-current setting is set as a percentage of the nominal current and an operation time is set when using a definite time operation. The inverse time function uses a time constant, instead of a time setting.

The inverse characteristic equation applies as follows:

$$t = \frac{k \times A}{\left(\frac{I}{I_{pick-up}}\right)^{B} - 1} \qquad \text{(equation 8)}$$

where: $t = trip\ time$

$k = time\ constant$

$A = 0.14\ (standard\ value\ for\ normal\ inverse\ characteristics)$

$I = current$

$I_{pick\text{-}up} = pick\text{-}up\ setting\ (e.g.\ 1.12\ x\ I_{Nominal})$

$B = 0.02\ (standard\ value\ for\ normal\ inverse\ characteristics)$

(VAMP Ltd., 2011a, p. 147)

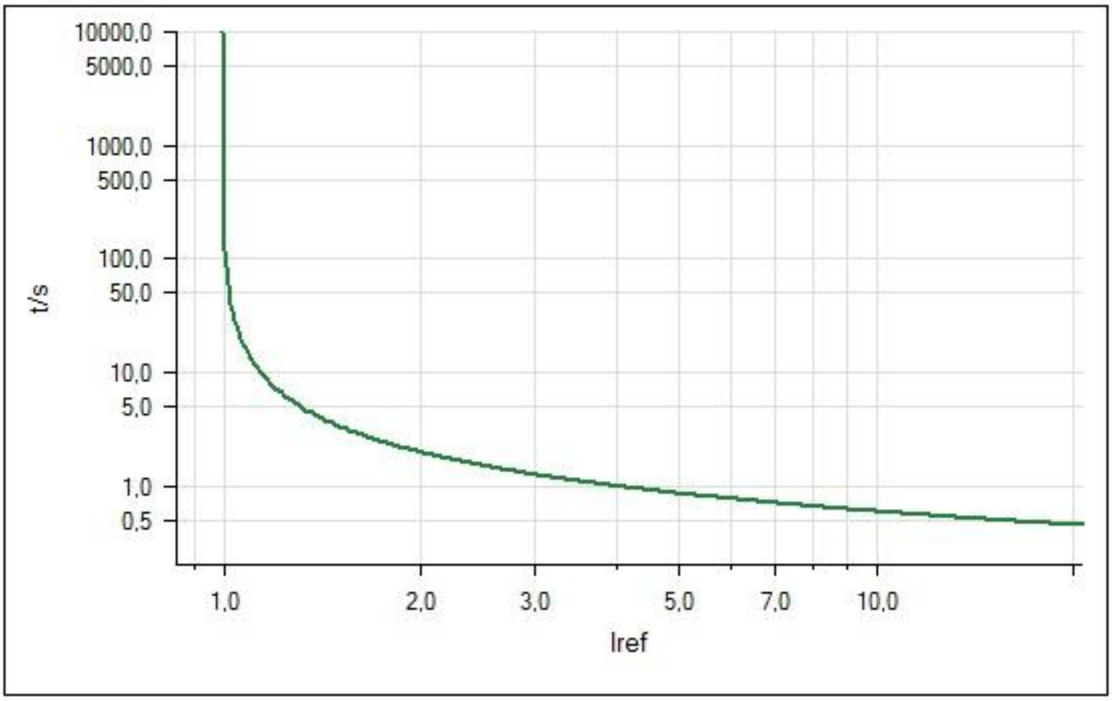


Figure 2. Inverse time operation graph (Omicron Test Universe)

The other setting for *I*> and the only available setting for the two other stages is called definite time operation (DT). This means that the relay operates at the same set operation delay no matter how far over the set operation limit the current magnitude reaches (Sleva, 2009, pp. 82-83).

The characteristic looks like the following figure:

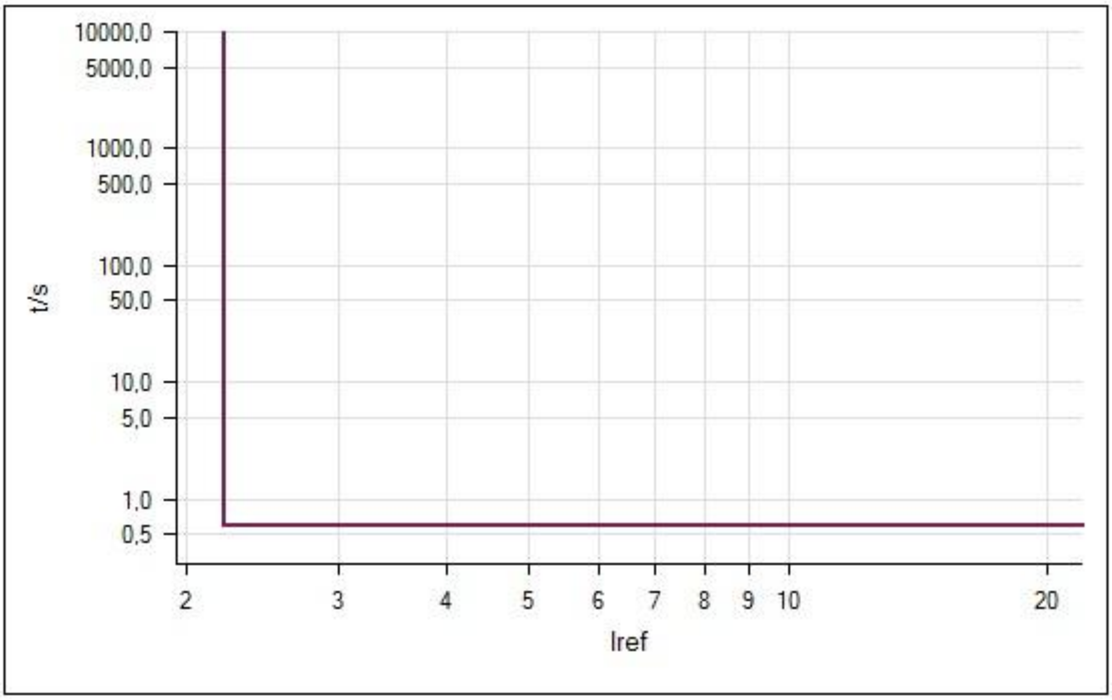


Figure 3. Definite time characteristics (Omicron Test Universe)

3.1.2 Over-voltage, *U*>

Over-voltage might occur if the Automatic Voltage Regulator, AVR, malfunctions or if there is a sudden load shedding. The latter is caused by over-speed in the turbine. The over-voltage protection measures the fundamental frequency line-to-line and detects, due to this, any over-voltage between phases. Line-to-neutral is an earth fault and is avoided by earth-fault protections. The over-voltage is implemented in three stages, $U>_{\mathrm{alarm}}$, *U*> and *U*>>. The first stage, $U>_{\mathrm{alarm}}$, issues an alarm start signal when the stage picks up and starts alarming when the operation delay is exceeded. The two other stages issue the normal start signal at pick-up conditions and the trip signal when operation time is greater than the delay setting. Over-voltage setting is usually set in percent of the nominal voltage, e.g. 110% gives an operation when the voltage is 1.10 times the nominal voltage (Ungrad, Winkler, Wiszniewski, 1995, p. 32, p. 223; VAMP Ltd., 2011a, pp. 91-92).

3.1.3 Under-voltage, *U*<

A generator can end up in a state where the voltage is lower than the nominal voltage, also known as under-voltage. Under-voltage situations in a generator are mostly a result of a fault in the power system. It might be a phase-to-phase fault or phase-to-ground as well. In situations like this one, the relay has to pick up and trip when the conditions are not anymore within the set limits (Ungrad et al., 1995, p. 32).

In the practical part of this thesis a special kind of under-voltage protection is used. It is special because the measuring of the voltage is done at the generator's side of the circuit breaker. It also has a special feature, self blocking, which means that the function blocks itself during startup and shutdown of a generator when the voltage naturally exceeds the limits. The under-voltage setting is set exactly as in over-voltage except that the percentage is below 100% of the nominal voltage (VAMP Ltd., 2011a, pp. 97-99).

3.1.4 Reverse power, *P*<

Reverse power is mainly used to prevent motoring of the generator if the operational power, from the turbine, is lower than the power in the feeding power lines or bus-bars , which means that the generator does not produce power but consumes it. Without this protection the driving turbine might take a lot of damage, depending on turbine type (Öhlén, 2012, p. 382).

The reverse power protection measures the active power produced or consumed by the generator. When the generator starts consuming active power, the active power is negative. Usually the protection is set to a low level, between 1-4 % of the nominal active power. The flowing current in an abnormal situation, as in reverse power, can be so low that the accuracy of the angle measuring is of a great significance. When the active power drops below the set limit, the protection issues a start signal and, after the set operation delay, a trip signal (VAMP Ltd., 2011a, p. 129; Öhlén, 2012, p. 382).

Figure 4 is a power diagram of reverse power where the radius is the nominal active power. The right side of the power circle figure stands for forward power and the left side stands for reverse power. If the power phasor somehow ends up in the red, striped area, which happens if the generator starts consuming power, the criteria for reverse power are fulfilled and the relay will start and trip.

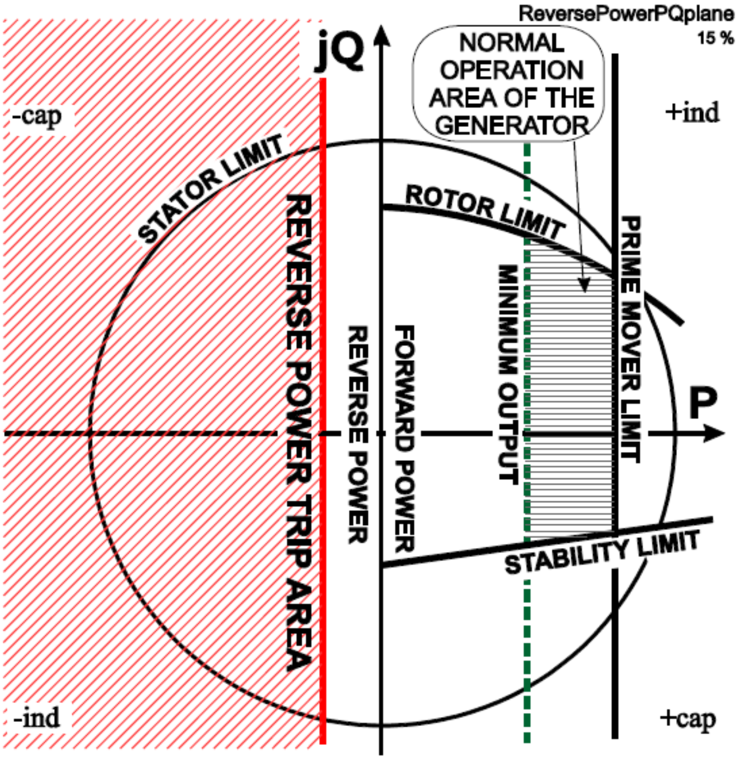


Figure 4. Reverse power in PQ plane (VAMP Ltd. 2011a, p. 130).

3.1.5 Under-excitation, *Q*<

A synchronous generator needs a certain level of excitation to remain stable and synchronized. However, in some cases the generator starts to produce capacitive power and therefore works as an induction generator. That means that the phase vector for the reactive component is negative. The generator will in this case eventually lose synchronism and go out of step with the rest of the power system. To avoid incidents like this, an under-excitation protection is recommended (Horowitz & Phadke, 1996, p. 188; VAMP Ltd., 2011a, p. 121).

Figure 5 represents the under-excitation situation where the radius is the nominal reactive power. It is considered to be an abnormal condition if the power phasor enters the shaded area since the excitation is lost if a too high level of reactive power is in the reverse direction. The relay detects under-excitation conditions by measuring the amount of capacitive power. When the amount of capacitive power exceeds the settings, the stage picks up. In such cases a start signal is issued and after the set operation delay time is exceeded, a trip signal is issued (VAMP Ltd., 2011a, pp. 121-122).

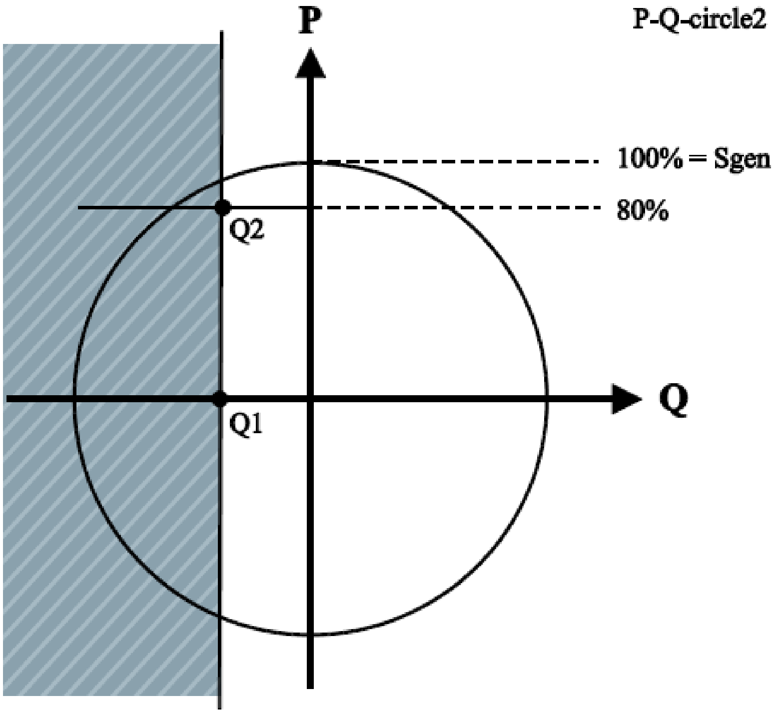


Figure 5. P-Q circle diagram, where the shading is the under-excitation area (VAMP Ltd. 2011a, p. 122).

The under-excitation function is set by multiplying the nominal reactive power with a certain negative percentage, since negative reactive power means that there is no magnetization (VAMP Ltd., 2011a, pp. 121-122).

3.1.6 Current unbalance, I_2

Current unbalance is an unsymmetrical fault and can produce more severe heating in the machine than normal, symmetrical faults. The reason for more severe heating is because an unsymmetrical fault causes double frequency currents in the rotor, whose surface warms up so much that the rotor might even start to melt, damaging the rotor’s structure (Horowitz & Phadke, 1996, p.181)

There are several reasons for unsymmetrical loads that cause unbalance in the current flow. Some of the reasons are:

- feeding only one phase due to open leads or bus bars

- unbalanced faults or failures of relays or breakers
- single-phase tripping without rapid reclosing
- unbalanced step-up transformers.

A relay with a negative sequence function alerts the operator to an unbalance in current flows and issues a start and trip signal, separating the generator from the power grid to avoid any unnecessary damage to the generator (Horowitz & Phadke, 1996, pp.181-182)

The trip time can be calculated from the following equation:

$$t = \frac{K_1}{\left(\frac{I_2}{I_{gn}}\right)^2 - K_2^2} \qquad \text{(equation 9)}$$

where: $t = trip\ time$

$K_1 = delay\ multiplier\ constant$

$K_2 = pick\text{-}up\ setting$

$I_2 = measured\ negative\ sequence\ phase\ current$

$I_{gn} = nominal\ generator\ current$

(VAMP Ltd., 2011a, p. 67)

3.1.7 Thermal overload, *T*>

Light and medium overloads are not detected by the over-current protection unless the set pick-up value is really low. As a result, the relay will trip for the smallest light or medium overload, i.e. the protection is overprotecting. A thermal overload protection measures the true RMS current value for each phase which is derived and sent to the thermal overload protection (Asea Brown Boveri, 2013c, p. 319; Horowitz & Phadke, 1996, p. 183).

From the largest of the three phase currents, a final temperature is calculated as follows:

$$\theta_{final} = \left(\frac{largest\ phase\ current}{reference\ current}\right)^2 \qquad \text{(equation 10)}$$

The trip time can be calculated from an equation and the characteristic follows the same equation:

Trip time:

$$t = \tau \times ln \times \frac{I^2 - I_p^2}{I^2 - a^2} \qquad \text{(equation 11)}$$

Alarm:

$$a = k \times k_\theta \times I_{gn} \times \sqrt{alarm} \qquad \text{(equation 12)}$$

Trip:

$$a = k \times k_\theta \times I_{gn} \qquad \text{(equation 13)}$$

Pre-load current:

$$I_p = \sqrt{\theta} \times k_\theta \times I_{gn} \qquad \text{(equation 14)}$$

where:

τ = thermal time constant tau

I = measured current

I_p= pre-load current

a = alarm or trip value (only trip for REG 670)

k = overload factor

k_θ = ambient temperature factor

I_{gn} = rated current

alarm =alarm set e.g. 60 % = 0.6

θ = temperature rise factor, a.k.a. thermal factor at start

(VAMP Ltd., 2011a, p. 70)

3.1.8 Over- and under-frequency, *f*> and *f*<

When generating power it is important that the frequency stays at a nominal level. Changes in frequencies are caused by sudden load drops or shunt faults in the power grid. Also generator governor problems can cause over-frequency if the problem is near the generating plant. A decrease in the load makes the generator over-speed, which makes the frequency rise. An increasing load slows down the generator and makes the frequency drop. The frequency remains at the nominal level by regulating the input power, e.g. when the load is increasing, the input power should be increased and, when the load is decreasing, the input power should also be decreased. These abnormal situations occur if the generator is connected to a dynamically unstable system (Horowitz & Phadke, 1996, pp. 185-186; Ungrad et al., 1995, pp. 224-225).

Over- and under-frequency protection issues a start signal immediately when the frequency is higher or lower than the nominal value and, when the operation time is exceeded, a trip signal is issued. Abnormal frequency levels mostly damage the turbine, but over-frequency also makes the generator overheat, which reduces the life time of the generator (Asea Brown Boveri, 2013c, p. 426, p. 431; Horowitz & Phadke, 1996, p.186)

3.1.9 Directional earth-fault, $I_{0\varphi}>$

When over-current occurs, the fault currents can flow in both directions through the short circuit. At the point where the fault occurs, the voltage vectors will meet in such a way that there will be zero voltage across the fault but, at the neutral point at the generator, the zero-sequence voltage will be the vector sum of all the phases. To be more specific, this protection is sensitive to the fundamental frequency component of the residual current, the zero-sequence voltage and the phase angle between them. When these three criteria meet, the relay picks up (GEC Alsthom T&D Protection & Control Limited, 1987, p. 145).

The negative sequence voltage, $-U_0$, can either be calculated from the phase voltages or measured from the energizing input U_0, depending on which kind of measurement mode is chosen (VAMP Ltd., 2011a, p. 79)

The characteristic for this protection follows the normal inverse equation and definite time (VAMP Ltd., 2011a, p. 84; Asea Brown Boveri, 2013c, p. 288).

3.1.10 Earth-fault, I_0>

Earth-fault protection is a non-directional protection compared to the last described protection. It is sensitive to the residual current $3I_0$, which can be measured from the residual current inputs in the relay, I_{01} or I_{02}, or calculated from the vector sum of phase I_{L1}, I_{L2} and I_{L3}. This protection is mainly used in low impedance networks and only as back-up protection in high impedance, isolated or compensated networks. Normal inverse and definite time can be applied to this protection (VAMP Ltd. 2011a, pp. 74-75).

3.1.11 Zero-sequence voltage, U_0>

Zero-sequence voltage protection is used as back-up protection for earth faults and especially if the generator has a unit transformer between the generator and the bus bar. The zero-sequence voltage can be measured in three different ways:

- with three voltage transformers, e.g. broken delta connection
- via a voltage transformer between the generator's neutral point and earth
- calculated from measured phase-to-earth voltage.

This protection follows the definite time characteristics (VAMP Ltd., 2011a, pp. 103-104).

3.1.12 Differential current, DI>

According to the laws of Kirchhoff, a feeding circuit's currents' vector sum is equal to zero. The differential current protection works according to this principle. There is a CT at each phase and at each side of the generator, one on the bus-bar side and one on the neutral point side. If any of the phase currents flowing through the generator are not equal in both CTs, the protection will trip immediately (GEC Alsthom T&D Protection & Control Limited, 1987, p. 283; VAMP Ltd., 2011b, p.51).

There are several ways in which the connection group is configured but, when the generator is the only protected area, the connection group is always set as Yy0, which means that the measured currents are also winding currents.

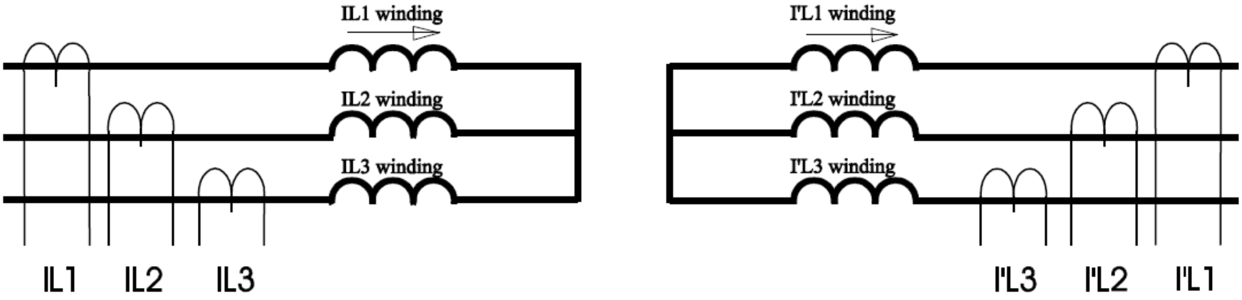


Figure 6.The Yy0 connection in a generator and how the CTs are connected to the phases (VAMP Ltd., 2011b, p. 51).

