YRKESHÖGSKOLAN NOVIA

Modernization and Development of a Synchronizing Tester

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Bachelor's Thesis

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BACHELOR'S THESIS

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Abstract

This bachelor's thesis is written for ABB's Energy Industries department in Vaasa. This thesis work is a part of the constant product development going on at ABB.

The objective of this thesis is to modernize and develop a new synchronizing tester as addition to the old existing one. This synchronizing tester has the purpose of simulating when generators are synchronized.

The execution of this thesis work started out with the planning of the layout and functions for the synchronizing tester. The drawings are designed and created in the drawing program E^3, that ABB Energy Industries uses as their drawing system for drawing the control panels.

The result of this thesis work is a quick and easy to use synchronizing tester, that makes the synchronizing tests at ABB's FAT area faster and easier to perform. The result of this thesis is meant to function as ABB's new synchronizing tester.

The result of this thesis is considered sensitive material and will not be shared with the public.

Language: english Key words: synchronizing, transformer, generator,

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EXAMENSARBETE

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Utbildning och ort:	El – och automationsteknik, Vasa
Inriktningsalternativ:	Elkraftsteknik
Handledare:	Matts Nickull, Tony Bäck

Titel: Modernisering och utveckling av synkroniseringstester

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Abstrakt

Detta examensarbete är skrivet för ABB Energy Industries avdelning i Vasa. Examensarbetet är en del av den fortgående produktutvecklingen vid ABB.

Syftet med examensarbete var att modernisera och utveckla en ny synkroniseringstester som tillägg till den gamla befintliga synkroniseringstestern. Denna synkroniseringstester har som syfte att simulera när generatorer synkroniseras.

Utförandet av examensarbetet började med planering av layout och funktioner för synkroniseringstestern. Ritningarna designades och skapades i ritningsprogrammet E^3, vilket är ritprogrammet som ABB Energy Industries använder för skapande av deras kontrollpanelsritningar.

Resultatet av detta examensarbete är en snabb och lättanvänd synkroniseringstester som gör att synkroniseringstesterna på ABB:s FAT-område kan utföras snabbare och lättare än förut.

Resultatet för detta examensarbete anses innehålla känsligt material och kommer inte att delas med allmänheten.

Språk: engelska Nyckelord: synkronisering, tranformator, generator

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Nimike: Synkronointitesterin modernisointi ja kehittäminen

Päivämäärä: 11.4.2019 Sivumäärä: 35 Liitteet: 5

Tiivistelmä

Tämä opinnäytetyö on tehty ABB:n Vaasan Energy Industries-osastolle. Opinnäytetyö on osa ABB:n jatkuvaa tuotekehitystä.

Opinnäytetyön tavoitteena oli uudistaa ja kehittää olemassa olevaa synkronointitesteriä ja luoda siitä uusi versio. Tällä synkronointitesterillä on tarkoitus simuloida generaattoreiden synkronointia.

Opinnäytetyön toteutus aloitettiin suunnittelemalla synkronoivan testerin asettelua ja toimintoja. Piirustukset suunniteltiin ja luotiin piirustusohjelmassa E^3, joka on yksi ABB Energy Industriesin käyttämistä piirustusjärjestelmistä.

Opinnäytetyön tulos on nopea ja helppokäyttöinen synkronointitesteri, joka tekee ABB:n FAT-alueen synkronointitestit nopeammin ja helpommin. Tämän työn tulos on tarkoitus toimia ABB:n uudenaikaisena synkronointitestauslaitteena.

Opinnäytetyön tulosta pidetään arkaluonteisena, eikä sitä jaeta yleisölle.

Kieli: englanti Avainsanat: synkronointi, muuntaja, generaattori

Table of Contents

1 Introduction

The objective of this thesis is the modernization and development of a new synchronizing tester. This will involve the planning and designing of the new tester and the construction of the cabin. This Bachelor's thesis was commissioned by ABB, Energy Industries department in Vaasa.

1.1 The commissioner

ABB is a pioneering technology leader in power grids, electrification products, industrial automation, robotics and motion, serving customers in utilities, industry, infrastructure and transportation globally, with a turnover of about 35 billion USD in year 2017. The ABB group was formed in 1988 through a merge between the Swedish company Asea AB and the Swiss company BBC Brown Boveri AG, continuing a history of innovation spanning more than 130 years. The strong focus on research and development relates in the great success ABB has achieved. The ABB group operates in more than 100 countries with approximately 147 000 employees. (ABB, 2019)

The four main divisions consist of Power Grids, Electrification Products, Industrial Automation, Robotics and Discrete and Motion. (ABB, 2019)

This thesis is commissioned by ABB, Energy Industries. ABB, Energy Industries has more than 3000 employees worldwide. The Finnish Energy Industries department consists of approximately 80 employees, almost all of them working in Vaasa. The office is located in Stromberg Park in Vaasa. The Energy Industries department plans and delivers electrical-, automation-, instrumentation- and control systems for different power plants, e.g. diesel, gas, nuclear and hydro power plants. (ABB, 2019)

1.2 Background

The synchronizing tester is a key component at ABB Energy Industries FAT area. A synchronizing tester is used to test that the synchronization mechanism for the control system cabins is working correctly before they are shipped away to the customers. ABB Energy Industries already owns and uses a synchronizing tester. The electrical and automation field is constantly changing and evolving and with it the products surrounding them.