In this case the differential protection relay measures the difference between the IL and $I'L$ windings, which should be near zero in normal cases and, if the difference exceeds set limits, the relay will trip (VAMP Ltd., 2011b, p. 51).

The following equation shows how to calculate the differential current with the Yy0 connection:

$$I_d = \left|\bar{I}_w + \bar{I'}_w\right| \qquad \text{(equation 15)}$$

where: I_d = *differential current*
$\bar{I}_w$ = *primary winding current*
$\bar{I}'_w$ = *secondary winding current*

There is also a bias current calculation system which calculates the average current flow in the transformers. The bias can be calculated with the following equation:

$$I_b = \frac{|\bar{I}_w| + |\bar{I'}_w|}{2} \qquad \text{(equation 16)}$$

where: I_b = *bias current*
$\bar{I}_w$ = *primary winding current*
$\bar{I}'_w$ = *secondary winding current*

Both slopes in figure 5 are calculated as follows:

$$slope = \frac{\Delta Ioperate}{\Delta Irestrain} \times 100\ \% \qquad \text{(equation 17)}$$

The protection has got, as showed, a differential current, which works as operating current, and a bias current, known as restrain current, which together form the characteristics in figure 7 (Asea Brown Boveri, 2013c, p.132; VAMP Ltd., 2011b, p. 52).

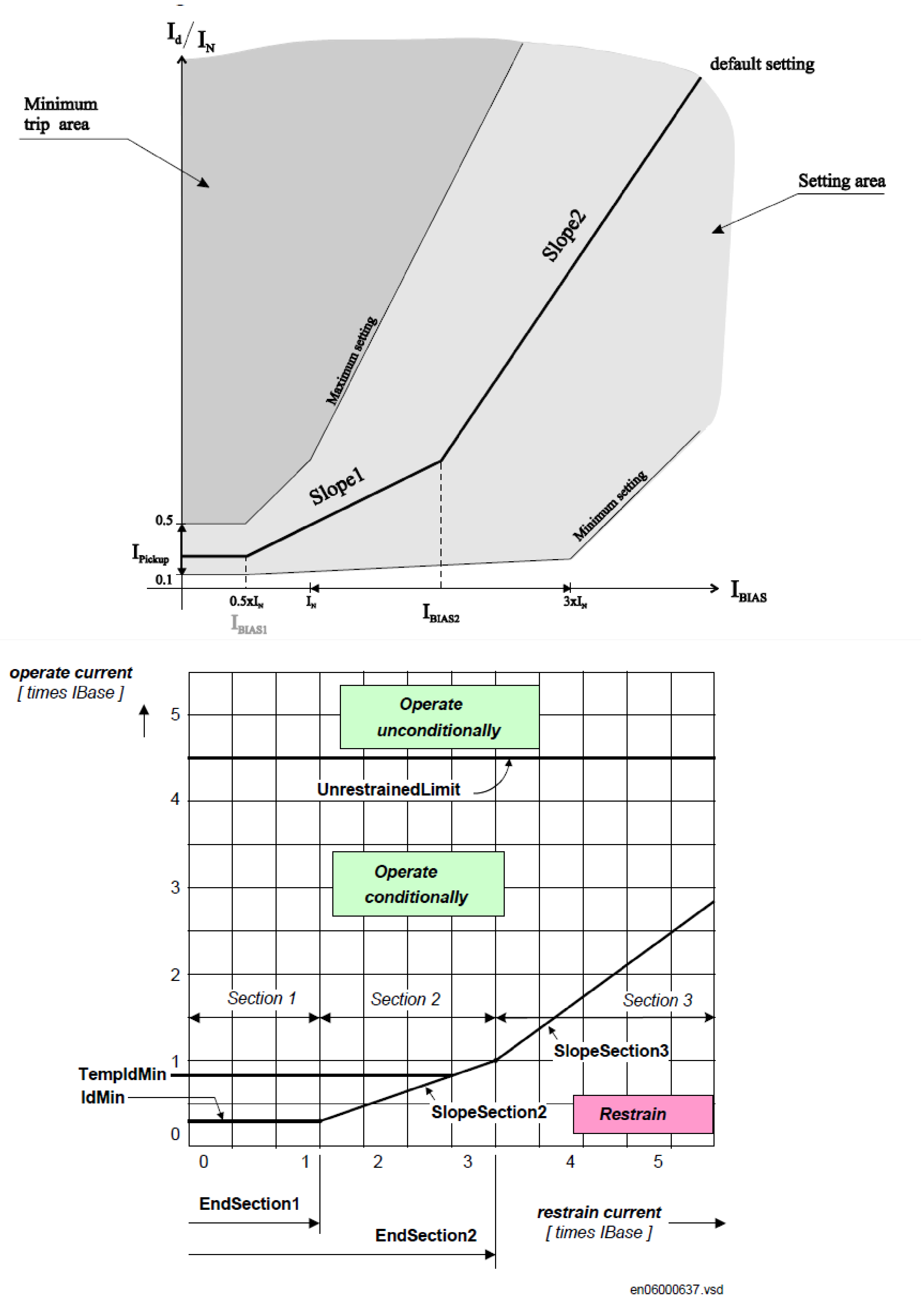


Figure 7. Differential protection characteristics from VAMP and ABB protection relay manuals respectively (VAMP Ltd., 2011b, p.54; Asea Brown Boveri, 2013c, p.132).

The latter graph in figure 7 is from ABB's manual and is described as follows:

- IdMin (Sensitivity in section 1, set as multiple of generator-rated current)
- EndSection1 (End of section 1, set as multiple of generator-rated current)
- EndSection2 (End of section 2, set as multiple of generator-rated current)
- SlopeSection2 (Slope in section 2 of the characteristic, set in percent)
- SlopeSection3 (Slope in section 3 of the characteristic, set in percent)

The same thing applies to the first graph in figure 7, VAMP265, except that the first section starts at slope 1 and the second section at slope 2.

These characteristics apply to the lower stage *ΔI*>, in which a second harmonic blocking function is also included, and the *ΔI*>> stage. The unrestrained limit, seen in figure 7, is the setting for the *ΔI*>> stage and this particular stage does not apply to the bias current calculation but to the differential current calculation. Some relays have got a fifth harmonic blocking function whose principle is the same as for the second harmonic blocking function but it blocks the fifth harmonic instead. The second harmonic is calculated from the winding currents and its ratio is calculated as follows:

$$Harmonic\ ratio = \frac{I_{f2\_Winding}}{I_{f1\_Winding}} \times 100\ \% \qquad \text{(equation 18)}$$

where: $I_{f2\_Winding} = Current\ for\ 2{:}nd\ fundamental\ frequency$

$I_{f1\_Winding} = Current\ for\ 1{:}st\ fundamental\ frequency$

(Asea Brown Boveri, 2013c, pp. 131-132; VAMP Ltd., 2011c, p. 54)

3.2 Extended protective functions

These functions also belong to the same standard as the one mentioned in chapter 3.1 but these are given the name "extended protective functions". This is to separate them from the standard settings since these are not normally implemented in the relay, unless at the customer's request.

3.2.1 Over-excitation, U_f>

When a generator's laminated core is exposed to a magnetic flux that exceeds the limits that it is designed for, random flux will appear causing vortex currents that will affect non-laminated components which are not designed to withstand magnetic flux. The vortex currents can cause damage to insulated parts quite quickly and therefore it is important to prevent over-excitation as quickly as possible. Usually over-excitation occurs during start-up and shutdown of the generator when the frequency changes happen in a wide range, especially if the generator is energized during start-up and shutdown (VAMP Ltd., 2011a, p. 94; Asea Brown Boveri, 2013c, pp. 401-402).

Since the voltage goes hand in hand with the frequency, i.e. the lower the frequency the lower the voltage, this protection is based on calculating the ratio between the voltage and the frequency:

$$P.U. = \frac{U}{f} \qquad \text{(equation 19)}$$

The nominal volts/hertz setting can be calculated by the following equation:

$$1P.U. = \frac{U_{nominal}}{f_{nominal}} \qquad \text{(equation 20)}$$

where: $P.U. = Over\text{-}excitation\ ratio\ in\ per\ unit$
$U = Voltage$
$f = frequency$

This makes the protection function sensitive to the ratio of changes in voltage, frequency or both instead of in voltage only (VAMP Ltd., 2011a, p. 95)

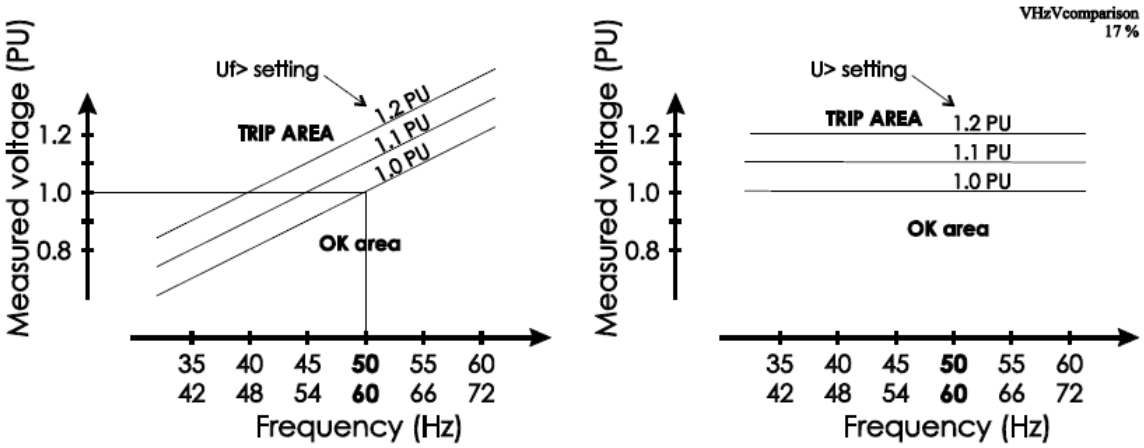


Figure 8. Example of operating characteristics of U/f protection (left graph) and normal overvoltage protection (right graph) (VAMP Ltd., 2011a, p. 94).

3.2.2 Under-impedance, *Z*<

Under-impedance is the protection used in distance protections to detect short-circuit faults in cables and lines. It works as a complement to the differential protection as well. The good thing with impedance measuring protections, compared to current measuring protections, is that they can detect the fault at an exact distance without being influenced by the short-circuit power (Öhlen, 2012, p. 355).

The under-impedance protection works by measuring the ratio between voltage and current, also known as Ohm’s law. The nominal impedance for the generator can be calculated by using nominal current and voltage in the following formula:

$$Z_1 = \frac{U_1}{\sqrt{3} \times I_1} \qquad \text{(equation 21)}$$

where:

$Z_1 = primary\ impedance$

$U_1 = primary\ voltage$

$I_1 = primary\ current$

The characteristics of impedance protections are usually that they are circular, polygonal or a combination of these two mentioned. Regardless of characteristics, as soon as the impedance phasor ends up inside the characteristics, the relay trips. Nominal impedance would, in figure 9, be at the stator limit and, if the impedance decreases and ends up in the red, striped area, which is the user’s trip setting, the relay starts operating (Öhlen, 2012, p. 355; VAMP Ltd., 2011a, pp. 117-118).

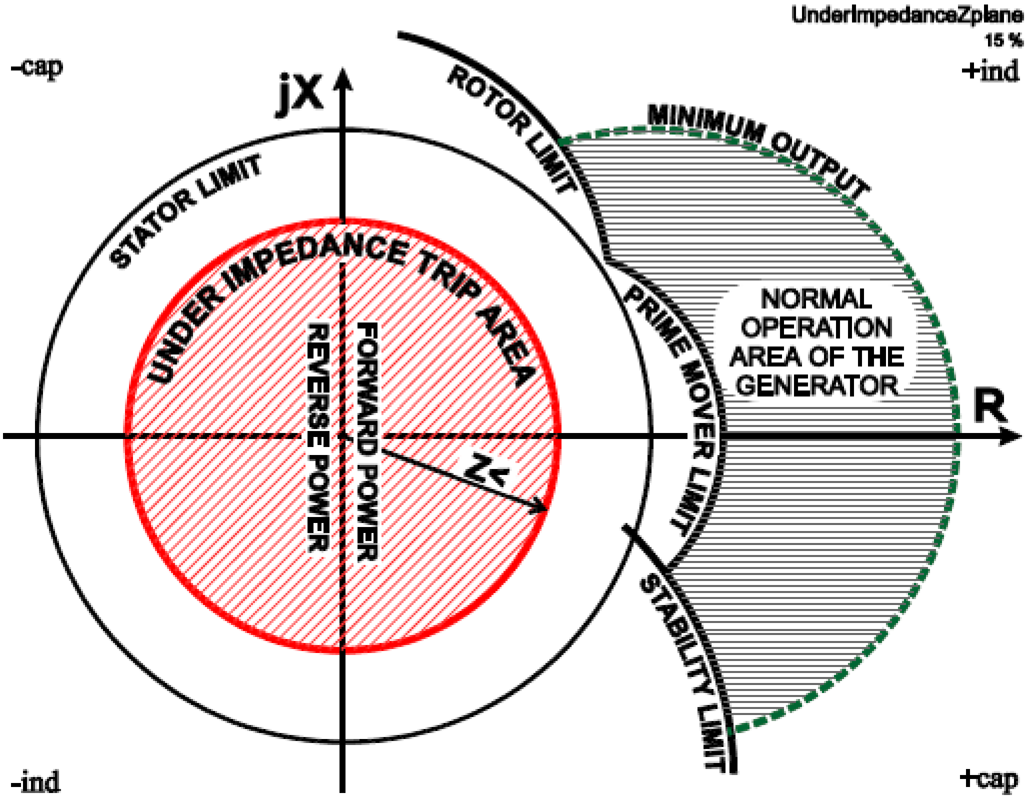


Figure 9. Example of under-impedance characteristics (VAMP Ltd., 2011a, p. 117).

3.2.3 Loss of excitation, *X*<

Loss of excitation is practically the same as if the generator is under-excited. The difference here, when using loss of excitation protection instead of under-excitation protection, is that loss of excitation protection is sensitive to situations where the generator is losing excitation but is still not exceeding the settings for under-excitation, i.e. the protection supervises that the generator is operating in the stable area since a reduction in excitation might weaken the connection between the rotor and the stator (Asea Brown Boveri, 2013c, p. 205; VAMP Ltd., 2011c, p. 124).

The protection works by measuring the positive sequence impedance, seen from the generator, for all three phases. The equation looks like this:

$$\bar{Z}_1 = \frac{\bar{U}_1}{\sqrt{3} \times \bar{I}_1} \qquad \text{(equation 22)}$$

where:
$\bar{Z}_1$ = *positive sequence impedance*
$\bar{U}_1$ = *positive sequence voltage*
$\bar{I}_1$ = *positive sequence current*

Nominal impedance can be calculated as in chapter 3.2.2 or by the following equation:

$$Z_N = \frac{U_N^2}{S_N} \qquad \text{(equation 23)}$$

where: Z_N = nominal impedance
U_N = nominal voltage
S_N = nominal apparent power

The characteristic is set by giving it a reactive and resistive offset. The resistive and reactive offset can be calculated as follows:

Resistive offset: $Ros = 0{,}14 \times \left(X'_d + \frac{X_d}{2}\right)$

Reactive offset: $Xos = -\left(X'_d + \frac{X_d}{2}\right)$

where: X'_d = *transient reactance for the synchronous machine*
X_d = *synchronous unsaturated reactance*

(VAMP Ltd., 2011a, p. 126; Asea Brown Boveri, 2013c, p. 206)

In figure 10 the set loss of the excitation limit is the radius of the red striped area. It has a reactive offset which is, in this case, the same as the radius and it is slightly displaced due to the resistive offset. The loss of excitation area needs to be turned -90 degrees because it is in this area excitation is starting to fade (VAMP Ltd., 2011a, p. 125).

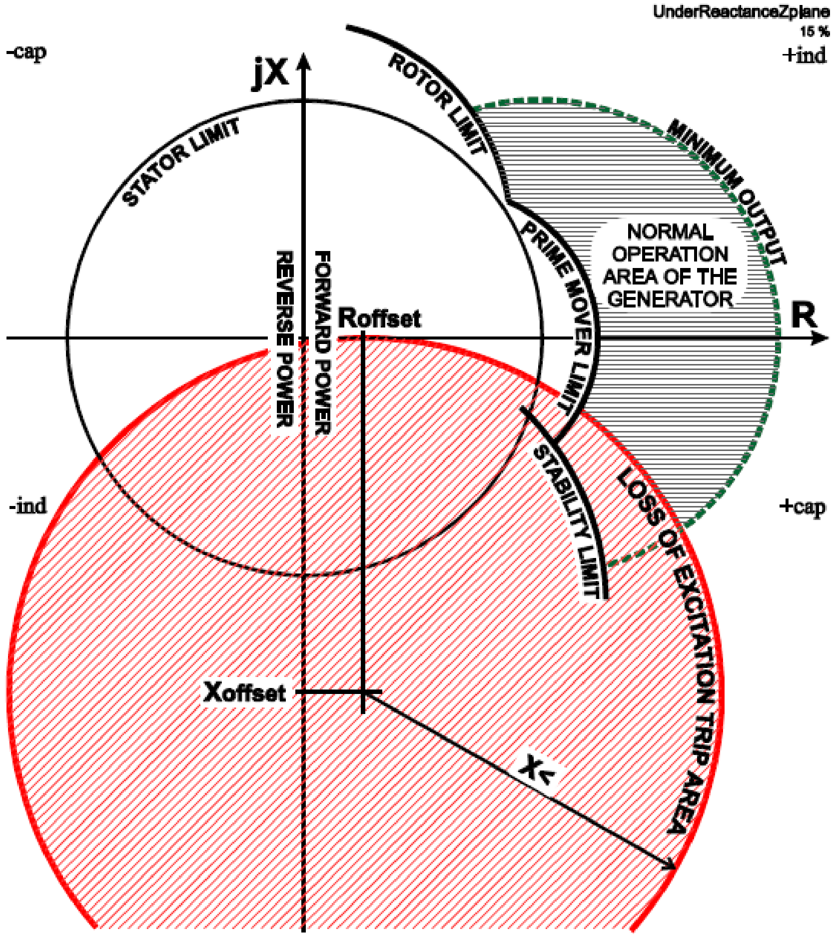


Figure 10. Example of loss of excitation characteristics where the red loss of excitation area overlaps the part of the power circle where loss of excitation occurs (VAMP Ltd,. 2011a, p. 125).

3.2.4 100% stator earth-fault, $U_{0f3}<$

The zero-sequence voltage protection protects nearly 95 percent of the stator winding and an earth fault on the remaining 5 percent is quite rare. However, there is still a chance of an earth fault on the remaining 5 percent, especially if the generator is a large one or if there are two earth faults successively, the second one occurs in one of the phases, since the first earth fault makes the power grid solidly earthed. The earth-fault protection, which protects the remaining 5 percent of the generator, can therefore be implemented. This protection is based on measuring the third harmonic, which is filtered in the zero-sequence voltage protection. If this harmonic tone is lost even if the generator is energized when not operating, it indicates an earth fault near the neutral point of the generator windings (Öhlen, 2012, p. 381; VAMP Ltd., 2011a, p. 106).

The third harmonic is three times the nominal frequency and when the neutral point voltage with the third harmonic tone falls under the set limit, the relay starts operating. It is hard, though, to find the right pick-up setting because the third harmonic in generators depends on the generator's construction, loading, power factor, amount of excitation and other conditions. Due to this, the pick-up setting is in practice set on the basis of empirical values (VAMP Ltd., 2011a, pp. 107-108).

The ABB REG670 calculates the third harmonic tone with two voltage sources, one in the voltage transformer from a broken delta connection and one from the zero-sequence voltage transformer at the neutral point. A beta setting is also needed to avoid operation under non-faulted conditions. The angle between $U_{3\mathrm{N}}$ and $U_{3\mathrm{T}}$ is near 180 degrees and therefore used in the equation. The equation is the following:

$$Beta \times U_{3N} = \sqrt{(U_{3N} + U_{3T} * cos(180))^2 + (U_{3T} * \sin(180))^2} \quad \text{(equation 24)}$$

where:
$U_{3N} = Zero\ sequence\ voltage\ at\ neutral\ point$
$U_{3T} = Zero\ sequence\ voltage\ at\ terminal\ side$
$Beta = Beta\ factor$

(Asea Brown Boveri, 2013b, pp. 199-200)

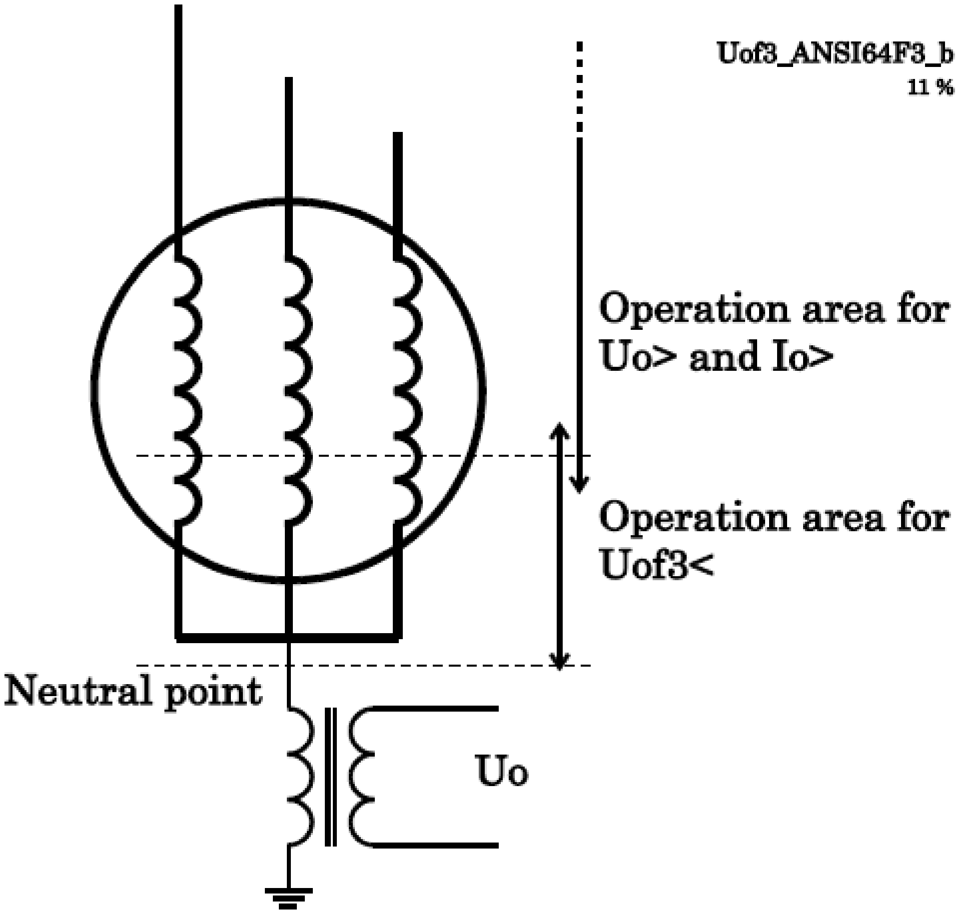


Figure 11. Picture of operation area for 100% earth-fault protection and 95% earth-fault protection (VAMP Ltd. 2011a,, p. 106).

3.2.5 Rate of change of frequency (ROCOF), *df/dt*

Rate of change of frequency, *df/dt*, is used to obtain a faster operation time of under- or over-frequency and also to detect a loss of grid at sudden load drops. The protection is also sensitive to fast oscillations in frequency, which might occur at short-circuit faults or when the load is changing, before the generator itself obtains its nominal frequency (Asea Brown Boveri, 2013c, p. 434; VAMP Ltd., 2011a, p. 112).

The protection measures the fundamental frequency from either two or three phases, depending on relay settings, and compares the value with the set operation value. Both inverse operation time and definite time are options of the characteristic but, in this thesis, only definite time is used (Asea Brown Boveri, 2013c, p. 434; VAMP Ltd., 2011a, p. 114).

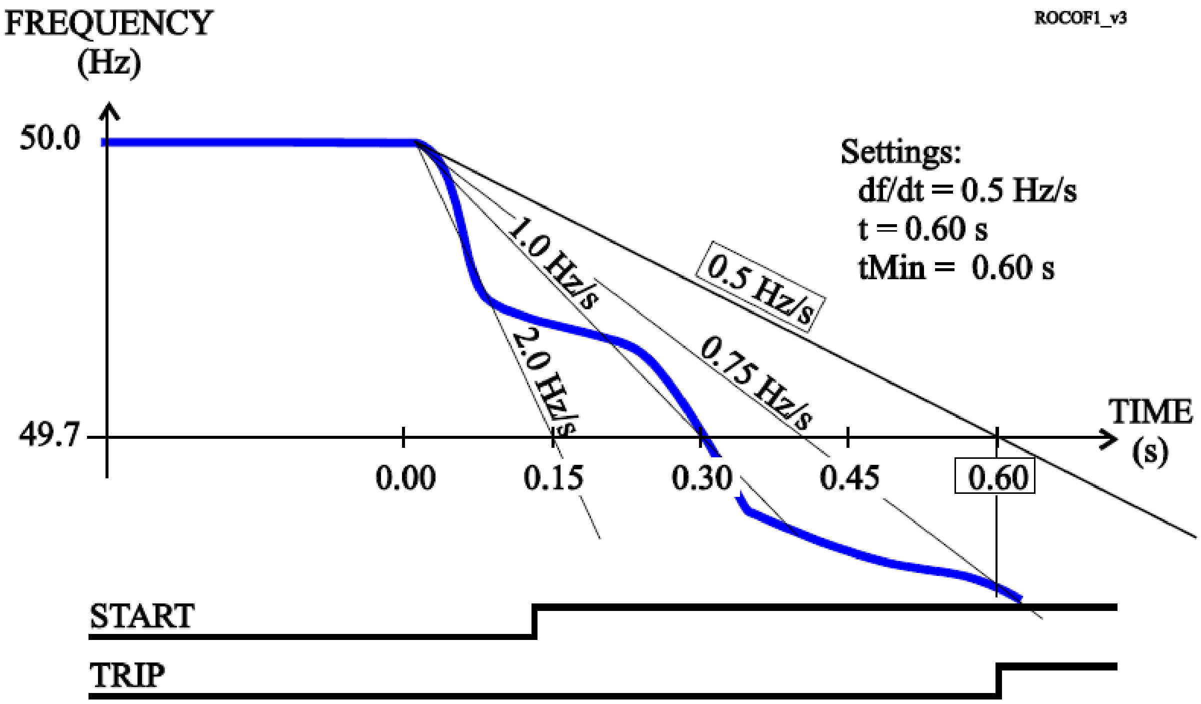


Figure 12. Example of ROCOF protection definite time where the df/dt setting is 0.5 Hz/s and the time delay t is 0.60 s (VAMP Ltd., 2011a, p. 113).

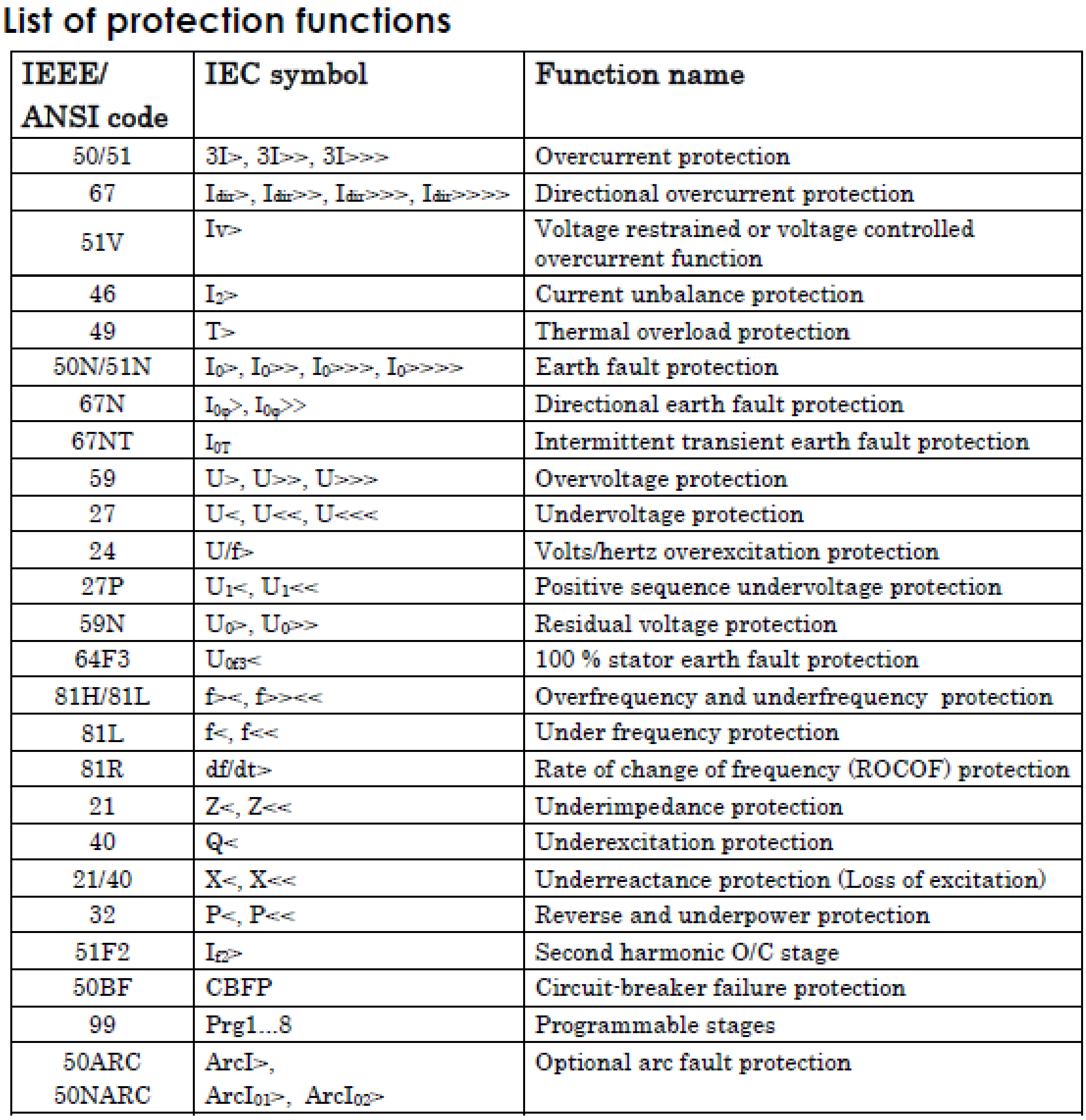
3.3 Relays

This chapter will describe the relays, relay manufacturers and the relays' attributes that were used in this thesis work. There will also be examples of how they can be connected to a generator and how they have been assumed to be connected during the testing

3.3.1 VAMP 210

VAMP 210 is manufactured by a company named VAMP Ltd. from Vaasa, Finland. The manufacturing of VAMP relays is today done by a company named Schneider Electric since VAMP is, today, a part of Schneider Electric (Schneider Electric, n.d.)

VAMP 210 is a multifunctional protective relay for generators. The relay has got plenty of different protection functions which make it ideal for utility, industrial, marine and off-shore power distribution applications (VAMP Ltd. 2011a, p. 4).



List of protection functions

IEEE/ ANSI code	IEC symbol	Function name
50/51	3I>, 3I>>, 3I>>>	Overcurrent protection
67	$I_{dir}>$, $I_{dir}>>$, $I_{dir}>>>$, $I_{dir}>>>>$	Directional overcurrent protection
51V	$I_V>$	Voltage restrained or voltage controlled overcurrent function
46	$I_2>$	Current unbalance protection
49	T>	Thermal overload protection
50N/51N	$I_0>$, $I_0>>$, $I_0>>>$, $I_0>>>>$	Earth fault protection
67N	$I_{0\varphi}>$, $I_{0\varphi}>>$	Directional earth fault protection
67NT	I_{0T}	Intermittent transient earth fault protection
59	U>, U>>, U>>>	Overvoltage protection
27	U<, U<<, U<<<	Undervoltage protection
24	U/f>	Volts/hertz overexcitation protection
27P	$U_1<$, $U_1<<$	Positive sequence undervoltage protection
59N	$U_0>$, $U_0>>$	Residual voltage protection
64F3	$U_{0f3}<$	100 % stator earth fault protection
81H/81L	f><, f>><<	Overfrequency and underfrequency protection
81L	f<, f<<	Under frequency protection
81R	df/dt>	Rate of change of frequency (ROCOF) protection
21	Z<, Z<<	Underimpedance protection
40	Q<	Underexcitation protection
21/40	X<, X<<	Underreactance protection (Loss of excitation)
32	P<, P<<	Reverse and underpower protection
51F2	$I_{f2}>$	Second harmonic O/C stage
50BF	CBFP	Circuit-breaker failure protection
99	Prg1...8	Programmable stages
50ARC 50NARC	ArcI>, $ArcI_{01}>$, $ArcI_{02}>$	Optional arc fault protection

Figure 13. List of protection functions in VAMP 210 (VAMP Ltd., 2011a, p. 4).

There are several ways of connecting the relay to the CTs and VTs. The things that decide how it has to be connected is for instance if the generator's neutral point is grounded or not or if there is a transformer unit between the generator and the bus bar. The following example describes a directly connected generator:

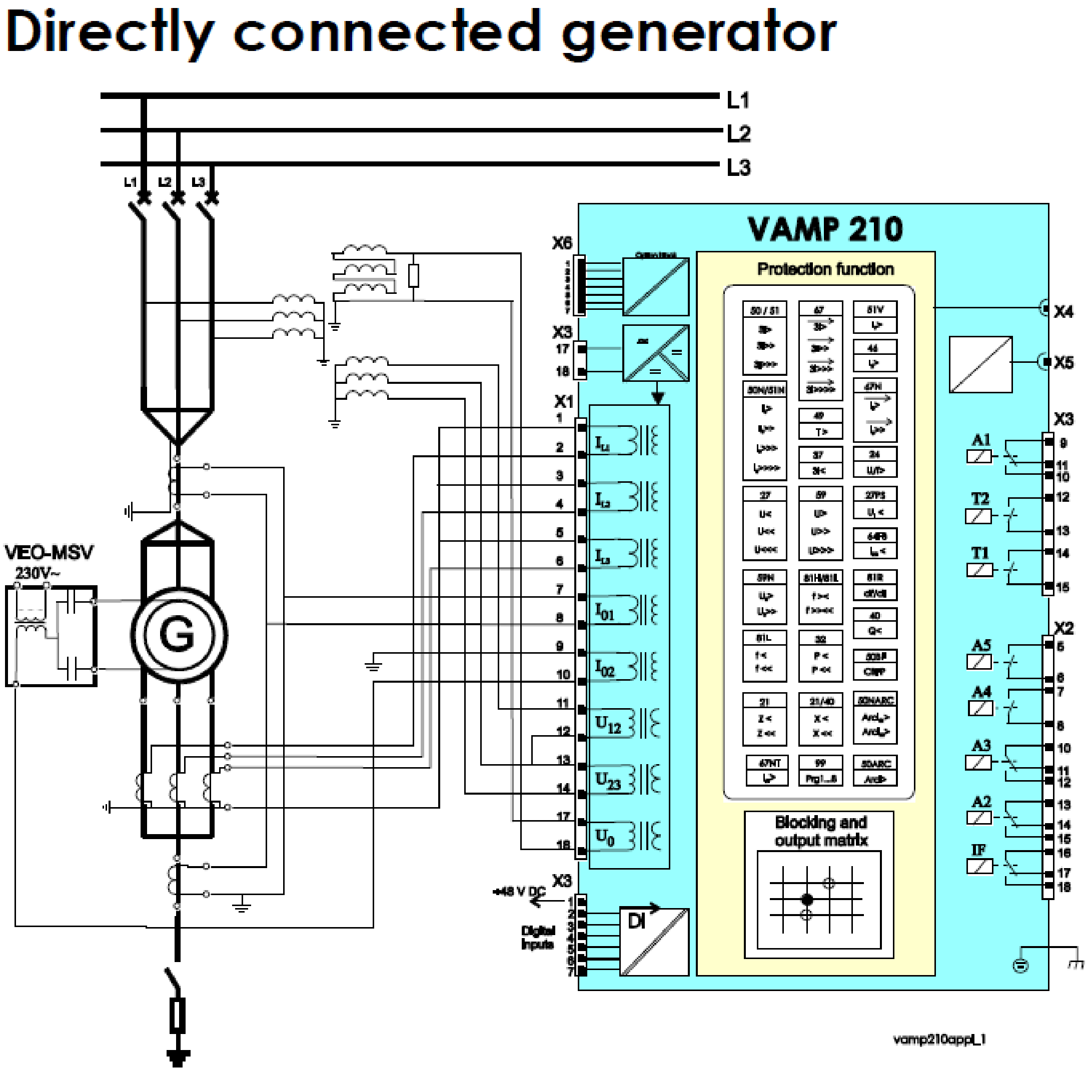


Figure 14. Directly connected generator (VAMP Ltd., 2011a, p. 239).

In this example it is possible to spot the analog inputs, X1:1 to X1:18, which are connected to the CTs and VTs. X3:1 to X3:7 are digital inputs which can be used if the user needs to block, reset or switch setting groups with binary signals generated from an external source. X3:9 to X3:15 and X2:5 to X2:15 are used as digital outputs from which start, trip and alarm signals are generated (VAMP Ltd., 2011a, pp. 239-241)

The relay can be configured via its control panel or with its configuring software program named VAMPSET. It has a user-friendly graphical interface in which configurations are made. In addition to the possibility of configuring the protection functions' settings it is also possible to configure the digital outputs and the digital inputs and to decide e.g. which digital output should be used as a trip and which digital input will block a certain function. (Schneider Electric, 2012, p. 6)

The interface looks as follows:

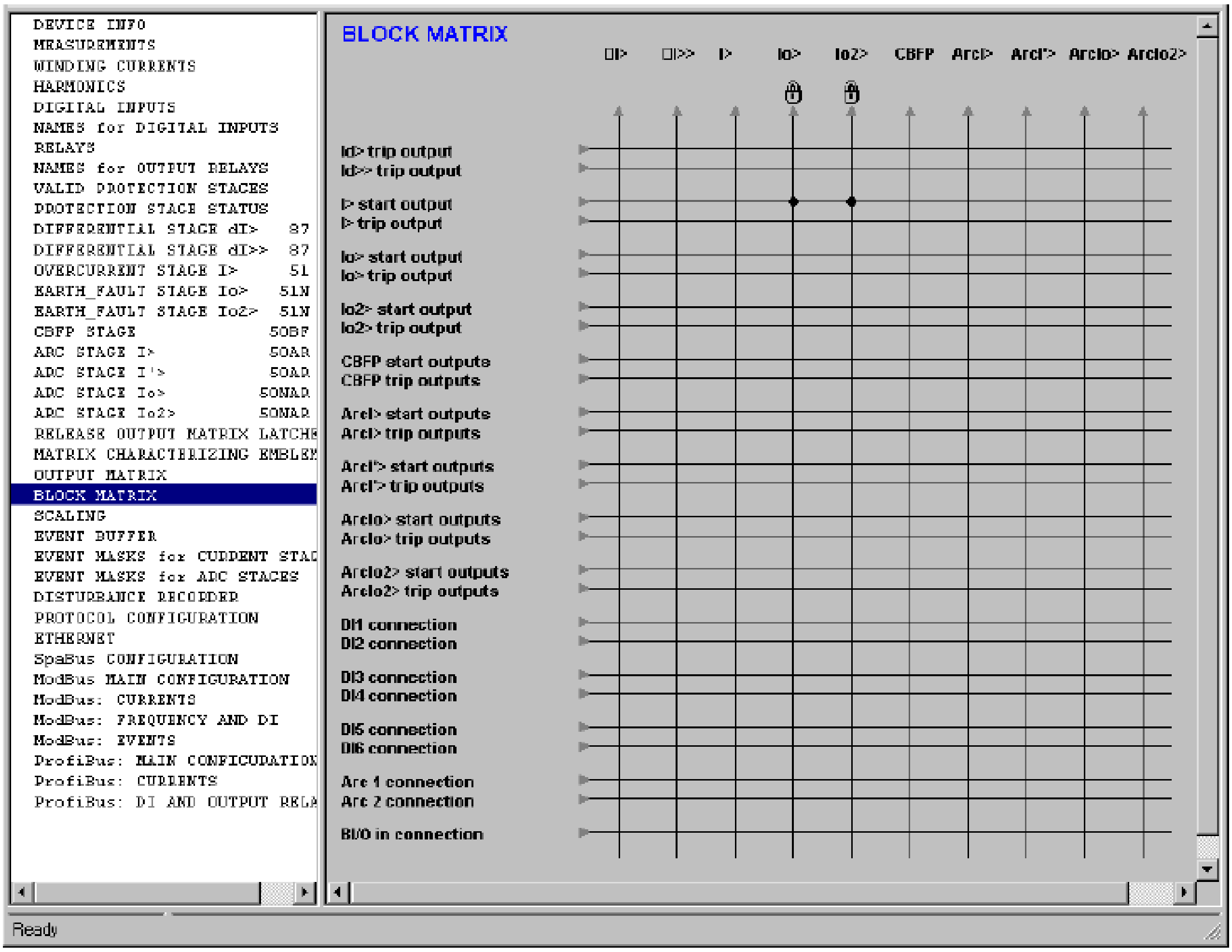
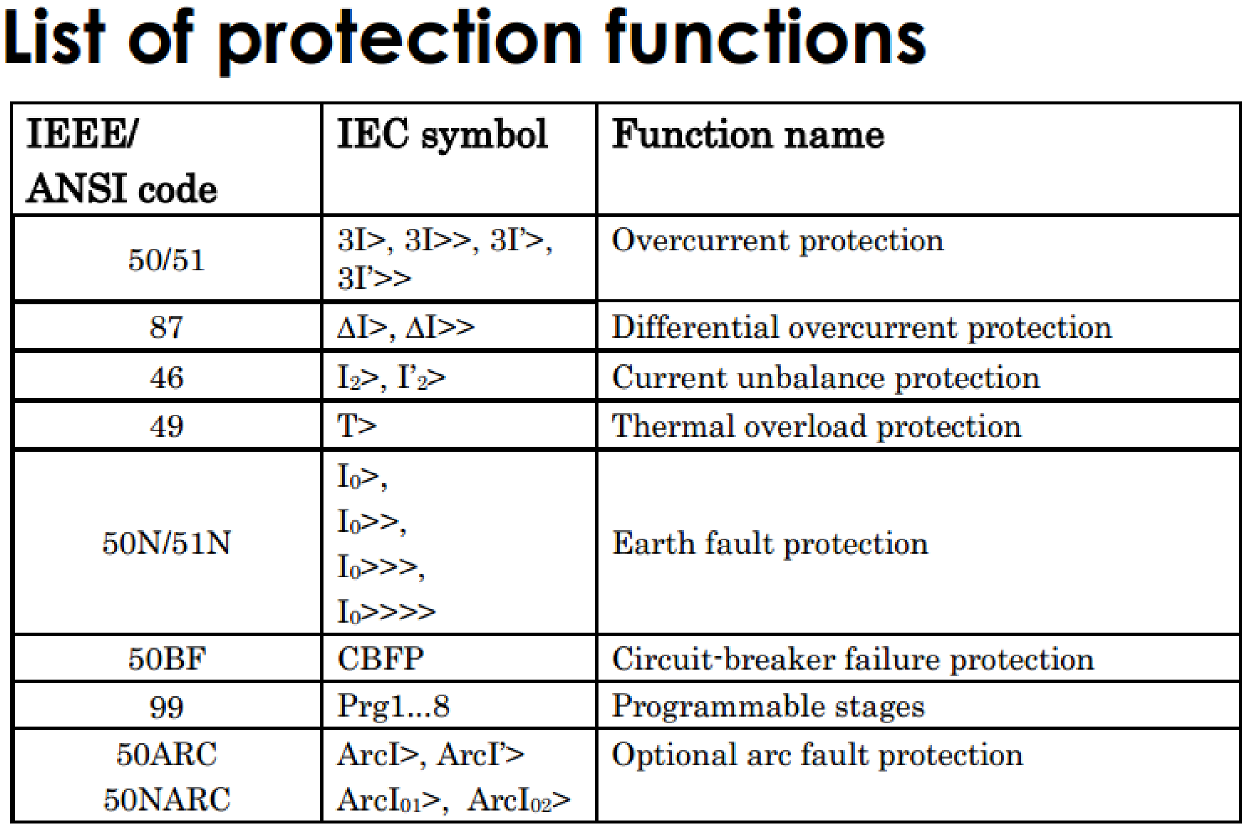


Figure 15. VAMPSET interface of block matrix options (Schneider Electric 2012, p. 40).