1.3 Problem area

ABB is already using a synchronizing tester for testing of the synchronizing. The pre-existing synchronizing tester that has been in commission since 2002 is still fully functional, but is in order of an upgrade on grounds of its significant bulk, both size and weight. This led ABB to assign the author with the task to design and create an improved version of said tester. When there are many different teams working on different projects at the same time, a smaller and neater synchronizing tester is optimal. Having two fully working synchronizing testers would also speed up the testing of the synchronizing function in the control cabins. It will be an improvement to have a second smaller and newer synchronizing tester.

1.4 Purpose

The purpose of this thesis work is to develop a modernized synchronizing tester cabin simulating a generator used at power plants. The tester will be used at ABB's FAT area when function tests are done by engineers working for ABB, before the control system cabins are shipped off to the customers. The goal of this thesis is to create a fully functional and neat synchronizing tester for the FAT testing area at Energy Industries that will improve and shorten their synchronizing tests.

1.5 Confidentiality

A part of this thesis work has to be confidential. The methodology, Test Cabin Components and appendices will not be shared with the public.

2 Theory

Synchronization is a process of matching the voltage, frequency and phase angle of a generator to an existing power system, so the two systems can be operated in parallel. Synchronizing a generator to a power system must be done carefully. Therefore it is essential to test the synchronizing functions in the control systems. To be able to build a fully functional synchronizing tester, some essential components have to be explained and understood. Transformers and frequency drivers are the two main components that needs more explanation. The synchronizing process needs to be comprehended before construction of a synchronizing tester can be done.

In order for the two systems to safely run in parallel, the two sources must be paralleled in regards to voltage, frequency and phase-angle. Poor synchronization can:

- Damage the generator because of the rapid acceleration or deceleration.
- Damage the generator caused by high currents.
- Cause disturbance to the power system.

In normal conditions, the control system is fitted with a synchronization panel which lets the operator make readings of the current values, such as frequency, voltage, phase angle and slip, in order to correctly close the breaker. In many cases, an automatic synchronizer is used, with manual controls available only as backup. (Thompson, 2012)

2.1 Synchronizing criteria

A generator can only be connected to the electrical bus or grid if certain criteria are fulfilled. There are four main criteria that has to be fulfilled before a synchronization to the grid can be executed.

1) Frequency
2) Voltage magnitude
3) Phase sequence
4) Phase angle

2.1.1 Frequency

The incoming generator frequency and the bus bar frequency has to be equal to each other. If the frequency on the generator side and the bus bar side doesn't match, high acceleration and deceleration in the prime mover increases the transient torque. (Thompson, 2012) (Ransom, 2014) (Edvard, 2013)

2.1.2 Voltage magnitude:

RMS voltage of the bus bar or electric grid has to be the same as the RMS voltage coming from the generator. There will be a high reactive power flowing from the generator to the grid if the incoming generator voltage is higher than the voltage on the bus bar side. If the voltage on the generator side is lower than the bus bar voltage, the generator will absorb high reactive power from the grid. (Thompson, 2012) (Ransom, 2014) (Edvard, 2013)

2.1.3 Phase sequence:

For a proper synchronization the phase sequence is very important. The generators three phase sequence must be the same as the three-phase sequence of the bus bar or electric grid. Matching the sequence is called “phasing”, when the phasing is done the source is then said to be in phase. The only time the phase sequence could be wrong is at initial installation or after maintenance (Ransom, 2014) (Thompson, 2012) (Edvard, 2013)

2.1.4 Phase angle

Incoming generator voltage and the voltage of the bus bars phase angle has to be close to zero-degree angle difference. When the phase angle between the generator voltage and the system voltage is near 0 degrees, the operator initiates closing of the breaker. (Berg, 2016) (Thompson, 2012) (Edvard, 2013)

2.1.5 Synchronization Window

Closing the breaker when the frequency, voltage and phase angle matches perfectly is nearly impossible. The generator and the grid are therefore paralleled within an acceptable tolerance window. If the frequency, phase angel and the voltage of the generator is within this "window", the two systems can be paralleled with almost no disturbance. (Ransom, 2014)

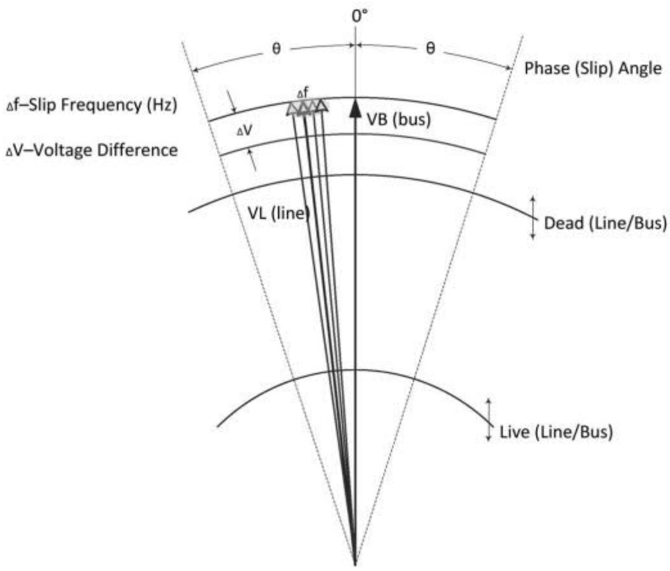

Figure 1. Synchronization Window.

The synchronizing window in Figure 1 shows the synchronizing target and the allowed differences between the two power systems for the breaker to be able to close without disturbance. VB (bus) is the bus voltage, on the vertical axis. VL (line) is the oncoming generator, a phasor sweeping clockwise. ΔV is the acceptable variance in voltage, the acceptable variance in voltage is determined by the settings. Settings also determine the acceptable slip frequency Δf, in hertz. Slip frequency is measured in Hz and is the difference between the frequencies of two systems. The range of the slip frequency is usually between 0.05 - 0.5 Hz. Acceptable phase angel is also determined by the settings. The synch check allows the close command if all the criteria are fulfilled and denies the close command if they are not fulfilled. (Ransom, 2014)

2.2 Synchronization Methods

To be able to close the circuit breaker at the correct moment there is three different methods: manual switching, assisted manual switching and automatic switching. Each of these methods has related equipment and indicators. The oncoming generator voltage and frequency phase angle need to be matched with the existing source. Matching is done either manually or by a synchronizing relay. The circuit breaker is allowed to close when the voltage and frequency phase angle is within the synchronizing window, the generator is then connected in parallel to the bus. (Ransom, 2014) (Thompson, 2012)

2.2.1 Manual Synchronization

Manual synchronization is the cheapest and simplest method, it has to be performed by operating personnel at the power plant and that may not be the most optimal solution. An operator at the power plant controls the switches at the control panel, adjusting voltage and frequency of the generator. When the criteria are met an operator can manually close the circuit breaker to connect the generator to the bus by pressing the circuit breaker close button on the panel. For an operator to be able to perform a manual synchronization and close the circuit breaker at the right moment the control panel has to provide the operator with the right information. This panel usually includes the following metering devices:

1. Synchro scope.
2. Indicating lamps.
3. Separate bus-frequency and generator-frequency meters, for matching the frequency.
4. Separate bus and generator AC voltage meters for matching the voltage.

(Ransom, 2014) (Thompson, 2012)

Synchro scope

The most important instrument on the control panel is the synchro scope. The synchro scope is used to determine a couple of things. It indicates the difference in frequency between the voltages in two systems. It is capable of displaying whether the generator frequency pace is faster or slower than the bus frequency. A pointer is rotating clockwise or counter clockwise depending on the mismatch of the frequency. The pointer will rotate clockwise when the generator frequency is higher than the bus frequency and vice versa. When the pointer is at 12 o’clock position, the phase-angel is at 0°. To minimize the power flow transients and generator damage, the generator circuit breaker is closed at 0° phase-angel. The synchro scope does not indicate voltage difference, so voltmeters are always included. (Ransom, 2014)

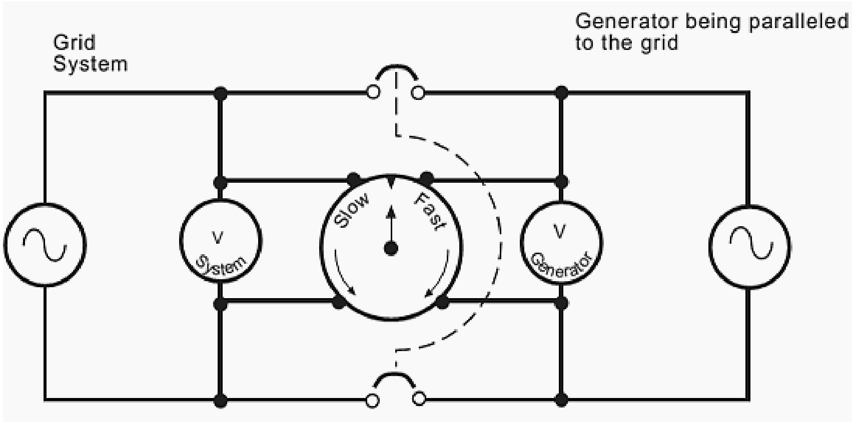

Figure 2. Synchro scope.