3.3.2 VAMP 265

VAMP 265 was, like the 210 model, manufactured by VAMP in the early days. Even if the 265 looks a lot like 210, there are some small differences in the protective functions. VAMP 265 is a differential protection relay and suits motors, generators, transformers and short cables. The 265 has got fewer functions than 210 but these two relays can of course be used together. (VAMP Ltd., 2011b, p. 4)

The VAMP 265 includes the following functions:



List of protection functions

IEEE/ ANSI code	IEC symbol	Function name
50/51	3I>, 3I>>, 3I'>, 3I'>>	Overcurrent protection
87	ΔI>, ΔI>>	Differential overcurrent protection
46	$I_2>$, $I'_2>$	Current unbalance protection
49	T>	Thermal overload protection
50N/51N	$I_0>$, $I_0>>$, $I_0>>>$, $I_0>>>>$	Earth fault protection
50BF	CBFP	Circuit-breaker failure protection
99	Prg1...8	Programmable stages
50ARC 50NARC	ArcI>, ArcI'> $ArcI_{01}>$, $ArcI_{02}>$	Optional arc fault protection

Figure 16. Functions in VAMP 265 (VAMP Ltd., 2011b, p. 4).

Connecting the VAMP 265 to the generator is also a little bit different than connecting the VAMP 210. The biggest difference is the differential function in VAMP 265 which needs a completely different set of analog inputs. Furthermore, the VAMP 265 is missing analog inputs for voltages completely. The connection can be seen in the following connection scheme:

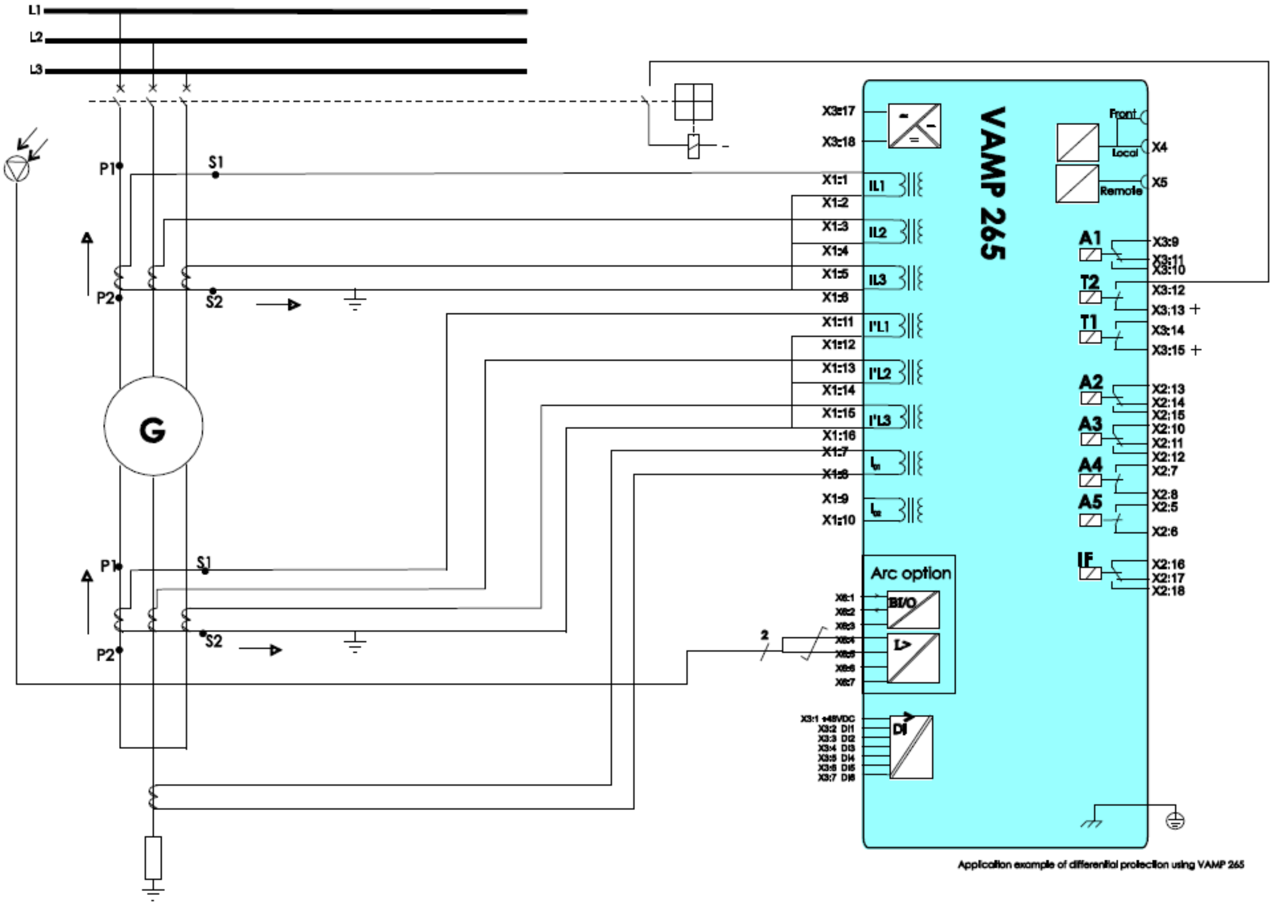


Figure 17. Connection description of VAMP 265 (VAMP Ltd., 2011b, p. 169).

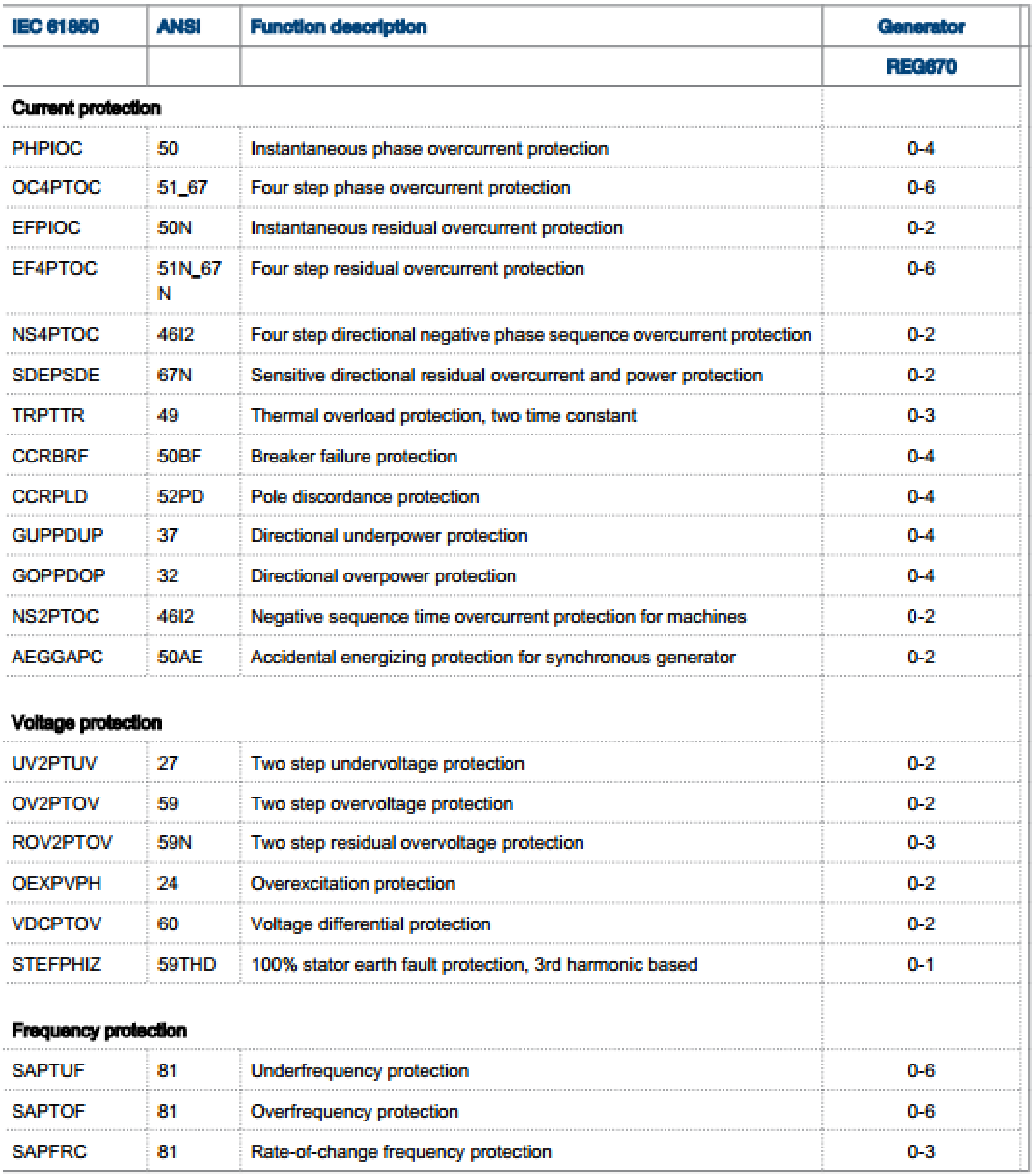
The digital inputs and outputs have the same principles as in VAMP 210. Also the configuring of the relay is done in VAMPSET and the configuring of the blocking matrix and the output matrix is done in the same way.

3.3.3 ABB REG 670

ABB REG 670 is a multifunctional protective relay which is manufactured by Asea Brown Boveri. This relay suits generators well. Compared to VAMP relays, this relay has a lot more possibilities but it also requires a lot more from the user configuring the protective functions (Asea Brown Boveri, 2013a, p. 3).

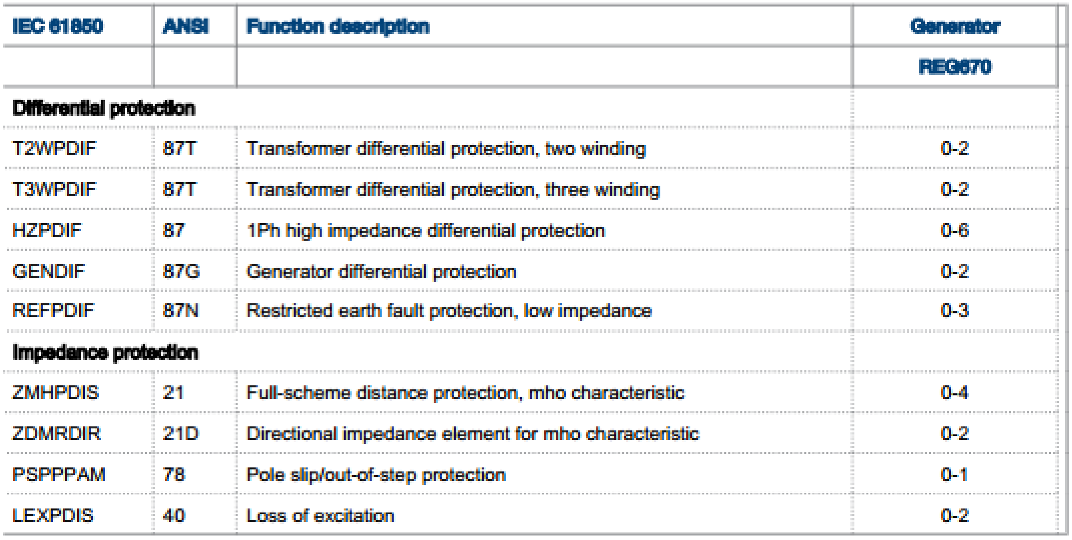
The relay is practically “empty” in the beginning, which means that each protective function needed to protect a generator must be configured from the beginning with logic blocks and function blocks. Also disturbance recording and led indication lights must be configured. This is done with PCM600, which is the tool to configure ABB relays with. The software in the relay is not the only thing to be configured, the analog inputs, digital outputs and digital inputs are not specified as in VAMP's relays. This gives the user a possibility to choose which channels are going to be what. The same thing applies to the relay software; the user can combine functions and customize the relay exactly according to his needs (Asea Brown Boveri, 2013c, p. 27, p. 30)

Once a function block is applied to the software, a parameter setting section will automatically be created, i.e. parameter settings are done almost in the same way as in VAMPSET. The relay has got plenty of protection functions which are visualized in the following figures (Asea Brown Boveri, 2013c, p. 30, pp. 58-60).



IEC 61850	**ANSI**	**Function description**	**Generator**
			REG670
Current protection			
PHPIOC	50	Instantaneous phase overcurrent protection	0-4
OC4PTOC	51_67	Four step phase overcurrent protection	0-6
EFPIOC	50N	Instantaneous residual overcurrent protection	0-2
EF4PTOC	51N_67 N	Four step residual overcurrent protection	0-6
NS4PTOC	46I2	Four step directional negative phase sequence overcurrent protection	0-2
SDEPSDE	67N	Sensitive directional residual overcurrent and power protection	0-2
TRPTTR	49	Thermal overload protection, two time constant	0-3
CCRBRF	50BF	Breaker failure protection	0-4
CCRPLD	52PD	Pole discordance protection	0-4
GUPPDUP	37	Directional underpower protection	0-4
GOPPDOP	32	Directional overpower protection	0-4
NS2PTOC	46I2	Negative sequence time overcurrent protection for machines	0-2
AEGGAPC	50AE	Accidental energizing protection for synchronous generator	0-2
Voltage protection			
UV2PTUV	27	Two step undervoltage protection	0-2
OV2PTOV	59	Two step overvoltage protection	0-2
ROV2PTOV	59N	Two step residual overvoltage protection	0-3
OEXPVPH	24	Overexcitation protection	0-2
VDCPTOV	60	Voltage differential protection	0-2
STEFPHIZ	59THD	100% stator earth fault protection, 3rd harmonic based	0-1
Frequency protection			
SAPTUF	81	Underfrequency protection	0-6
SAPTOF	81	Overfrequency protection	0-6
SAPFRC	81	Rate-of-change frequency protection	0-3

Figure 18. List of protective functions for REG670 (Asea Brown Boveri, 2013a, p. 11).



IEC 61850	ANSI	Function description	Generator
			REG670
Differential protection			
T2WPDIF	87T	Transformer differential protection, two winding	0-2
T3WPDIF	87T	Transformer differential protection, three winding	0-2
HZPDIF	87	1Ph high impedance differential protection	0-6
GENDIF	87G	Generator differential protection	0-2
REFPDIF	87N	Restricted earth fault protection, low impedance	0-3
Impedance protection			
ZMHPDIS	21	Full-scheme distance protection, mho characteristic	0-4
ZDMRDIR	21D	Directional impedance element for mho characteristic	0-2
PSPPPAM	78	Pole slip/out-of-step protection	0-1
LEXPDIS	40	Loss of excitation	0-2

Figure 19. Differential and impedance protections for REG670 (Asea Brown Boveri, 2013a, p. 10).

The following connection scheme will visualize how the REG670 can be connected, how the CTs and VTs are connected:

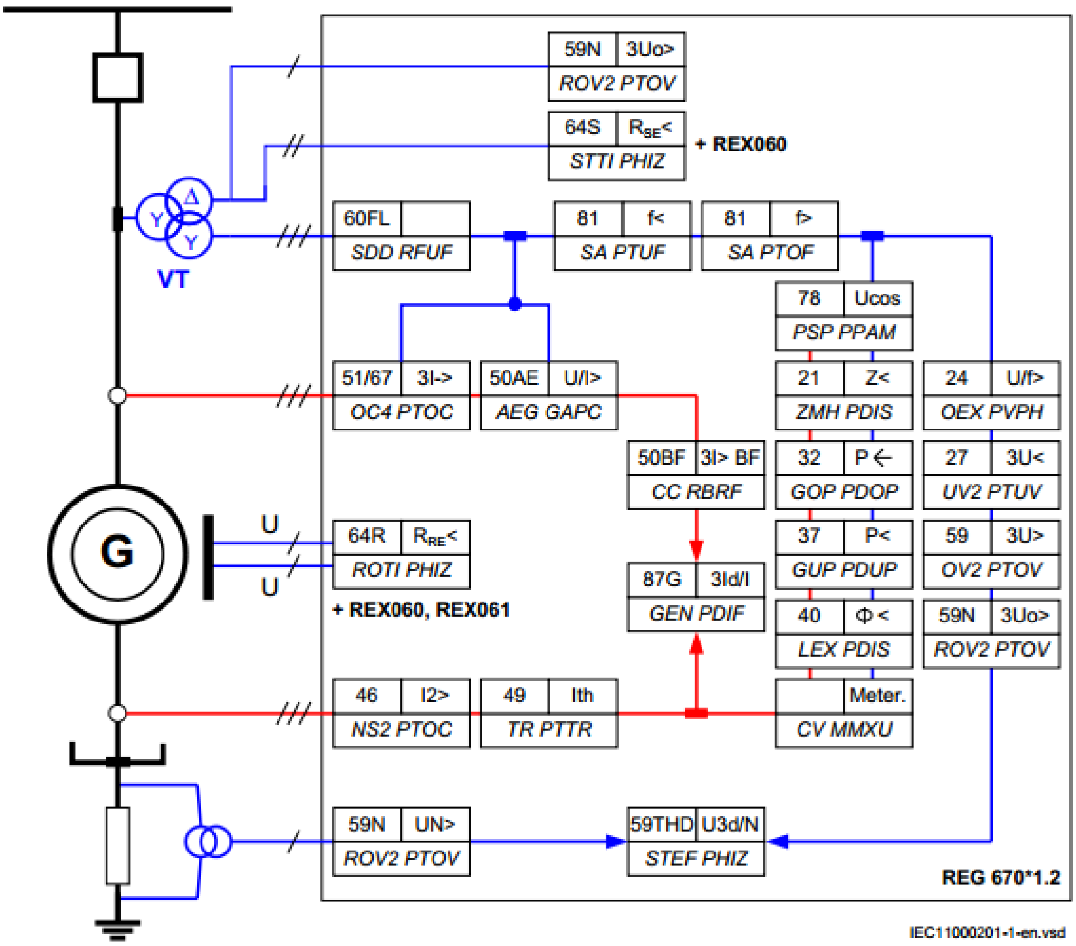


Figure 20. REG670 connected to a generator (Asea Brown Boveri, 2013a, p .4).

4 Factory Acceptance Test, FAT

This chapter will briefly describe what FAT is and what the main objectives of FAT are.

4.1 What is FAT?

A Factory Acceptance Test is a quality control test done by manufacturers and vendors to meet codes and standard requirements to ensure the customer that the equipment operates as intended. The testing is done according to a contract or specification where a system is tested with a number of test runs. The test can be summarized in a document where essential test information gives an overview of how the test has worked out. The tests are also normally witnessed by a third party agency (Inspection 4 Industry LLC, 2012-2013; TÜV RHEINLAND, 2014).

5 Omicron

This chapter deals with Omicron as a software program and its hardware. An example is given of how to set up the hardware to a relay and what kind of possibilities the user is offered, mostly in matters of relay testing. The most essential outputs and inputs for the CMC hardware module will be clarified.

5.1 Hardware

In this thesis work, Omicron CMC 256, 256 plus and 356 are used. The hardware is connected to a computer with an Ethernet connection cable. To control the hardware, the Omicron Test Universe needs to be installed.