Indication lamps

There are basically two different indication lamp methods. One is the dark-lamp method and the second is the bright-lamp method. The dark-lamp method is the first basic scheme, the scheme consists of three lamps and each lamp is connected to the same phases on either side of the breaker. There is 0 volt potential difference if the bus bar voltage and the generator are in phase; the lamps will be dark. (Thompson, 2012) (Ransom, 2014)

The bright-lamp method uses two illuminated lamps along with a dark lamp. The frequency can be adjusted so that the lamps will light and then go out in slow rating, by adjusting the speed of the oncoming generator. One lamp is dimming as two lamps are getting brighter. This makes it easier for the operator to know when the right moment for paralleling will occur. (Ransom, 2014)

Application of Manual synchronization

When the Manual synchronizing process starts, the generator speed is adjusted so that it is slightly faster than the bus frequency in order to create a positive slip rate. The generator frequency is set to a higher set point than the bus bar frequency. This is in order for the generator to immediately pick up the load when the breaker is closed, rather than engaging as a motor. The generator should not be operated in under-excited conditions, as this would allow the generator to consume reactive power, thus possibly pulling the generator out of sync. This is mitigated by the higher setpoint of the generator voltage compared to the bus voltage. When the circuit breaker is closed, a small amount of reactive power is exported from the generator. (Ransom, 2014)

2.2.2 Assisted-Manual Synchronization

By adding a sync-check relay to a manual synchronization process an assisted-manual synchronization process is created. Adding the sync-check relay to a manual synchronization process leads to a proper synchronization. This method still requires an operator to adjust the voltage and frequency of the generator. The sync-check relay implements a synchronizing window, the window consists of safe conditions that has to be fulfilled before the circuit breaker can be closed. Voltage difference, slip frequency and the phase-angel difference between the generator and the bus bar is compared by the sync-check relay. (Ransom, 2014) (Thompson, 2012)

These are typical ranges of parameters that are installed to the sync-check. The sync-check relay does not allow the circuit breaker to close if not all of these parameters are met.

Parameter	Value
Voltage difference	10 - 15 V
Slip frequency	0.05 - 0.1 Hz
Phase-angle	0° - 12°

When all these parameters are met and the operator manually closes the control switch the circuit breaker will close. That means that the sync-check relay and the control switch are connected in series. If one of the above-mentioned requirements is not fulfilled, the circuit breaker will not be able to close. (Ransom, 2014)

2.2.3 Automatic Synchronization

Manual synchronizing and assisted-manual synchronizing both have its defects. Both methods require skilled operators controlling the voltage and the frequency. To avoid risking damage to the equipment caused by bad synchronization, automatic synchronizer is used. (Ransom, 2014)

The automatic synchronizer device can perform all the functions to synchronize a generator. The automatic synchronizer is applied for synchronization of a generator to the bus bar. The synchronizer closes the breaker when the voltage difference, slip frequency and phase-angels are within the pre-set limits. (DEIF) Main advantage of having an automatic synchronizer instead of a manual synchronizer is that the automatic synchronizer is able to connect the generator to the network more consistently at the right moment. The synchronizer monitors voltage, frequency and phase-angle. The synchronizer corrects the voltage and frequency level until they are matched and provides the circuit-breaker-close output contact. (Ransom, 2014)

Application of Automatic synchronization

The synchronizer is activated when the generator voltage reaches a set trigger-point. The synchronizer detects the generator's voltage, frequency and phase angle. The synchronizer performs the following set of actions:

1) Voltage comparison
2) Frequency comparison
3) Changes voltage level until it matches the bus
4) Changes frequency level until it matches the bus
5) Phase angle comparison
6) Sends a close-command to the circuit breaker

When the synchronizer is applied to the source, it can sense a large difference between the generator and the bus. The oncoming generator voltage signals and the frequency signals is corrected by the synchronizer so it matches with the bus. The process is repeated until the generator is synchronized with the bus and the circuit breaker is closed. Circuit breaker closure do not happen instantaneously. The breaker-close signal from the synchronizer has to be sent in advance, to achieve circuit-breaker closure at 0°. While the frequency is slowly approaching the 0° phase angle, the close command is given by auto synchronizer.

The advance angle calculated by the synchronizer (A_A), the advance angle is required for compensation of the circuit-breaker-closing time and the pre-set slip-rate value for breaker closing. Then it adds a constant of the movement time of the physical parts completing the calculation. (Ransom, 2014)

Mathematic relationship:

$(A_A) = 360 \bullet (T_{CB} + T_R) \bullet F_S$, where:

- A_A: Advance angle, electrical phase angle of the generator with respect to the bus when the synchronizer initiates a close command.
- T_{CB}: Circuit breaker close time, the time between the close command and the actual contact of the circuit-breaker poles.
- T_R: Response time of the relay.
- F_S: slip frequency

Reducing the advance angle A_A also reduces the value of the slip frequency. With less slip frequencies there is less system disturbance and machine damage. If you have larger slip frequencies the synchronization will happen faster, but then there is more system disturbance. (Ransom, 2014)

2.3 Frequency Converter

Frequency driver is an electronic device that converts AC of one frequency to another frequency. The frequency converter generates a variable supply from a supply with fixed parameters. Frequency drivers have developed very fast since the late 1960s. The fast development of the frequency drivers has been made thanks to developments within the fields of microprocessor and semiconductor technology.