To start testing, the CMC must be correctly connected to the relay. The CMC’s voltage output looks as follows:

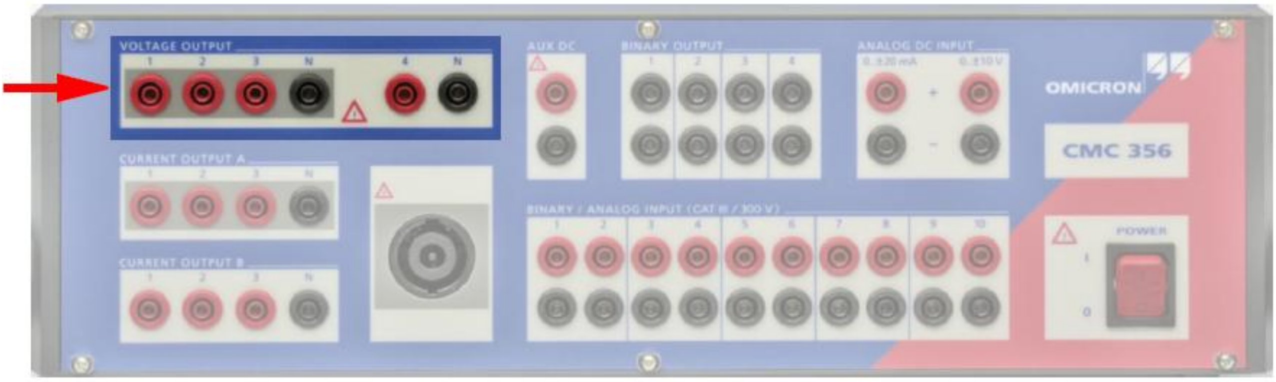


Figure 21. Voltage output (OMICRON Electronics GmbH. 2011, p. 22).

There are three voltage outputs for phase one to three and a neutral point output. The fourth voltage output, with a neutral output, is used as an output for injecting zero-sequence voltage (OMICRON Electronics GmbH. 2011, p. 22).

The currents can be injected from two separate three-phase current outputs, as seen in the following figure:

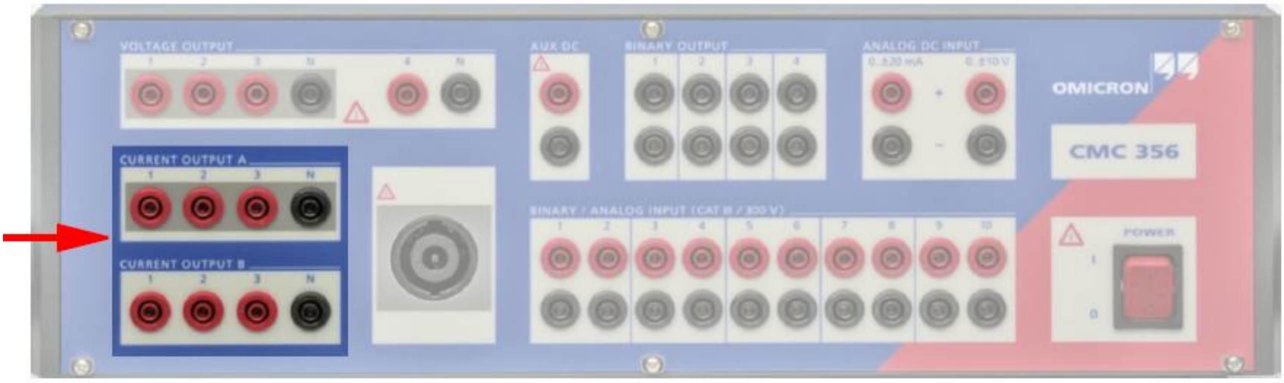


Figure 22. Current outputs (OMICRON Electronics GmbH. 2011, p. 25).

The current outputs are separated, as mentioned, into two different channels, channels A and B. Channel A is used as three-phase nominal currents. Channel B's current outputs are used for earth-fault current injections and as the differential currents at the neutral side of the generator. These outputs can be configured for other tasks also and they do not have to serve as mentioned (OMICRON Electronics GmbH. 2011, p. 25).

The binary outputs, digital outputs, are potential-free outputs and only connect the output above with the output below when a binary signal is high. An external voltage source is needed to give the outputs potential (OMICRON Electronics GmbH 2011, p. 11).

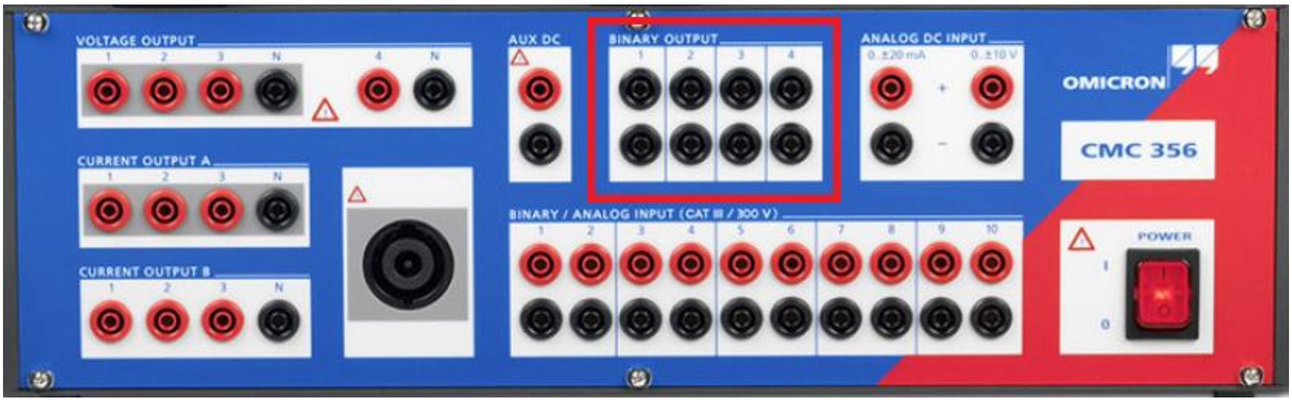


Figure 23. Binary outputs (OMICRON Electronics GmbH 2011, p. 7).

The binary/analog inputs are connected to the relay's trip and start outputs, which lets the software program know when the relay is tripping and starting (OMICRON Electronics GmbH. 2011, p. 10).

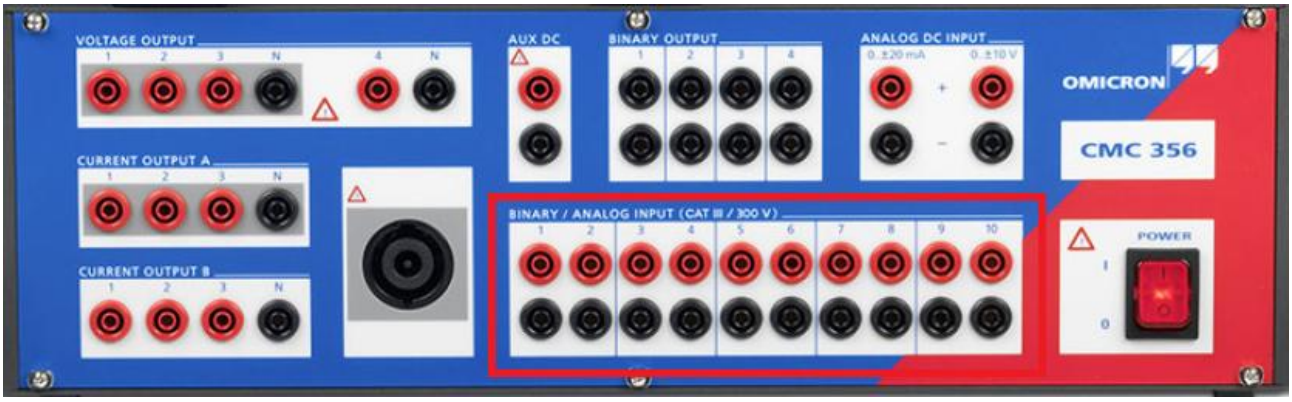


Figure 24. Binary/analog inputs (OMICRON Electronics GmbH 2011, p. 7).

The configuring of these inputs and outputs will be described in greater detail in chapter 5.2.

5.2 Omicron as software

Omicron Test Universe is a software program designed to control the CMC test sets from a computer. The software program offers the following features:

- computer-controlled manual testing
- optimized software modules for specific testing
- generic testing for special requirements
- combination of all three above
- using premade test files provided by Omciron.

(OMICRON Electronics GmbH. 2013, p. 7)

The QuickCMC test module is, as the name says, a quick way to use the test module CMC. The QuickCMC directly controls voltages, currents, frequencies and angles. It also monitors digital inputs and outputs, which gives the user a good overview of what is happening in the relay. Testing with QuickCMC is done manually (OMICRON Electronics GmbH. 2013, p. 7).

For automatic testing, manual testing also if the user wants to, it is recommended to create an Omicron Control Center (.OCC) test document in which the user can implement different kinds of multifunctional tests. This is built up by test modules which contain specific tests for e.g. over-current, differential current, state sequencer for operation time testing, ramp testing to ramp magnitudes and many more. Several test modules can be embedded in the same test and if the user presses the “start all” button, all selected test modules will be tested automatically. This requires that the hardware settings are correctly configured according to the user’s purpose. The crucial values such as nominal values are embedded in a test object file which is described in the next chapter (OMICRON Electronics GmbH. 2013, p. 8)

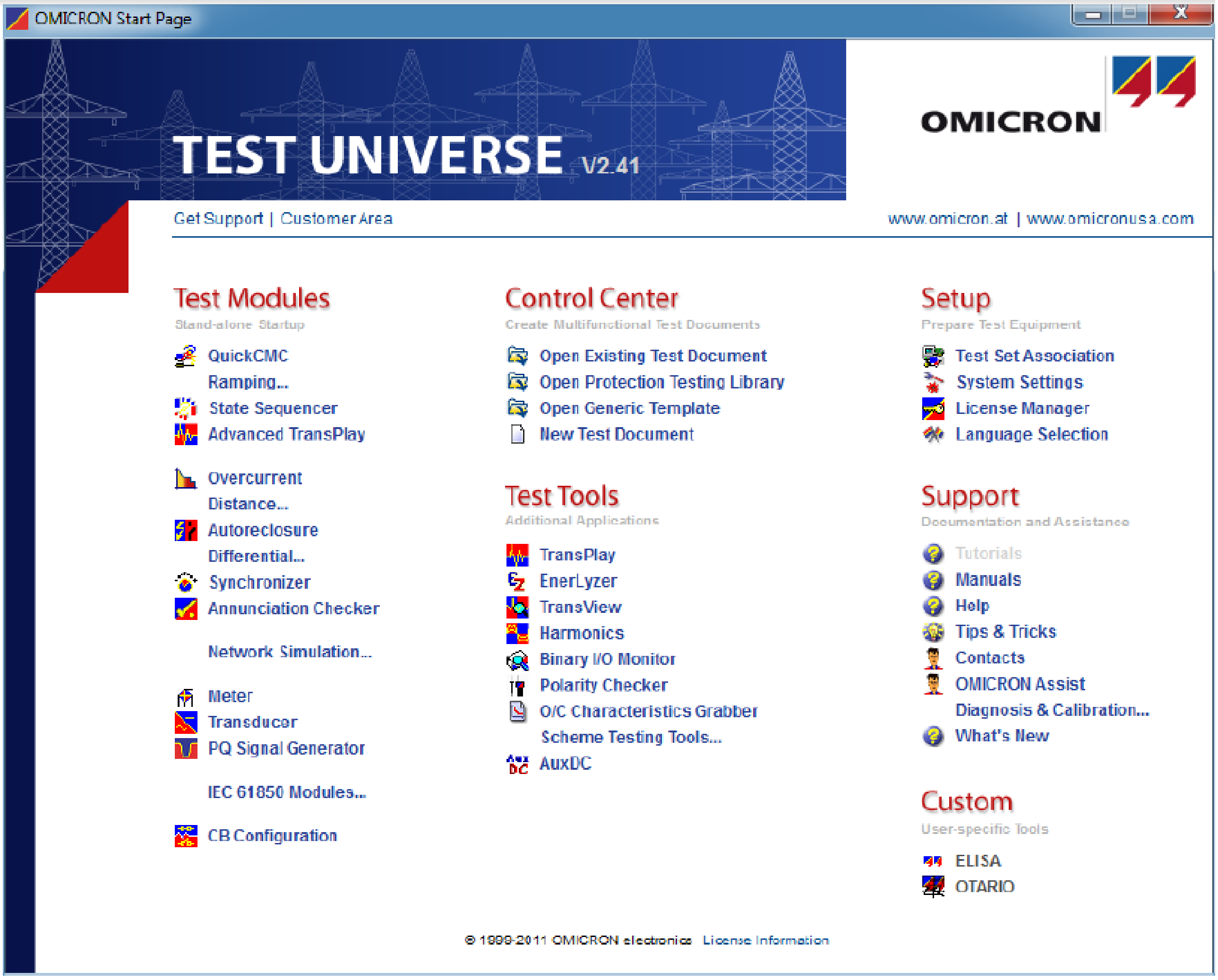


Figure 25. Test Universe start page (OMICRON Electronics GmbH. 2013, p. 11).

5.2.1 Test object, XRIO

The test modules can work by manually setting the operation values but, if the test is somewhat standardized, plenty of time can be saved by implementing a test object in the .OCC file. The test object module contains information about the test such as grounding points, operation values, trip times, deviations and, for a certain test module, more essential information. There is also a possibility to create one’s own folders, parameters and equations to get hold of values that are needed for the test. The calculated values can then be linked to the test modules and, if changes are made in the calculations in the test object file, the test modules will get the updated values (OMICRON Electronics GmbH. 2013, p. 24).

Test object parameters can also be imported and exported as XRIO files. ABB’s relays support the XRIO system, which means that configured settings in a relay can be exported to the test object file. Unfortunately, VAMP’s relay parameter settings can’t be exported as XRIO files and therefore important parameter settings must be implemented manually (OMICRON Electronics GmbH. 2013, p. 26).

The hardware also needs to be configured and needs to work as a data container so that the right test module is applied with the right hardware configurations. This is done by embedding a hardware configuration module in the .OCC file as seen in figure 26. It is possible to implement several hardware configuration modules if some of the test modules require other configurations. By configuring the hardware the user can configure analog outputs, digital outputs and digital inputs and what the output or input is used as (OMICRON Electronics GmbH. 2013, p. 21, p. 39).

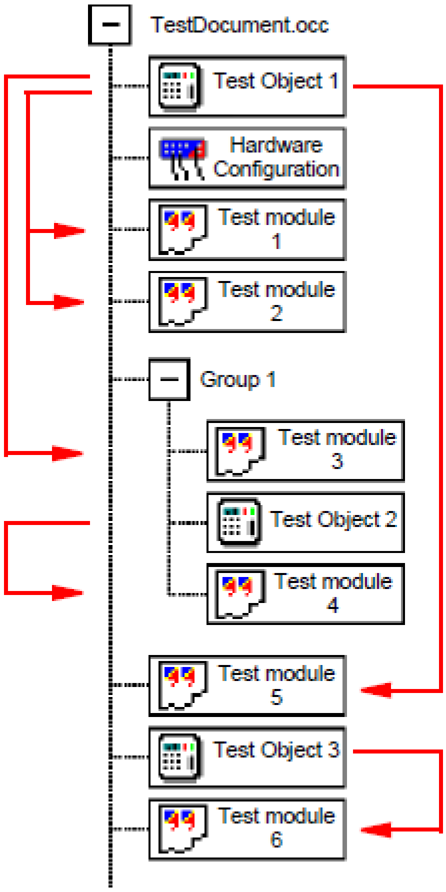


Figure 26. Example of how several test objects can work as a data container for different test modules (OMICRON Electronics GmbH. 2013, p. 21).

6 Implementation

Chapter six describes the approach of the practical part of this Bachelor’s thesis. It includes how the test equipment was connected with all tested relays, the blocking of interfering functions, calculations and the implementation of each test function. The implementations and calculations are done in Omicron where all essential procedures are going to be explained.

6.1 Relay and test equipment

The testing was done for relays VAMP 210, VAMP 265 and ABB REG670. The settings implemented in these relays are based on a real life project that has been done several years ago, but the same standards are used today which made this standard a perfect test case. The standard can be seen in appendix 3 and the settings and nominal generator values are used in accordance with the standard. The function settings followed by the word alarm are alarm stages and they have their own start and trip input in the Omicron hardware called alarm start and alarm.

The configuring of both VAMP relays was not difficult. VAMPSET was used to set the configurations for each function. The computer was connected to the VAMP relay by a programming port and all configured settings were uploaded to the relay. By having the computer connected it was possible to follow the connected relay’s actions in the disturbance recorder where start and trip notifications could be found. It also made it possible to follow different kinds of phasor diagrams and measurement modes which were very useful when calculating trip values.

ABB REG670 was not that simple. The most time-consuming part was to configure the functions since the relay was not configured as required. The relay was connected to a computer with an Ethernet cable, which the configurations made in PCM600 were uploaded with. Uploading of operation settings was done in the same way but, unlike VAMP, there were more parameters, which allow more customized settings if needed.

The OmicronCMC test apparatus was also connected to the computer with an Ethernet cable. When tests were done with ABB’s relay, a switch was used to make it possible to stay connected both to the relay and the test equipment at the same time.

6.1.1 Inputs and outputs

When testing, the relays were connected to the test equipment in a certain way. As for the analog inputs for the relays, VAMP 210 was connected according to figure 14 and VAMP 265 was connected as shown in figure 17. ABB REG670 was connected according to a real life case, see figure 27. The digital inputs and outputs for all relays had the same function so it was most important to configure the relays so that each digital input and digital output had their specific task. Appendix 1 defines how the test equipment was connected from Omicron to the relays.

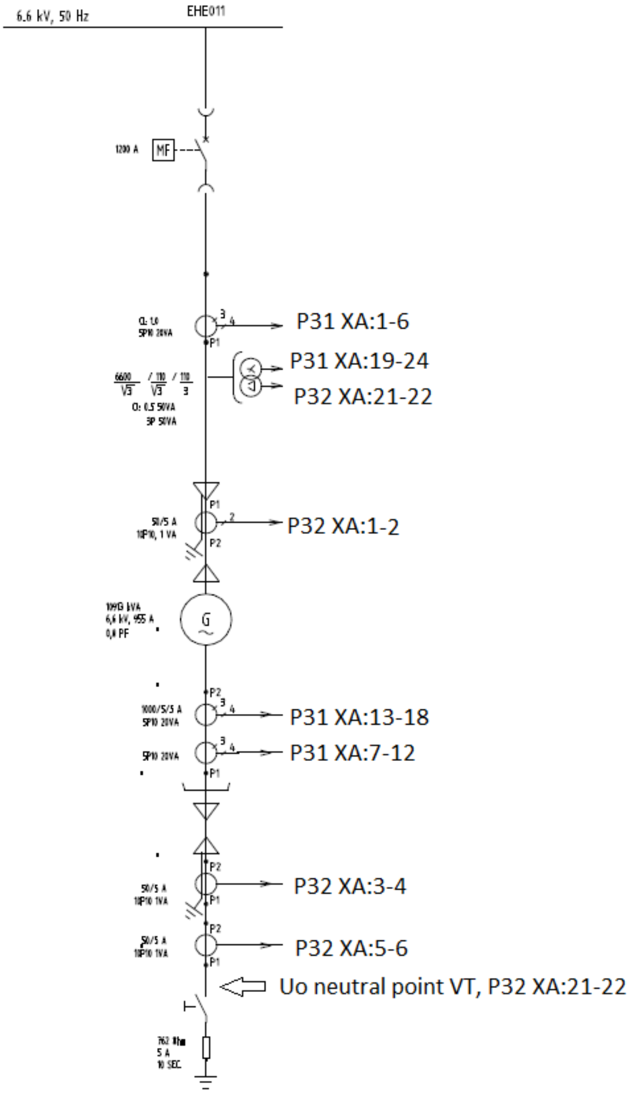


Figure 27. Connection between REG670 and respective transformers (Asea Brown Boveri, cut-out scheme from a drawing).

6.1.2 Block matrix

Since the test procedure was supposed to be able to run automatically as long as possible, it was also necessary to configure a blocking system. This was because when running e.g. an under-impedance test, high currents cause the under-impedance state but, if the over-current function is also active, the over-current function might start and trip instead of the under-impedance protection. This blocking system was configured so that when a certain output of Omicron’s CMC’s digital outputs was active during a certain test, the active output blocked the interfering functions that were not supposed to operate. This had to be configured in the relays’ PC software. VAMPSET had a menu called *Block matrix* where functions can be blocked when some of the four digital inputs in the relay are active. In PCM600 the configured digital signals were connected directly to the function block that was supposed to be blocked by a certain digital input. A matrix was done in Excel to make it easier to understand which of Omicron's outputs blocks which function in the relay. The block matrix can be found in appendix 2.

6.2 Testing of standard protective functions

This chapter will illustrate calculations for each function with base values, or nominal values, according to the standard parameter appendix 3. Equations for the functions' calculations can be found under the respective title in the theoretical part. Some test functions in Omicron Test Universe did not require any more calculations than a per unit value and a time reference from which the software program itself calculated inverse curves and definite time curves.

6.2.1 Pre-calculations

To make it as easy as possible, a module was created in XRIO where, according to the standard parameter setting sheet, the most essential information about the generator, CTs and VTs could be set. The parameters were the following:

Table 1. Nominal values.

Generator rating	12163 kVA
Voltage	11000 V
Frequency	50 Hz
Earth fault current (max)	5 A
Engine rating	9730 kW
Phase CT primary ampere	800 A (800/1)
PT primary voltage	11000 V (11000/110)
Cable CT primary ampere	50 A (50/1)

These values were then linked to equations which were saved as new parameters. The new parameters were set in another folder where they were calculated further. With e.g. information about active power and voltage, the nominal current can be calculated, according to equation 1, and then further processed to get the value of secondary nominal current which could be calculated according to equation 6. *Cosφ* was calculated according to equation 4.

$$cos\varphi = \frac{9730\ kW}{12163\ kVA} \approx 0.8$$

$$I_n = \frac{9730\ kW}{\sqrt{3} \times 11000\ V \times 0.8} \approx 638.4\ A$$

$$I_{nominal\ secondary} = 638.4\ A \times \frac{1\ A}{800\ A} \approx 0.798\ A$$

6.2.2 Over-current

The over-current was tested by inserting an over-current test module. In XRIO it was then possible to create equations which were linked to the test module.

The over-current test function automatically calculated the normal inverse curve and the definite time curve. The only thing to calculate was the per unit value for what was considered to be over-current, which was then linked to the over-current parameter folder in XRIO. This was done as follows:

$$1.12\ \times 638.4 = 715\ A \rightarrow \frac{715\ A}{800\ A} \approx 0.894\ p.u.$$

The time reference could be found in the parameter setting standard.

As for the definite time function, the current was calculated in the same way as in the previous stage but, instead of 1.12 times, the fault current is 2.5 times the nominal current and then it is calculated as a per unit value. The definite time function does not have a time constant but a trip time value which was 0.6 s.

6.2.3 Over-voltage

The over-voltage test function was implemented in a ramping module. The needed values were nominal secondary voltage, which was linked as start voltage in the test module, and secondary fault voltage for each stage, which was multiplied to reach a little above the fault voltage and linked as maximum voltage ramping.

The fault voltage on the secondary side could, for each stage, be calculated according to the parameter standard. The first stage was calculated as follows:

$$1.05 \times 11000\ V = 11550\ V \rightarrow 11550\ V \times \frac{110V}{11000\ V} = 115.5\ V\ phase - to - phase$$

$$\frac{115.5\ V}{\sqrt{3}} \approx 66.68\ V\ per\ phase$$

Since the injected voltages were expressed as a phase-to-neutral value, the fault voltage had to be divided with the square root of three. The same applied to the start voltage, the secondary nominal voltage, which was 110 volts, giving the result:

$$\frac{110\ V}{\sqrt{3}} \approx 63.51\ V\ per\ phase$$

The same calculations were used for the two other overvoltage stages but the overvoltage settings were 1.12 for *U*> and 1.4 for *U*>>, as seen in the standard.

6.2.4 Under-voltage

The under-voltage was tested exactly in the same way as the overvoltage, but the setting for the first stage was 0.95 and the setting for the second stage was 0.88. Hence the same calculations can be used. The ramping also started from nominal voltage but ramped, instead of upwards, downwards to reach and exceed the set under-voltage pick-up.

6.2.5 Reverse power

Reverse power was tested in a ramping module but, instead of ramping the voltage, the injected current was ramped and turned 180 degrees. The fault current could also be calculated from the given information in the setting standard. The following calculated values, from equation 1, were created in XRIO and linked to the test module:

Reverse power at -4% of Pn, 9730 kW = -389 kW

$$I_{reverse\ power} = \frac{-389\ kW}{\sqrt{3} \times 11000\ V \times 0.8} \approx 25.52\angle 180^{\circ}\ mA$$

The current was ramped in an interval from 0.8 times the reverse power current so that the current slightly exceeds the pick-up value of the reverse power current to obtain the relay’s pick-up operation and trip operation.

6.2.6 Under-excitation

The only difference between under-excitation and reverse power is 90 degrees, i.e. under-excitation is done in a way similar to the reverse power but the pick-up current is different and angled -90 degrees relative to the nominal angle. The fault value, -30 percent of the apparent power, is given in the setting standard. Thus the result is according to the following calculation:

$$Q <= -0.3 \times 12163\ kVA \approx -3649\ kVAr$$

Notable is that it is a question about when the *reactive power* is under -30 percent of the apparent power, and then we'll get an under-excitation state. Hence it can be calculated with equation 1. The current could be calculated, as mentioned, according to equation 1 in the same way as in reverse power:

$$I_{under-excitation} = \frac{-3649}{\sqrt{3} \times 11000\ V \times 0.8} \approx 239.40\angle -90°\ mA$$

The expression -90 degrees cannot be calculated in this way, but the user must be aware of the fact that under-excitation means that the phasor is angled downwards seen from a power-phasor diagram.

6.2.7 Current unbalance

Current unbalance was implemented in an over-current test module because there were several options of current injection including current unbalance. The needed implemented information was reference current, as in over-current, and a time constant when using the inverse characteristic. The definite time characteristic, which was used when the current unbalance exceeded the nominal current, required reference current and trip time.

VAMP 210 required its own characteristic based on equation 9. The tested REG670 did not have this particular protection since it was quite an old version. Instead it had a multipurpose function but it was not possible to make a characteristic in Omicron Control Center that would have matched the relay's characteristic. Instead a normal inverse curve was done for testing current unbalance with REG670 since newer versions have normal inverse as an option as the characteristic for unbalance current protection.

The reference current for the inverse time characteristic of VAMP was calculated as follows:

$$I_{ref} = 0.08 \times 638.4\ A = 51.072\ A \rightarrow \frac{51.072\ A}{800\ A} \approx 0.06384\ A$$

The rest of the values were given in the setting standard. The custom characteristic for VAMP was calculated as in the following example where the current is assumed to be four times the reference current:

$$t = \frac{20}{\left(\frac{4 \times 0.06384\,A}{0.798\,A}\right)^2 - 0.08^2} = 208.33\,s$$

This equation was done for several test points to get a reference characteristic curve. The reference curve for the REG670 was set as normal inverse, and the reference current and the settings from the setting standard were the only required information by the program to get a normal inverse characteristic defined.

The definite time reference current was set to 100%, i.e. when I_{ref} was 0.798. The trip time for the definite time characteristic could be calculated from equation 9, provided that I_2/I_{gn} is equal to one, e.g.:

$$t = \frac{20}{\left(\frac{0.798\,A}{0.798\,A}\right)^2 - 0.08^2} = 20.13\,s$$

6.2.8 Thermal overload

Thermal overload was also implemented with an over-current test module. For VAMP one module was made for testing the pick-up and another for testing the trip time. The thermal factor, which indicates in percent how much thermal overload there is, makes the relay pick up at 90 percent and trip happens at 100 percent. The thermal factor has to be restored manually after each test point since it follows a cooling characteristic which is a real life characteristic of how a generator is cooling down, and it is definitely not a quick process. To speed up the testing as well, the custom characteristic was calculated assuming that the thermal factor is set to 85 percent. This means that, instead of restoring the thermal factor to zero percent, the user can set it to 85 percent in VAMPSET, upload it to the relay and start the test. The custom characteristic was calculated with equations 11, 12 and 14 for the pick-up stage and equations 11, 13 and 14 for the trip time test. The ambient temperature factor k_θ is equal to one in both cases. The symbol *I* stands for the reference current and in this case the injected current is assumed to be four times the reference current.

$$I_{ref} = I = 1.06 \times 0.798 = 0.84588$$

$$a = 1.06 \times 1 \times 0.798 \times \sqrt{0.9} \approx 0.802472$$

$$I_p = \sqrt{0.85} \times 1 \times 0.798 \times 1.06 \approx 0.779863$$

$$t_{alarm} = 60 \times ln \times \frac{(4 \times 0.84588)^2 - 0.779863^2}{(4 \times 0.84588)^2 - 0.802472^2} \approx 0.198\, min \times 60\, s = 11.9\, s$$

According to this it takes the relay 11.9 seconds before the pick-up starts. This same equation applies to the trip time but the constant *a* is calculated in a different way since the trip action happens at 100 % overload.

$$a = 1.06 \times 1 \times 0.798 = 0.84588$$

$$t_{trip} = 60 \times ln \times \frac{(4 \times 0.84588)^2 - 0.779863^2}{(4 \times 0.84588)^2 - 0.84588^2} \approx 0.597\, min \times 60\, s = 35.8\, s$$

The trip time is 35.8 seconds for VAMP 210.

ABB REG670’s thermal overload function is tested with only one over-current module because its pick-up reacts when the current is exceeding the limit of 1.06 times the nominal current. The pick-up value is tested with a test function included in the test module. It has also got a digital input which restores the thermal factor to zero when receiving a binary signal to the reset input. Because of this, the equation used is calculated differently in relation to the two earlier equations. The thermal overload equation for the REG670 is calculated as follows:

$$a = 1.06 \times 1 \times 0.798 = 0.84588$$

$$I_p = \sqrt{0} \times 1 \times 0.798 \times 1.06 = 0$$

$$t_{trip} = 60 \times ln \times \frac{(4 \times 0.84588)^2 - 0^2}{(4 \times 0.84588)^2 - 0.84588^2} \approx 3.87\, min \times 60\, s = 232.3\, s$$

6.2.9 Over- and under-frequency

Over- and under-frequency was probably one of the easiest protective functions to test. The only things to calculate were the fault frequencies. The fault frequencies were then linked to a ramping test module. The ramping started from nominal frequency and increased the frequency, exceeding the fault limit a bit, to make sure the relay incepts the fault. The same thing was done for under-frequency. The fault values are seen in the setting standard and they are calculated as in the following examples which are for over-frequency and under-frequency:

$$f >_{alarm} = 1.02 \times 50\ Hz = 51\ Hz$$

$$f <_{alarm} = 0.98 \times 50\ Hz = 49\ Hz$$

6.2.10 Directional earth fault

Directional over-current, or directional earth fault, was tested in an over-current test module. Besides the phase currents that are injected in a reversed direction, a zero-sequence voltage is also injected to simulate the directional earth fault, i.e. to fulfill the criteria for directional earth fault there has to be a zero-sequence voltage as well.

According to the settings in the standard, the limit for directional earth-fault current for the secondary side can be calculated in the following way:

$$I_{ref} = 0.04 \times 50\ A = 2\ A \rightarrow 2\ A \times \frac{1\ A}{50\ A} = 40\ mA$$

The CT is a cable CT with the scaling 50/1 A as shown in table 1.

The characteristic is a definite time curve and the trip time is, as seen in the standard, 0.3 s. The zero-sequence voltage is linked to the test module where a setting for zero sequence-voltage can be found. The zero-sequence voltage is calculated from the secondary VT value.

A ramping module was also implemented to test the zero-sequence function, since the directional earth-fault function has a built-in zero-sequence protection. The ramping module is ramping the zero-sequence voltage to find the pick-up value while an earth-fault current is injected at the same time.

6.2.11 Earth fault

The over-current test module served as the test module for earth fault as well since there were options allowing the testing of regular earth faults. As for the over-current protective function, there were two stages but in this case both stages operated according to the definite time characteristic with trip times of one second for the lower stage and 0.6 seconds for the higher stage. The setting seen in the standard is calculated from the cable CT. The reference current was implemented in the module for both stages and the software program did the rest of the work. The calculation looked like this:

$$I_{ref} = 0.04 \times 50\ A = 2\ A \rightarrow 2\ A \times \frac{1\ A}{50\ A} = 40\ mA$$

6.2.12 Zero-sequence voltage

Zero-sequence voltage was calculated as over- and under-voltage but the zero-sequence voltage was injected from the CMC’s fourth voltage output. The voltage was ramped in the intervals that caused both pick-up and drop-off. The setting standard is slightly misleading since the zero-sequence voltage is calculated from a case where the zero sequence is calculated from the U_0 VT transformer as phase-to-neutral. In this case the relay is set to calculate the zero sequence between two phases and a separate U_0 transformer which makes the voltage relative to it. The secondary voltage is 110 V, giving the equation:

$$U_0 >= 0.1 \times 110\ V = 11\ V$$

The same thing applies to the higher stage where the fault voltage is 20 % of the nominal secondary voltage.

6.2.13 Differential current

The differential current protection could be tested with separate differential test modules. These are quite complex but do not require any calculations at all. The only things to implement in the test modules are the settings, which are found in the setting standard. However, the equations for this protective function can be found in chapter 3.1.12. These are equations 15, 16, 17 and 18, which provide a clue for how the differential current protection works and processes measured data.

The used test modules were, among others, the differential pick-up characteristic, the differential trip time characteristic and the second harmonic blocking test. As mentioned in the theoretical part, some relays have a fifth harmonic blocking function as well, but it was only tested with the REG670 since the VAMP 265 was of an older version which did not have the fifth harmonic blocking function.

6.3 Testing of extended protective functions

The test functions in this chapter were implemented in their own folder named *Extended settings*. These are, as mentioned in the theory, only implemented in the relays if requested by the customer.

6.3.1 Over-excitation

Over-excitation, *Volts/Hertz*, was tested with a ramping module. The nominal voltage divided by the nominal frequency gives a nominal *V/Hz* value. Since the setting standard did not have this implemented, a random value was chosen as the setting. The setting was chosen to be 105 % of the nominal and the calculations were done as follows, according to equations 19 and 20:

$$U/f_{nominal} = \frac{11000\ V}{50\ Hz} = 220\ V/Hz$$

$$U/f_{fault} = 220\frac{V}{Hz} \times 1.05 = 231\ V/Hz$$

In other expressions the fault state happened when the voltage was at a certain level. This level was calculated for the secondary side for each phase by the following calculations:

$$U_{fault} = 231\frac{V}{Hz} \times 50\ Hz = 11550\ V$$

$$U_{fault,secondary} = 11550\ V \times \frac{110\ V}{11000\ V} = 115.5\ V \rightarrow \frac{115.5\ V}{\sqrt{3}} \approx 66.68\ V\ per\ phase$$

6.3.2 Under-impedance

The testing of under-impedance was done with a test module called advance distance. The nominal impedance, either primary or secondary, has to be calculated to obtain the characteristic, which was a circle-shaped area. The test has two steps, one called shot test where test points are set randomly inside and outside the characteristic to find out if the characteristic in Omicron matches the relay's characteristic. The second test is called search test where vectors are placed randomly over the limits of the characteristic to find out where the relay's characteristic goes.

The calculations for this test, the calculation of nominal impedance at the primary side and the impedance limit, are calculated according to equation 21 with the following result:

$$Z_{nominal\ primary} = \frac{11000\ V}{\sqrt{3} \times 638.4\ A} \approx 9.95\ \Omega$$

The operation limit is, as seen in the setting standard, 0.4 times the nominal impedance, giving following result:

$$Z_{trip} = 0.4 \times 9.95\ \Omega \approx 3.98\ \Omega$$

6.3.3 Loss of excitation

Loss of excitation was also done with an advanced distance test module. The characteristic was in this case also a circle but the radius was, according to the standard, 1.67 times the nominal impedance. The characteristic also has a resistive and reactive offset which can be calculated according to the offset formulas in chapter 3.2.3. However, the offsets for this case were given in the setting standard and hence they do not need to be calculated.

The nominal impedance can be calculated as in the under-impedance or as an option according to equation 23:

$$Z_{nominal\ primary} = \frac{11000^2\ V}{12163000\ VA} \approx 9.948\ \Omega$$

The fault impedance was calculated with the given information in the standard:

$$Z_{trip} = 1.67 \times 9.948\ \Omega \approx 16.61\ \Omega$$

The resistive offset is zero according to the standard and the reactive offset is -1.67 times nominal impedance. The 0.3 x Z_n setting in the standard is not essential in this case, it is probably some sort of miscalculation.

When the loss of the excitation protective function in REG670 was tested, the characteristic in the relay did not really match the one in Omicron. There was some kind of resistive offset even if it was set to zero. The reason why it did not work properly was never analyzed but low secondary currents made the current angles inaccurate, which could be one explanation.

6.3.4 100% stator earth fault

This test is difficult to perform since, as explained in the theoretical part, the third harmonic differs a lot from generator to generator. The pick-up setting was randomly set to 50 percent when testing VAMP, since no pick-up setting was mentioned in the standard. The pick-up setting was probably in the upper margin because the usual setting can be from about a few percent up to about 10 percent.

The third harmonic tone has got a frequency of three times the nominal, in this case 150 *Hz,* since the nominal frequency was 50 *Hz*. When this function was tested with VAMP, a zero-sequence voltage with the nominal magnitude of 110 volts with the frequency 150 *Hz* was injected into the U_0 input in the relay. The voltage was ramped downwards and when the 150 *Hz* voltage was less than 50 percent the relay picked up the fault.

Testing of the REG670 was far more complicated. A constant voltage with 150 *Hz* had to be injected as U_{3T}, which was considered the voltage at the zero-sequence voltage transformer at the neutral point. The U_{3T} was set to a random value because, as mentioned in the theory, the 100 percent earth fault depends on the generator, powers etc. The zero-sequence voltage was set at 15 volts and the beta setting was set at 3. According to these values and equation 24, the U_{3N}'s pick-up voltage could be calculated with an equation of the second degree. In equation 24 it can be seen that sine for 180 degrees is zero and cosine for 180 degrees is -1 and therefore the equation can be written as follows:

$U_{3N} = x$
$U_{3T} = 15$
Beta = 3

$$3 \times x = \sqrt{(x-15)^2} \rightarrow (3x)^2 = (x-15)^2$$

This gives a second degree equation:

$$8x^2 + 30x - 225 = 0$$

$$x = \frac{-30 + \sqrt{30^2 - 4 \times 8 \times (-225)}}{2 \times 8} = 3.75\ V$$

In this case it is not necessary to use the second value from this equation since it is a negative value.

The U_{3N} injected voltage was ramped from 15 volts to zero volts and the relay started operating at 3.75 volts.

6.3.5 Rate of change of frequency (ROCOF)

Rate of change of frequency was tested in a pulse ramping module. The pulses increased the rate of frequency changes per second in a certain interval and when the pick-up limit was achieved the relay started operating. The setting standard did not have a particular setting given so the setting 1 *Hz/s* was chosen randomly. Usually the frequency is not allowed to change much at all so it was considered an approved value.

This test was not more remarkable than this. Luckily the test values and settings are possible to change so the most important thing was achieved: to make sure the test works.

6.4 Test report

The described and calculated functions were tested with the relays VAMP 210 and VAMP 265 to obtain a test report which this test results in. The report, appendix 5, contains exactly the same values as calculated with and shows the nominal pick-up values, drop-off values and operation-time sequences and the actual pick-up, drop-off and operation time including deviations. The goal of the report is to clarify if the relay tested actually works within the manufacturer’s given deviations and to detect if the relays have got some malfunctions.

7 Result

As mentioned in the introduction, the standard test procedure was supposed to work automatically as long as possible. The objective was achieved but there are still situations, e.g. differential protection, where the connections from the Omicron CMC had to be re-connected in other terminals in the relay. With more analog outputs from the CMC hardware, it could be possible to connect everything at once to avoid having to reconnect the relay.

There are also situations where settings have to be changed in the XRIO file, e.g. if the configuration settings for the relay do not follow the setting standard. This is, however, easily done in the parameter folder in the test file. Changes might also be needed depending on if the earth points are installed, as they are expressed in the Omicron software program, to the protected object or from the protected object.

Even if the test is done in a way that should make it easy and comfortable to use, there are, as mentioned, situations where changes are needed. This requires the user to be familiar with the relay, its configuration software and the Omicron software program, not only because of possible needed changes but also because of the function blocking procedure which is done in the relay and also when connecting the relay to the CMC. It is not necessary to use the blocking system but, if the blocking system is used, the user must test and block each function manually or alternatively run the relay in a so-called test mode.

The outcome of this thesis work was two Omicron Control Center files, one for the testing of VAMP relays and one for the testing of ABB REG relays, which are configured to test the mentioned protective functions. All functions do not have to be tested, but the user can choose the tests that are essential to test. A user manual was also made to clarify how the testing has been done and what things are important to take into consideration when the testing is about to begin. The performed tests result in a test report in which it is possible to see the used magnitudes, the pick-up, drop-off and trip times and if these are inside the set tolerances. The total test time takes about one and a half hours, excluding the pre-configurations such as blocking and connecting the CMC to the relay.

Theoretically this test should work for any relay but differences in the measuring of magnitudes might be a main reason if problems occur. This test can still be useful, even if it is not used as it was intended to be used, since the test modules can be modified, linked values can be unlinked and replaced with a chosen value and be used “manually” by testing one protective function at the time. This saves time because it is a time-consuming procedure to configure test modules for a whole test.

The test report is, as mentioned, an important part since it is the evaluation of the relay and its ability to operate safely and protect the generator from situations that might cause harm to it. The report that was obtained showed that the relays were working as intended.

8 Discussion

After I had had the subject for my thesis, my main approach was to study the user manuals for Omicron and VAMP and install the software programs. When I had gotten familiar with the manuals I started configuring the test program in Omicron Control Center. It was quite difficult to try to implement the test modules since Omicron was totally unfamiliar to me. The test equipment, CMC, also had to be booked and it took a while before I got the equipment, which made the implementation difficult since I had no idea of how the testing worked and if the configurations in the test modules were correctly implemented.

After getting the test equipment and after having tested it for the first time, everything became much clearer since I got an overview of how the software program worked, not only the Omicron software program but the relays' software programs as well. The testing and implementation progressed, even if it was sometimes difficult to find the correct answers to some calculations.

After the testing had been completed with VAMP, I considered modifying the test file so it would work with the REG670. I had to make two different test files since the REG670 had a few protective functions that measured and calculated values differently from VAMP, but this did not become obvious immediately. The test template was still the same as in the test file for VAMP. A future modification suggestion for the REG670 test file is to make a new XRIO file and configure it according to the XRIO files that can be exported from ABB's relays, which contain all settings from the relay. This will not require the user to change anything in the XRIO file when the testing is about to be done. The reason why I did not do this was because I tried to modify the program so that I would only get one test file, but when I realized that it is not possible, there was not enough time to make this modification since it takes a lot of time to link values and create formulas in XRIO.