There are basically two different types of frequency drivers: Direct converters and Converter with intermediate circuit. (Danfoss, 2014)

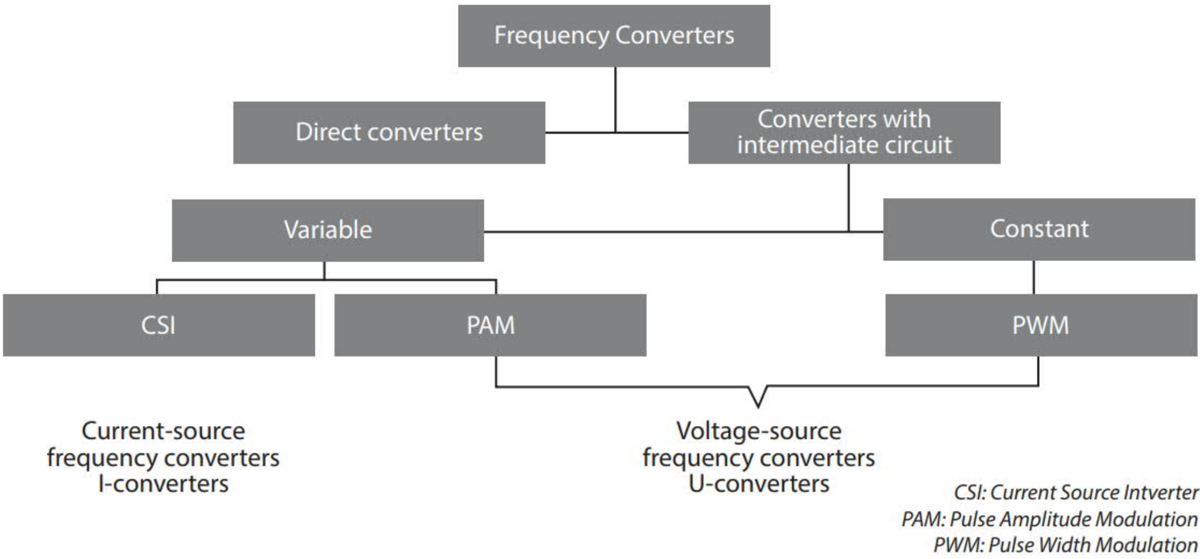

Figure 3. Overview of frequency converter types.

Direct converter is generally only used in high-power applications, the perform conversion with no intermediate storage. (Danfoss, 2014)

2.3.1 Converter with intermediate circuit

The majority of FC are equipped with an intermediate circuit also called DC bus. There are two subtypes of converters with intermediate circuits: constant intermediate circuit and variable intermediate circuit. Frequency drivers with an intermediate circuit consist of four main components as shown in Figure 4. (Danfoss, 2014)

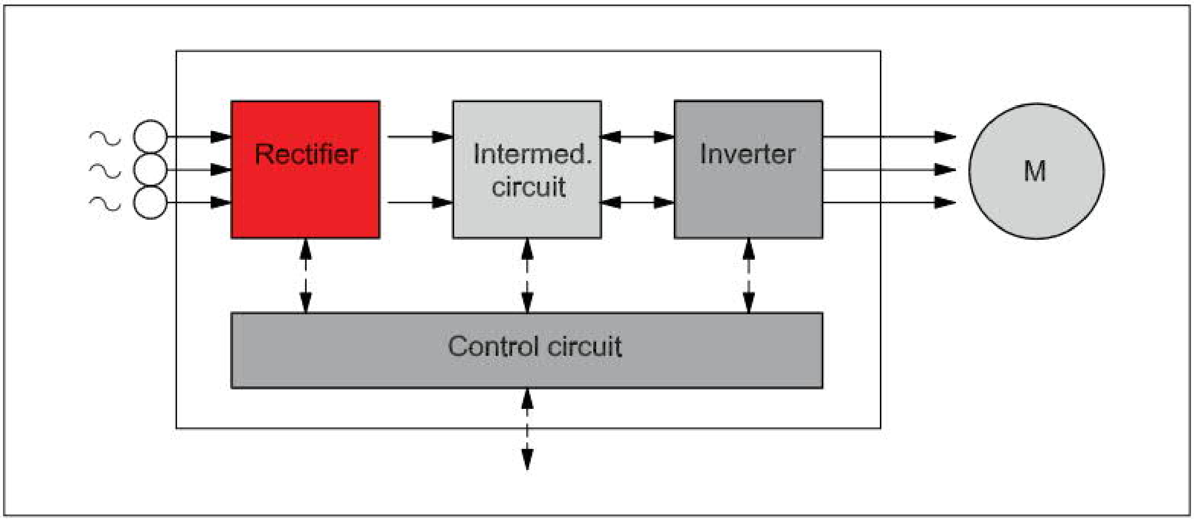

Figure 4. Block diagram of a frequency driver with an intermediate circuit.

2.3.2 Rectifier

A three-phase or single-phase VAC supply is supplying the rectifier. A pulsating VDC is generated by the rectifier. The rectifiers can be categorized in four basic types: (Danfoss, 2014)

- Controlled
- Semi-controlled
- Uncontrolled
- Active front-end

2.3.3 Intermediate circuit

Depending on the design the intermediate circuit can function in three different ways. The three functions performed by the intermediate circuit are:

- Act like an energy buffer so that the motor or generator can draw energy from/return energy to the grid via the inverter.
- Disconnect the rectifier from the inverter.
- Decreasing mains interference.

(Danfoss, 2014)

2.3.4 Inverter

As for the main components of the FC, the inverter is the final component in the process of output voltage generation and frequency generation. The inverter gets: variable direct current, variable DC voltage or constant voltage from the intermediate circuit.

The inverter must ensure that the supply to the motor is an AC voltage. In the inverter the frequency of the motor voltage is generated. Control method of the inverter depends on whether it receives a variable or a constant value. The basic design is always the same, even though inverters work in different ways. (Danfoss, 2014)

2.3.5 Control circuit

The function of the control circuit is to transmit signals to – and receives signals from – the rectifier, the intermediate circuit and the inverter. All FC's have one function in common, that is that the control circuit uses signals to switch the inverter semiconductors on and off. The control circuit has four main tasks:

- Controlling the semiconductors.
- Exchanging data between the FC and peripherals.
- Measuring, detecting and displaying faults, conditions and warnings.
- Performing protective functions for the FC and motor.

(Danfoss, 2014)

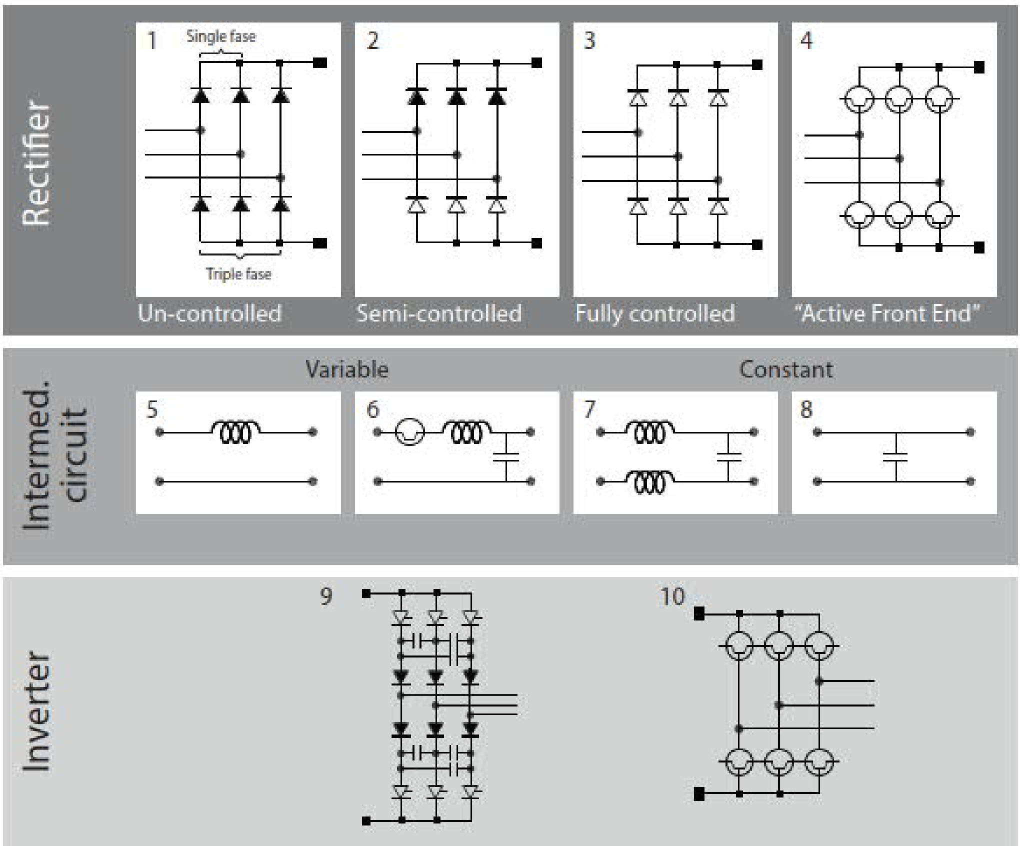

Figure 5. Main component topologies.