When all the implementing was done, the last task was to make a user manual for how to use the implemented test. It is hard to say if the manual is well written since when writing I knew how the implemented test worked and some important information may not be mentioned since it was obvious to me.

Generally this thesis work has been quite a challenge but still very educating. The big challenge was to learn how the different software programs worked and to familiarize oneself with the hardware in a relatively short time. The most problematic part was probably when I started configuring the ABB REG670. I had no experience of PCM600 whatsoever, but luckily my mentor could educate me in a few days so I understood the most essential things about how to configure the relay.

Calculations for the protective functions have also been a challenge, but with help from my mentor and a lot of research into my old school notes, I have tackled the problem quite well.

The only thing that cannot be answered right now is how useful the test procedure is, if it is useful at all. From my point of view it should be useful, even if a completely different relay is used than the ones I used in the tests, since the basics are implemented. However, the factor that determines whether the test procedure is successful or not is, in my opinion, the user’s familiarity with the software programs and the hardware since they form the basics of this procedure.

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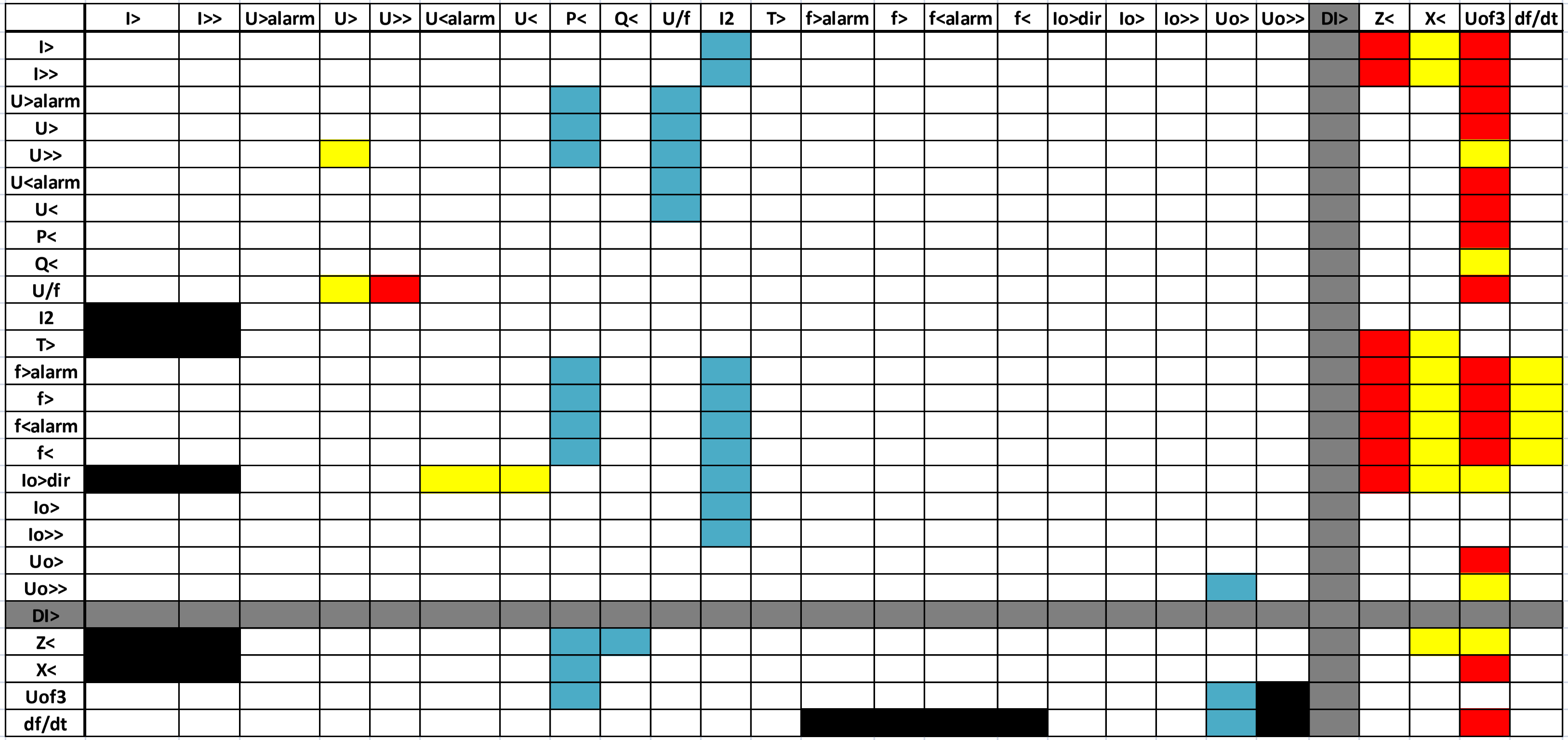
Appendix 1

OMICRON		VAMP 210	VAMP265	ABB REG670	REG670 Diff & Ufo3
U L1	Voltage phase 1	X1:11	■	P31 XA:19	P32 XA:21
U L2	Voltage phase 2	X1:12, X1:13	■	P31 XA:21	■
U L3	Voltage phase 3	X1:14	■	P31 XA:23	■
U N	Neutral point	■	■	P31 XA:20,22,24	P32 XA:22
I L1 (A)	Current channel A phase 1	X1:2	X1:1	P31 XA:7	P31 XA:1
I L2 (A)	Current channel A phase 2	X1:4	X1:3	P31 XA:9	P31 XA:3
I L3 (A)	Current channel A phase 3	X1:6	X1:5	P31 XA:11	P31 XA:5
I N (A)	Current neutral point	X1:1, X1:3, X1:5	X1:2,X1:4,X1:6	P31 XA:8,10,12	P31 XA:2,4,6
I L1 (B)	Current channel B phase 1	X1:8	X1:11	P32 XA:1	P31 XA:13
I L2 (B)	Current channel B phase 2	X1:10	X1:13	P32 XA:3	P31 XA:15
I L3 (B)	Current channel B phase 3	■	X1:15	P32 XA:5	P31 XA:17
I N (B)	Current neutral point	X1:7, X1:9	X1:12, X1:14, X1:16	P32 XA:2,4,6	P31 XA:14,16,18
Uo L	Zero sequence voltage output	X1:18	■	P32 XA: 23	P32 XA: 23
Uo N	Zero sequence neutral point	X1:17	■	P32 XA: 24	P32 XA: 24
DO					
1+	DC supply, Breaker closed	X3:1, X3:2	■	P3 XA:1	P3 XA:1
1-	DI 1	X3:3	■	P3 XA:7	P3 XA:7
2+			■		
2-	DI 2	X3:4	■	P3 XA:9	P3 XA:9
3+			■		
3-	DI 3	X3:5	■	P3 XA:11	P3 XA:11
4+			■		
4-	DI 4	X3:6	■	P3 XA:13	P3 XA:13
DI					
1+	TRIP +	X2:10	X2:10	P4 XA:1	P4 XA:1
1-	TRIP -	X2:11	X2:11	P4 XA:2	P4 XA:2
2+	START +	X2:7	■	P4 XA:4	P4 XA:4
2-	START -	X2:8	■	P4 XA:5	P4 XA:5
3+	ALARM +	X2:5	■	P4 XA:10	■
3-	ALARM -	X2:6	■	P4 XA:8	■
4+	ALARM START +	X2:13	■	P4 XA:7	■
4-	ALARM START -	X2:15	■	P4 XA:11	■

Appendix 2

BLOCKED FUNCTIONS

RUNNING TEST FUNCTION



	I>	I>>	U>alarm	U>	U>>	U<alarm	U<	P<	Q<	U/f	I2	T>	f>alarm	f>	f<alarm	f<	Io>dir	Io>	Io>>	Uo>	Uo>>	DI>	Z<	X<	Uof3	df/dt
I>											🟦											▨	🟥	🟨	🟥	
I>>											🟦											▨	🟥	🟨	🟥	
U>alarm								🟦		🟦												▨			🟥	
U>								🟦		🟦												▨			🟥	
U>>				🟨				🟦		🟦												▨			🟨	
U<alarm										🟦												▨			🟥	
U<										🟦												▨			🟥	
P<																						▨			🟥	
Q<																						▨			🟨	
U/f				🟨	🟥																	▨			🟥	
I2	⬛	⬛																				▨				
T>	⬛	⬛																				▨	🟥	🟨		
f>alarm								🟦			🟦											▨	🟥	🟨	🟥	🟨
f>								🟦			🟦											▨	🟥	🟨	🟥	🟨
f<alarm								🟦			🟦											▨	🟥	🟨	🟥	🟨
f<								🟦			🟦											▨	🟥	🟨	🟥	🟨
Io>dir	⬛	⬛				🟨	🟨				🟦											▨	🟥	🟨	🟨	
Io>											🟦											▨				
Io>>											🟦											▨				
Uo>																						▨			🟥	
Uo>>																				🟦		▨			🟨	
DI>	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Z<	⬛	⬛						🟦	🟦													▨		🟨	🟨	
X<	⬛	⬛						🟦														▨			🟥	
Uof3								🟦												🟦	⬛	▨				
df/dt													⬛	⬛	⬛	⬛				🟦	⬛	▨			🟥	

	OMICRON	VAMP	REG
🟦	BO1	DI2	BINBL 1
🟨	BO2	DI3	BINBL 2
🟥	BO3	DI4	BINBL 3
⬛	BO4	DI5	BINBL 4

Thermal factor reset with REG670 is done with Omicron's BO1

Appendix 3

1) GENERATOR RELAY SETTINGS

Generator rating	**12163 kVA**	**Engine rating**	**9730 kW**
Voltage	**11000 V**	**Phase CT primary Amperes**	**800 A**
Frequency	**50 Hz**	**PT primary voltage**	**11000 V**
Earth fault current	**5 A**	**Cable CT primary Ampere**	**50 A**

VAMP 210

ANSI	*Symbol*	*Setting*	*Primary / p.u values*			*Time setting*	
51	I>	1,12 x In	715 A	0,894 p.u	k	0,2	
50	I>>	2,5 x In	1596 A	1,995 p.u	t	0,6 s	
	U>	1,05 x Un	11550 V	1,05 p.u	t	30 s	Alarm
59	U>	1,12 x Un	12320 V	1,12 p.u	t	4,0 s	
	U>>	1,4 x Un	15400 V	1,4 p.u	t	2,0 s	
	U<	0,95 x Un	10450 V	0,95 p.u	t	30 s	Alarm
27	U<	0,88 x Un	9680 V	0,88 p.u	t	20 s	
32	P<	-4% x Pn	-389 kW	-0,02 p.u	t	2,0 s	
40	Q1<	-30% x Sn	-3649 kVAr	-0,24 p.u	t	2,0 s	
	Q2<	-30% x Sn	-3649 kVAr	-0,24 p.u			
46	I_2(k1)		20				
	I_2(k2)		0,08				
49	Θ(k)	1,06 x In	677 A	0,846 p.u			
	Θ(τ)		60 min				
81H	f>	1,02 x fn	51 Hz		t	30 s	Alarm
81H	f>	1,1 x fn	55 Hz		t	4 s	
81L	f<	0,98 x fn	49 Hz		t	30 s	Alarm
81L	f<	0,95 x fn	47,5 Hz		t	4 s	
67N/	Io>	4 %	2 A	0,04 p.u	t	0,3 s	
	Uo>	10 %					
51N	Io>	4 %	2 A	0,04 p.u	t	1 s	
50N	Io>>	6 %	3 A	0,06 p.u	t	0,6 s	
59N	Uo>	10 %	635 V	0,1 p.u	t	2 s	
	Uo>>	20 %	1270 V	0,2 p.u	t	1,2 s	

VAMP 265

87	DI>		25 %				
	Slope1		25 %				
	Ibias		3				
	Slope2		100 %				
	$I_{d>2.\text{harm block}}$		15 %	(on)			
	DI>>		5				

The following settings are not configured as standard and should be used only in case of special customer request.

24	U_f>		105 %	V/Hz	t	2 s	
21	Z<	1/2.5	3,98 Ohm	0,4	t	0,8 s	
40	X<	-0.30xSn	0,3 x Zn		t	2 s	
	Xr		1,67 x Zn				
	Ros		0 x Zn				
	Xos		-1,67 x Zn				
64/27	Uo			V	t	0,5 min	Alarm
81R	df/dt			Hz/s	t	0,15 s	

Appendix 4

Omicron Control Center report, testing of relay VAMP 210 (T>, I> and U>)

Hardware Configuration

Test Equipment

Type	Serial Number
CMC256-6	HD257Q

Hardware Check

Performed At	Result	Details
12.3.2014 16:04:58	Passed	

Test Object - Device Settings

Substation/Bay:

Substation:		Substation address:	
Bay:		Bay address:	

Device:

Name/description:	SETTINGS	Manufacturer:	Schneider-Electrics
Device type:	GenProtRelay	Device address:	
Serial/model number:			
Additional info 1:			
Additional info 2:			

QuickCMC

Test Module

Name:	OMICRON QuickCMC	Version:	3.00
Test Start:	12-maalis-2014 13:30:32	Test End:	
User Name:		Manager:	
Company:			

Test Results

Summary

0 tests passed, 0 tests failed, 0 tests not assessed

No results available!

T> Pick up test:

Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		
CurrentTolRel:	5,00 %		
Directional:	No		

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	Thermal Overload Pick-Up	Thermal Overload	0,85 Iref	1,00	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:40:09	Test End:	12-maalis-2014 13:41:55
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference:	Fault inception
Load current:	0,00 A
Load angle:	0,00 °
Prefault time:	0,10 s
Abs. max time:	240,00 s
Post fault time:	0,50 s
Rel. max time:	100,00 %
Enable voltage output:	No
Fault voltage LN (for all but two phase faults):	30,00 V
Fault voltage LL (for two phase faults):	51,96 V
Decaying DC active:	No
Time constant:	0,05 s
CB char min time:	0,05 s
Thermal reset active:	Yes
Thermal reset method:	Manual
Thermal reset message:	Please set the thermal memory to 85 % and upload to the relay. Continue the test immediately to avoid the termal memory to decrease below set value.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L1-L2-L3	Thermal Overload Pick-Up	3,000	2,54 A	n/a	21,73 s	18,64 s	25,40 s
L1-L2-L3	Thermal Overload Pick-Up	3,500	2,96 A	n/a	15,74 s	13,50 s	18,40 s
L1-L2-L3	Thermal Overload Pick-Up	4,260	3,60 A	n/a	10,43 s	8,948 s	12,19 s

Binary Outputs:

Name	State
Bin. Out 1	0
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	1

Binary Inputs:

Trigger Logic: And

Name	Trigger State
Start	1
Trip	X

Shot Test Results:

Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L1-L2-L3	Thermal Overload Pick-Up	3,000	2,54 A	n/a	21,73 s	22,08 s	No	Passed
L1-L2-L3	Thermal Overload Pick-Up	3,500	2,96 A	n/a	15,74 s	15,30 s	No	Passed
L1-L2-L3	Thermal Overload Pick-Up	4,260	3,60 A	n/a	10,43 s	10,63 s	No	Passed

State:

3 out of 3 points tested.
3 points passed.
0 points failed.

General Assessment: Test passed!

T>:
Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		
CurrentTolRel:	5,00 %		
Directional:	No		

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	Thermal Overload	Thermal Overload	0,85 Iref	1,00	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:43:49	Test End:	12-maalis-2014 13:46:53
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference:	Fault inception
Load current:	0,00 A
Load angle:	0,00 °
Prefault time:	0,10 s
Abs. max time:	240,00 s
Post fault time:	0,50 s
Rel. max time:	100,00 %
Enable voltage output:	No
Fault voltage LN (for all but two phase faults):	30,00 V
Fault voltage LL (for two phase faults):	51,96 V
Decaying DC active:	No
Time constant:	0,05 s
CB char min time:	0,05 s
Thermal reset active:	Yes
Thermal reset method:	Manual
Thermal reset message:	Please set the thermal memory to 85 % and upload to the relay. Continue the test immediately to avoid the termal memory to decrease below set value.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L1-L2-L3	Thermal Overload	3,000	2,54 A	n/a	65,50 s	56,17 s	76,59 s
L1-L2-L3	Thermal Overload	3,500	2,96 A	n/a	47,40 s	40,65 s	55,43 s
L1-L2-L3	Thermal Overload	4,260	3,60 A	n/a	31,39 s	26,92 s	36,70 s

Binary Outputs:

Name	State
Bin. Out 1	0
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	1

Binary Inputs:

Trigger Logic: And

Name	Trigger State
Start	1
Trip	0
Alarm	X
Alarm start	X

Shot Test Results:

Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L1-L2-L3	Thermal Overload	3,000	2,54 A	n/a	65,50 s	67,23 s	No	Passed
L1-L2-L3	Thermal Overload	3,500	2,96 A	n/a	47,40 s	47,95 s	No	Passed
L1-L2-L3	Thermal Overload	4,260	3,60 A	n/a	31,39 s	31,52 s	No	Passed

State:

3 out of 3 points tested.
3 points passed.
0 points failed.

General Assessment: Test passed!

Pause Module

Instruction Text:
Set temperature rise to 0% before continuing with overcurrent test

User Input:

Test State: Continue

Overcurrent L1-E:
Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		
CurrentTolRel:	2,00 %		
Directional:	No		

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	I> Overcurrent	IEC Normal Inverse	0,89 Iref	0,20	0,95	Non Directional
Yes	I>> Over overcurrent	IEC Definite Time	1,99 Iref	0,60 s	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:47:39	Test End:	12-maalis-2014 13:48:09
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference:	Fault inception
Load current:	0,00 A
Load angle:	0,00 °
Prefault time:	0,10 s
Abs. max time:	240,00 s
Post fault time:	0,50 s
Rel. max time:	100,00 %
Enable voltage output:	No
Fault voltage LN (for all but two phase faults):	30,00 V
Fault voltage LL (for two phase faults):	51,96 V
Decaying DC active:	No
Time constant:	0,05 s
CB char min time:	0,05 s
Thermal reset active:	No
Thermal reset method:	Manual
Thermal reset message:	Please reset the Thermal Memory of the device under test before continuing.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L1-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	5,823 s	10,91 s
L1-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	3,527 s	4,957 s
L1-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,200 s	2,719 s

L1-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	560,0 ms	1,876 s
L1-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	560,0 ms	640,0 ms
L1-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	560,0 ms	640,0 ms

Binary Outputs:

Name	State
Bin. Out 1	1
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	0

Binary Inputs:

Trigger Logic:	And

Name	Trigger State
Start	1
Trip	0
Alarm	X

Pick-up / Drop-off Test:

Type	Angle	Resolution	I Pick-up			Reset Ratio
			nom	min	max	nom
L1-E	n/a	0,02 s	0,89 A	0,84 A	0,94 A	0,95

Shot Test Results:

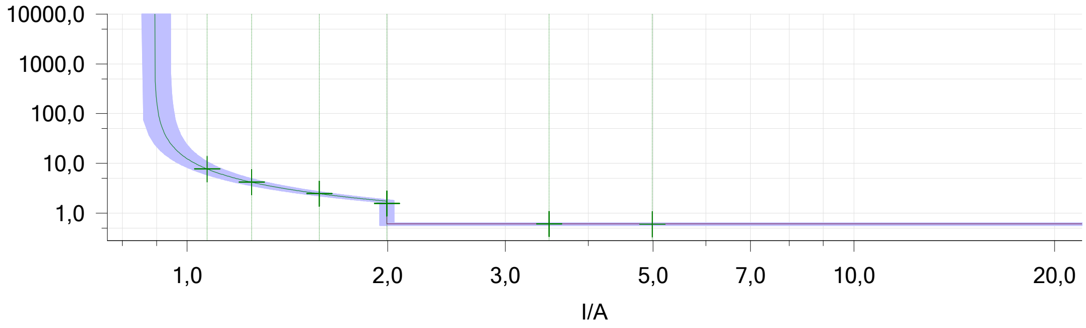
Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L1-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	7,726 s	No	Passed
L1-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	4,174 s	No	Passed
L1-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,444 s	No	Passed
L1-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	1,567 s	No	Passed
L1-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	603,9 ms	No	Passed
L1-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	596,8 ms	No	Passed

Pick-up / Drop-off Test Results:

Type	Angle	I Pick-up		I Drop-off	Reset Ratio			Result
		nom	act	act	nom	act	Error	
L1-E	n/a	0,89 A	0,91 A	0,85 A	0,95	0,94	-1,11 %	Passed

Charts for Fault Types:

Type	Angle	
L1-E	n/a	



State:

6 out of 7 points tested.

6 points passed.

0 points failed.

General Assessment: Test passed!

Overcurrent L2-E:

Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		

CurrentTolRel: 2,00 %
Directional: No

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	I> Overcurrent	IEC Normal Inverse	0,89 Iref	0,20	0,95	Non Directional
Yes	I>> Over overcurrent	IEC Definite Time	1,99 Iref	0,60 s	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:48:23	Test End:	12-maalis-2014 13:48:54
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference:	Fault inception
Load current:	0,00 A
Load angle:	0,00 °
Prefault time:	0,10 s
Abs. max time:	240,00 s
Post fault time:	0,50 s
Rel. max time:	100,00 %
Enable voltage output:	No
Fault voltage LN (for all but two phase faults):	30,00 V
Fault voltage LL (for two phase faults):	51,96 V
Decaying DC active:	No
Time constant:	0,05 s
CB char min time:	0,05 s
Thermal reset active:	No
Thermal reset method:	Manual
Thermal reset message:	Please reset the Thermal Memory of the device under test before continuing.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L2-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	5,823 s	10,91 s
L2-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	3,527 s	4,957 s
L2-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,200 s	2,719 s
L2-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	560,0 ms	1,876 s
L2-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	560,0 ms	640,0 ms
L2-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	560,0 ms	640,0 ms

Binary Outputs:

Name	State
Bin. Out 1	1
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	0

Binary Inputs:

Trigger Logic: And

Name	Trigger State
Start	1
Trip	0
Alarm	X

Pick-up / Drop-off Test:

Type	Angle	Resolution	I Pick-up			Reset Ratio
			nom	min	max	nom
L2-E	n/a	0,02 s	0,89 A	0,84 A	0,94 A	0,95

Shot Test Results:

Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L2-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	7,697 s	No	Passed
L2-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	4,152 s	No	Passed

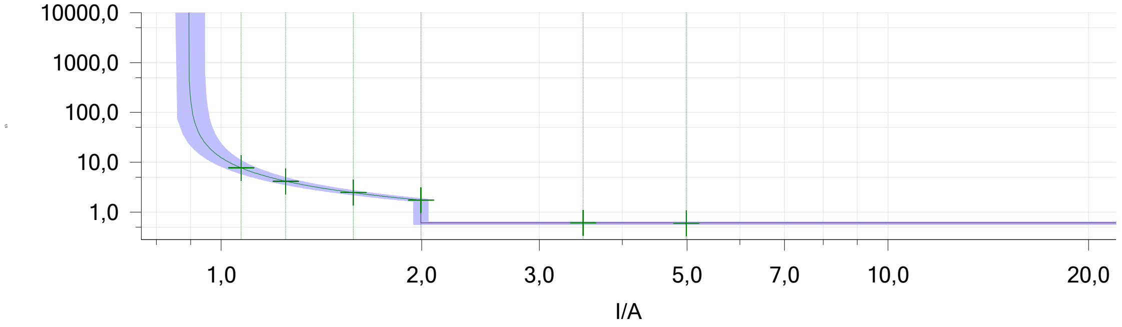
L2-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,460 s	No	Passed
L2-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	1,732 s	No	Passed
L2-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	605,1 ms	No	Passed
L2-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	599,3 ms	No	Passed

Pick-up / Drop-off Test Results:

Type	Angle	I Pick-up		I Drop-off	Reset Ratio			Result
		nom	act	act	nom	act	Error	
L2-E	n/a	0,89 A	0,91 A	0,85 A	0,95	0,94	-1,11 %	Passed

Charts for Fault Types:

Type	Angle	
L2-E	n/a	



State:

7 out of 7 points tested.
7 points passed.
0 points failed.

General Assessment: Test passed!

Overcurrent L3-E:
Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		
CurrentTolRel:	2,00 %		
Directional:	No		

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	I> Overcurrent	IEC Normal Inverse	0,89 Iref	0,20	0,95	Non Directional
Yes	I>> Over overcurrent	IEC Definite Time	1,99 Iref	0,60 s	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:49:11	Test End:	12-maalis-2014 13:49:40
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference: Fault inception

Load current: 0,00 A
Load angle: 0,00 °
Prefault time: 0,10 s
Abs. max time: 240,00 s
Post fault time: 0,50 s
Rel. max time: 100,00 %
Enable voltage output: No
Fault voltage LN (for all but two phase faults): 30,00 V
Fault voltage LL (for two phase faults): 51,96 V
Decaying DC active: No
Time constant: 0,05 s
CB char min time: 0,05 s
Thermal reset active: No
Thermal reset method: Manual
Thermal reset message: Please reset the Thermal Memory of the device under test before continuing.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L3-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	5,823 s	10,91 s
L3-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	3,527 s	4,957 s
L3-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,200 s	2,719 s
L3-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	560,0 ms	1,876 s
L3-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	560,0 ms	640,0 ms
L3-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	560,0 ms	640,0 ms

Binary Outputs:

Name	State
Bin. Out 1	1
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	0

Binary Inputs:

Trigger Logic: And

Name	Trigger State
Start	1
Trip	0
Alarm	X

Pick-up / Drop-off Test:

Type	Angle	Resolution	I Pick-up			Reset Ratio
			nom	min	max	nom
L3-E	n/a	0,02 s	0,89 A	0,84 A	0,94 A	0,95

Shot Test Results:

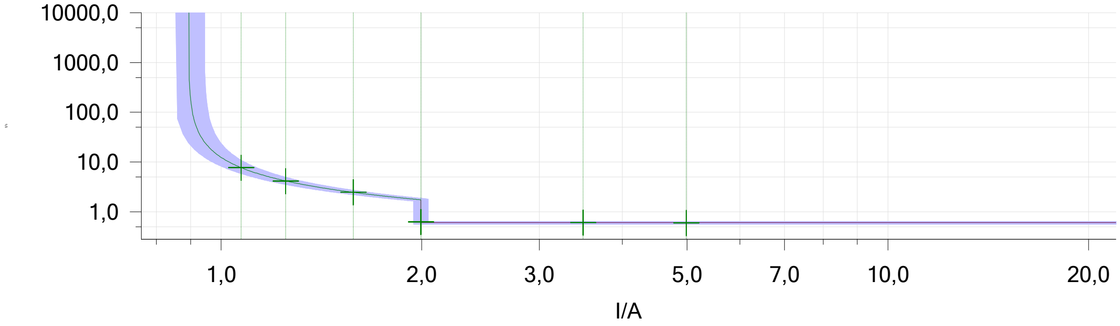
Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L3-E	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	7,673 s	No	Passed
L3-E	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	4,151 s	No	Passed
L3-E	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,451 s	No	Passed
L3-E	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	622,4 ms	No	Passed
L3-E	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	603,0 ms	No	Passed
L3-E	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	596,8 ms	No	Passed

Pick-up / Drop-off Test Results:

Type	Angle	I Pick-up		I Drop-off	Reset Ratio			Result
		nom	act	act	nom	act	Error	
L3-E	n/a	0,89 A	0,91 A	0,85 A	0,95	0,94	-1,11 %	Passed

Charts for Fault Types:

Type	Angle	
L3-E	n/a	



State:

7 out of 7 points tested.
7 points passed.
0 points failed.

General Assessment: Test passed!

Overcurrent L1-L2-L3:
Test Object - Overcurrent Parameters

General - Values:

TimeTolAbs:	0,04 s	VT connection:	At protected object
TimeTolRel:	5,00 %	CT starpoint connection:	To protected object
CurrentTolAbs:	0,05 Iref		
CurrentTolRel:	2,00 %		
Directional:	No		

Elements - Phase:

Active	Name	Tripping characteristic	I Pick-up	Time	Reset Ratio	Direction
Yes	I> Overcurrent	IEC Normal Inverse	0,89 Iref	0,20	0,95	Non Directional
Yes	I>> Over overcurrent	IEC Definite Time	1,99 Iref	0,60 s	0,95	Non Directional

Test Module

Name:	OMICRON Overcurrent	Version:	3.00
Test Start:	12-maalis-2014 13:49:55	Test End:	12-maalis-2014 13:50:24
User Name:		Manager:	
Company:			

Test Settings:

Fault Model:

Time reference:	Fault inception
Load current:	0,00 A
Load angle:	0,00 °
Prefault time:	0,10 s
Abs. max time:	240,00 s
Post fault time:	0,50 s
Rel. max time:	100,00 %
Enable voltage output:	No
Fault voltage LN (for all but two phase faults):	30,00 V
Fault voltage LL (for two phase faults):	51,96 V
Decaying DC active:	No
Time constant:	0,05 s
CB char min time:	0,05 s
Thermal reset active:	No
Thermal reset method:	Manual

Thermal reset message:	Please reset the Thermal Memory of the device under test before continuing.

Shot Test:

Type	Relative To	Factor	Magnitude	Angle	tnom	tmin	tmax
L1-L2-L3	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	5,823 s	10,91 s
L1-L2-L3	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	3,527 s	4,957 s
L1-L2-L3	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,200 s	2,719 s
L1-L2-L3	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	560,0 ms	1,876 s
L1-L2-L3	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	560,0 ms	640,0 ms
L1-L2-L3	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	560,0 ms	640,0 ms

Binary Outputs:

Name	State
Bin. Out 1	1
Bin. Out 2	0
Bin. Out 3	0
Bin. Out 4	0

Binary Inputs:

Trigger Logic: And

Name	Trigger State
Start	1
Trip	0
Alarm	X

Pick-up / Drop-off Test:

Type	Angle	Resolution	I Pick-up			Reset Ratio
			nom	min	max	nom
L1-L2-L3	n/a	0,02 s	0,89 A	0,84 A	0,94 A	0,95

Shot Test Results:

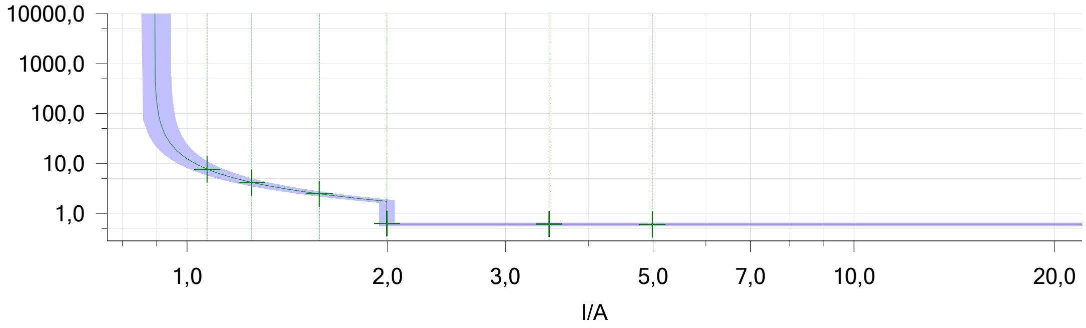
Type	Relative To	Factor	Magnitude	Angle	tnom	tact	Overload	Result
L1-L2-L3	I> Overcurrent	1,200	1,07 A	n/a	7,665 s	7,592 s	No	Passed
L1-L2-L3	I> Overcurrent	1,400	1,25 A	n/a	4,147 s	4,125 s	No	Passed
L1-L2-L3	I> Overcurrent	1,768	1,58 A	n/a	2,443 s	2,450 s	No	Passed
L1-L2-L3	I>> Over overcurrent	1,000	1,99 A	n/a	600,0 ms	624,2 ms	No	Passed
L1-L2-L3	I>> Over overcurrent	1,750	3,49 A	n/a	600,0 ms	608,0 ms	No	Passed
L1-L2-L3	I>> Over overcurrent	2,500	4,99 A	n/a	600,0 ms	596,8 ms	No	Passed

Pick-up / Drop-off Test Results:

Type	Angle	I Pick-up		I Drop-off	Reset Ratio			Result
		nom	act	act	nom	act	Error	
L1-L2-L3	n/a	0,89 A	0,90 A	0,85 A	0,95	0,94	-1,14 %	Passed

Charts for Fault Types:

Type	Angle	
L1-L2-L3	n/a	



State:

7 out of 7 points tested.
7 points passed.
0 points failed.

General Assessment: Test passed!

Test Settings

General

No. of ramp states:	2
Total steps per test:	236
Total time per test:	23,600
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L1-E; L2-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	69,35 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	69,35 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	63,51 V 120,00 ° 50,000 Hz
I L1	798,0 mA 0,00 ° 50,000 Hz	798,0 mA 0,00 ° 50,000 Hz
I L2	798,0 mA -120,00 ° 50,000 Hz	798,0 mA -120,00 ° 50,000 Hz
I L3	798,0 mA 120,00 ° 50,000 Hz	798,0 mA 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	63,51 V	69,35 V
Sig 1 To	69,35 V	63,51 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s
Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	118	118
Ramp Time	11,800s	11,800s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	X	X
Trip	X	X
Alarm	X	X
Alarm start	1	0
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	1,000 s	1,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 13:50:41	Test End:	12-maalis-2014 13:50:58
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Alarm start 0->1	V L1-E; L2-E	66,68 V	66,86 V	2,001 V	2,001 V	174,6 mV	+	44,50 ms
Drop-off	Ramp 2	Alarm start 1->0	V L1-E; L2-E	64,68 V	64,80 V	2,001 V	2,001 V	117,9 mV	+	62,10 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	236
Total time per test:	23,600
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L2-E; L3-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	63,51 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	69,35 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	69,35 V 120,00 ° 50,000 Hz
I L1	798,0 mA 0,00 ° 50,000 Hz	798,0 mA 0,00 ° 50,000 Hz
I L2	798,0 mA -120,00 ° 50,000 Hz	798,0 mA -120,00 ° 50,000 Hz
I L3	798,0 mA 120,00 ° 50,000 Hz	798,0 mA 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	63,51 V	69,35 V
Sig 1 To	69,35 V	63,51 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s

Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	118	118
Ramp Time	11,800s	11,800s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	X	X
Trip	X	X
Alarm	X	X
Alarm start	1	0
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	1,000 s	0,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 13:51:14	Test End:	12-maalis-2014 13:51:30
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Alarm start 0->1	V L2-E; L3-E	66,68 V	66,81 V	2,001 V	2,001 V	124,6 mV	+	59,60 ms
Drop-off	Ramp 2	Alarm start 1->0	V L2-E; L3-E	64,68 V	64,80 V	2,001 V	2,001 V	117,9 mV	+	70,20 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	236
Total time per test:	23,600
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L3-E; L1-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	69,35 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	63,51 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	69,35 V 120,00 ° 50,000 Hz
I L1	798,0 mA 0,00 ° 50,000 Hz	798,0 mA 0,00 ° 50,000 Hz
I L2	798,0 mA -120,00 ° 50,000 Hz	798,0 mA -120,00 ° 50,000 Hz
I L3	798,0 mA 120,00 °	798,0 mA 120,00 °

	50,000 Hz	50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	63,51 V	69,35 V
Sig 1 To	69,35 V	63,51 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s
Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	118	118
Ramp Time	11,800s	11,800s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	X	X
Trip	X	X
Alarm	X	X
Alarm start	1	0
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	1,000 s	0,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 13:51:46	Test End:	12-maalis-2014 13:52:02
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Alarm start 0->1	V L3-E; L1-E	66,68 V	66,81 V	2,001 V	2,001 V	124,6 mV	+	63,30 ms
Drop-off	Ramp 2	Alarm start 1->0	V L3-E; L1-E	64,68 V	64,75 V	2,001 V	2,001 V	67,90 mV	+	64,30 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	236
Total time per test:	23,600
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L1-E; L2-E; L3-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	69,35 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	69,35 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	69,35 V 120,00 ° 50,000 Hz
I L1	798,0 mA 0,00 ° 50,000 Hz	798,0 mA 0,00 ° 50,000 Hz
I L2	798,0 mA -120,00 ° 50,000 Hz	798,0 mA -120,00 ° 50,000 Hz
I L3	798,0 mA 120,00 ° 50,000 Hz	798,0 mA 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	63,51 V	69,35 V
Sig 1 To	69,35 V	63,51 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s
Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	118	118
Ramp Time	11,800s	11,800s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	X	X
Trip	X	X
Alarm	X	X
Alarm start	1	0
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	0,000 s	0,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 13:52:18	Test End:	12-maalis-2014 13:52:33
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Alarm start 0->1	V L1-E; L2-E; L3-E	66,68 V	66,81 V	2,001 V	2,001 V	124,6 mV	+	50,60 ms
Drop-off	Ramp 2	Alarm start 1->0	V L1-E; L2-E; L3-E	64,68 V	64,80 V	2,001 V	2,001 V	117,9 mV	+	60,30 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

U> alarm Timing:

Test Settings

State	State 1	State 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	69,35 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	69,35 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	69,35 V 120,00 ° 50,000 Hz
I L1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I L2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I L3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz

Test Module

Name:	OMICRON State Sequencer	Version:	3.00
Test Start:	12-maalis-2014 13:52:50	Test End:	12-maalis-2014 13:53:30
User Name:		Manager:	
Company:			

Test Results

Time Assessment

Name	Ignore before	Start	Stop	Tnom	Tdev-	Tdev+	Tact	Tdev	Assess
U> alarm	State 2	State 2	Alarm 0>1	30,00 s	30,00 ms	30,00 ms	30,00 s	-3,500 ms	+

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:
Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	414
Total time per test:	41,400
No. of test executions:	1

Input Mode: Direct

Fault Type:

Ramped Quantities

V L1-E; L2-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	67,95 V 0,00 ° 50,000 Hz	78,24 V 0,00 ° 50,000 Hz
V L2-E	67,95 V -120,00 ° 50,000 Hz	78,24 V -120,00 ° 50,000 Hz
V L3-E	63,51 V 120,00 ° 50,000 Hz	63,51 V 120,00 ° 50,000 Hz
I L1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I L2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I L3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	67,95 V	78,24 V
Sig 1 To	78,24 V	67,95 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s
Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	207	207
Ramp Time	20,700s	20,700s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	1	0
Trip	X	X
Alarm	X	X
Alarm start	X	X
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	0,000 s	0,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 14:37:09	Test End:	12-maalis-2014 14:37:24
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Start 0->1	V L1-E; L2-E	71,13 V	71,30 V	2,134 V	2,134 V	174,6 mV	+	67,10 ms
Drop-off	Ramp 2	Start 1->0	V L1-E; L2-E	69,00 V	69,14 V	2,134 V	2,134 V	146,8 mV	+	68,10 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	414
Total time per test:	41,400
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L2-E; L3-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	63,51 V 0,00 ° 50,000 Hz	63,51 V 0,00 ° 50,000 Hz
V L2-E	67,95 V -120,00 ° 50,000 Hz	78,24 V -120,00 ° 50,000 Hz
V L3-E	67,95 V 120,00 ° 50,000 Hz	78,24 V 120,00 ° 50,000 Hz
I L1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I L2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I L3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	67,95 V	78,24 V
Sig 1 To	78,24 V	67,95 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s
Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	207	207
Ramp Time	20,700s	20,700s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	1	0
Trip	X	X
Alarm	X	X
Alarm start	X	X
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	1,000 s	0,000 s

Test Module

Name:	OMICRON Ramping	Version:	3.00
Test Start:	12-maalis-2014 13:54:02	Test End:	12-maalis-2014 13:54:19
User Name:		Manager:	
Company:			

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Start 0->1	V L2-E; L3-E	71,13 V	71,25 V	2,134 V	2,134 V	124,6 mV	+	45,60 ms
Drop-off	Ramp 2	Start 1->0	V L2-E; L3-E	69,00 V	69,09 V	2,134 V	2,134 V	96,80 mV	+	62,20 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed

Test Settings

General

No. of ramp states:	2
Total steps per test:	414
Total time per test:	41,400
No. of test executions:	1
Input Mode:	Direct
Fault Type:	

Ramped Quantities

V L3-E; L1-E / Magnitude

Ramp States

Ramp	Ramp 1	Ramp 2
V L1-E	67,95 V 0,00 ° 50,000 Hz	78,24 V 0,00 ° 50,000 Hz
V L2-E	63,51 V -120,00 ° 50,000 Hz	63,51 V -120,00 ° 50,000 Hz
V L3-E	67,95 V 120,00 ° 50,000 Hz	78,24 V 120,00 ° 50,000 Hz
I L1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I L2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I L3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
V(2)-1	0,000 V 0,00 ° 50,000 Hz	0,000 V 0,00 ° 50,000 Hz
I(1)-1	0,000 A 0,00 ° 50,000 Hz	0,000 A 0,00 ° 50,000 Hz
I(1)-2	0,000 A -120,00 ° 50,000 Hz	0,000 A -120,00 ° 50,000 Hz
I(1)-3	0,000 A 120,00 ° 50,000 Hz	0,000 A 120,00 ° 50,000 Hz
Force abs. Phases	Yes	No
Sig 1 From	67,95 V	78,24 V
Sig 1 To	78,24 V	67,95 V
Sig 1 Delta	50,00 mV	-50,00 mV
Sig 1 d/dt	500,0 mV/s	-500,0 mV/s

Bin. Out 1	1	1
Bin. Out 2	0	0
Bin. Out 3	1	1
Bin. Out 4	0	0
dt per Step	100,0 ms	100,0 ms
Ramp Steps	207	207
Ramp Time	20,700s	20,700s
Trigger	Bin	Bin
Trigger Logic	AND	AND
Start	1	0
Trip	X	X
Alarm	X	X
Alarm start	X	X
Bin. In. 5	X	X
Bin. In. 7	X	X
Bin. In. 8	X	X
Bin. In. 9	X	X
Bin. In. 10	X	X
Step back	No	No
Delay Time	0,000 s	1,000 s

Test Module

Name: OMICRON Ramping
Version: 3.00
Test Start: 12-maalis-2014 13:54:34
Test End: 12-maalis-2014 13:54:51
User Name:
Manager:
Company:

Test Results

Assessment Results

Name/ Exec.	Ramp	Condition	Sig	Nom.	Act.	Tol.-	Tol.+	Dev.	Assess	Tact
Pick-up	Ramp 1	Start 0->1	V L3-E; L1-E	71,13 V	71,30 V	2,134 V	2,134 V	174,6 mV	+	56,20 ms
Drop-off	Ramp 2	Start 1->0	V L3-E; L1-E	69,00 V	69,09 V	2,134 V	2,134 V	96,80 mV	+	58,60 ms

Assess: + .. Passed x .. Failed o .. Not assessed

Test State:

Test passed