2.4 Output filter

When equipment is driven by electricity, especially if a drive controls the speed of an electric motor, the noise produced by the driver has to be taken into consideration along the entire line from the source to the load. Equipment can be damaged or malfunctioned if an output filter is not used. For cancellation of unwanted noises there is a wide range of different filters that can be used. The following types of passive output filters are commonly used to solve the problems with noise and interference on the output sine-wave:

- dv/dt reactors (increase inductivity, signal smoothing)
- dv/dt filters (low inductance, hardly any reduction in the control dynamic)
- Sinusoidal output filters (high L and C for optimizing the output signal, but also not universally applicable)

(Schaffner, 2012)

2.5 Sine wave filter

Sine wave filter, also known as LC-filters or named sinusoidal filters are low pass frequency filters. The sine wave filter converts the rectangular PWM output signal of the frequency drivers into a even sine wave voltage with low residual ripple. (Schaffner, 2012)

Differential mode sine wave output filter is one of the two basic output filters that are used for smoothening the sinusoidal output frequency. The differential mode sine wave output filter has the following advantages:

- Protect motor winding insulation against dv/dt voltage spike and overvoltage.
- Decrease the additional magnetic losses and eddy current losses in the motor.
- Decrease motor heating.
- Decrease the additional losses of the motor drives.
- Decrease motor bearing currents caused by circulating currents.
- Decrease the acoustic noise of the motor.
- Decrease electromagnetic emissions of motor cables.

Sine wave filters are very useful for special AC frequency driver applications requiring a smooth sine wave volts. (Schaffner, 2012)

2.6 Transformers

A transformer changes the voltage or current level on its input windings to another value on its output winding using a magnetic field. A transformer consists of two electrically isolated coils and operates on Faraday's principal of "mutual induction". To reduce eddy current and power lose, both the primary and the secondary coil winding are wrapped around a soft iron core. The sinusoidal AC power supply is connected to the primary winding of the transformer, while the secondary winding supplies power to the load. (ElectronicsTutorials, 2019) The most common used transformers are power transformers, distribution transformer, auto transformer and control transformer. (Elfving, 1993) (Alexander, 2009) (AL-BREIHI, 2014)

2.6.1 Distribution Transformer

Distribution transformer is a transformer for general power provision at power plants and industries, for stepping down the voltage used in the distribution lines to the level used by the customer. (Elfving, 1993) (AL-BREIHI, 2014)

2.6.2 Winding Connections

A three-phase transformer consists of three sets of primary windings, one winding for each phase and three sets of secondary windings. Primary windings can be connected in one of several ways. The two most common ways to connect the primary windings are delta (D) and wye (Y). In D-connection the polarity end of one winding is connected to the non-polarity end of the next winding. In a Y-connection all three polarity or non-polarity ends are connected to each other. The secondary windings are connected in the same way. That means that the secondary side is connected the same way as the primary or then opposite of the primary windings. A three-phase transformers primary and secondary windings can be configured in two different setups: one configuration with a setup of identical windings (delta-delta or wye-wye) and another setup with non-identical windings (delta-wye, wye-delta). A phase shift will occur if the primary and secondary windings are configured differently, as a configuration in which they are configured in the same way will result in no phase shift occurring. (Elfving, 1993) (Alexander, 2009) (AL-BREIHI, 2014) (Portal, 2012)

If the primary and the secondary windings are connected differently, there will be a 30° difference on the voltage waveform between the primary and secondary winding. When two transformers are paralleled their phase shift has to be identical, otherwise there might occur a short circuit when the transformer is energized. (Elfving, 1993) (Alexander, 2009) (AL-BREIHI, 2014)

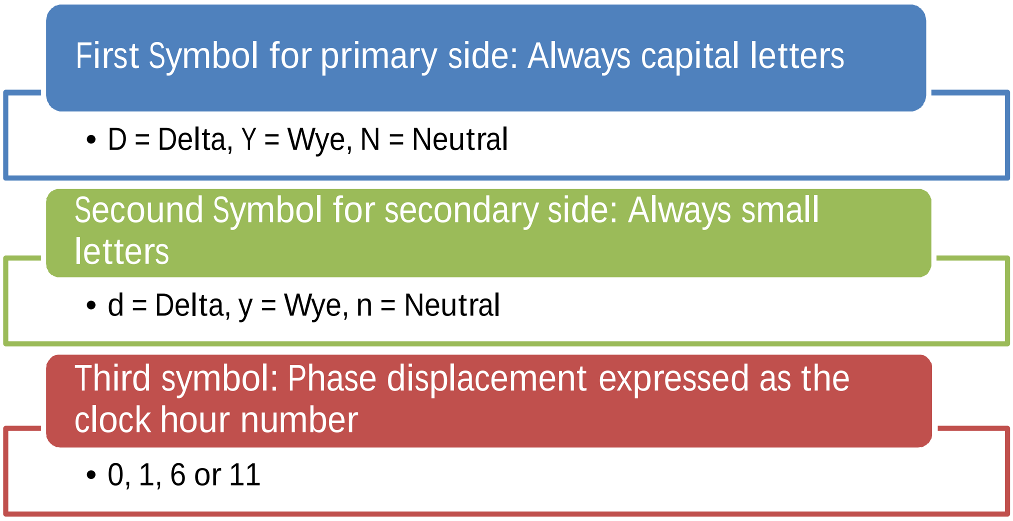

Figure 6. Winding connection description.

Three-phase transformers can be connected many different ways. The vector group of the generator can be determined, based on the winding connections. On the name plate of the transformer the vector group indication can be found. Before connecting two or more transformers together it is very important to determinate the vector group of the transformers.

The primary winding vector is taken as the reference vector. The displacement of the other windings vector is represented by the use of clock hour figure, with anticlockwise rotation. Displacement of the secondary winding vector varies from 0 degrees to -330 degrees, depending on the method of connections. Some commonly used connections with phase displacement are 0, -300, -180 and -330 degrees or in clock-hour settings 0, 1, 6 and 11. The digits 0, 1, 6 etc. are the phase displacement between the primary and the secondary windings referred to the clock face system. The primary phasor winding is set at 12 o'clock and used as a reference. From there the secondary phasor windings are rotated for example 30 degrees anti-clockwise, landing on 11 o'clock. Phase rotation is always anti-clockwise, and each hour on the clock represents 30 degrees. (Elfving, 1993) (AL-BREIHI, 2014) (Portal, 2012) (Alexander, 2009)

2.6.3 Dyn11

A Dyn11 transformer has a delta connected primary winding (D), a wye connected secondary winding (y) and a neutral point brought out (n) and a phase shifting leading of 30 electrical degrees. The connection of the Dyn11 is presented in figure 7. (Elfving, 1993) (AL-BREIHI, 2014)

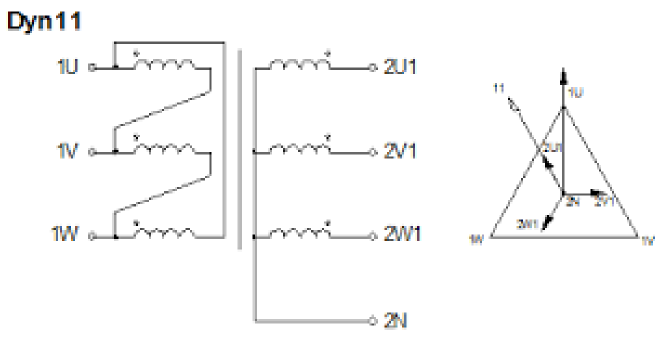

Figure 7. Dyn11 connection.

2.6.4 Variable autotransformer

An autotransformer has only one single voltage winding which is common to both sides. The construction of a variac is the same as for fixed transformers. A laminated magnetic core is surrounded by a single primary winding wrapped around it. The secondary voltage is tapped through a carbon brush instead of being fixed at a predetermined tapping point. A variable tap in the form of a carbon brush that slides up and down the primary winding. By sliding the carbon brush up and down the primary winding the length of the secondary winding can be controlled, which results in that the secondary output voltage is fully variable from the supply voltage value down to zero volts. (Castro, 2003) (Elfving, 1993) (Alexander, 2009) (AL-BREIHI, 2014)

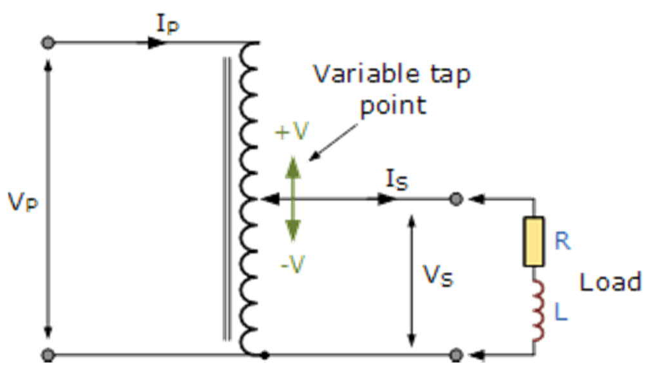

Figure 8. Variable autotransformer.

3 Methodology (Confidential)

4 Test Cabin Components (Confidential)

5 Result

The result of this Bachelor's thesis was to create a fully functional synchronizing tester for testing of the synchronizing circuits that are included in ABB's common panels. The first part of the thesis was planning and selection of right components. The chosen components are the best fit for the tester.

The second part was to create and design the drawings of the synchronizing tester. The drawings was planned and drawn in E^3. The drawings were completed and authorized.

The third part of this thesis work was to negotiate with the subcontractor and ordering of the synchronizing tester. Drawings and material list was sent to the subcontractor to be quoted. After receiving their quotation an investment decision from ABB's side had to be accepted. Investment decision accepted and the synchronizing tester could be ordered.

The functions of the synchronizing tester:

- Voltage and frequency adjustable for the generator side.
- Frequency adjustable for the bus bar side.
- Voltage level adjustable between 100 VAC, 110 VAC and 120 VAC on the bus bar side.
- Indication of voltage and frequency levels.
- Indication of breaker position.
- External control of voltage and frequency from connected device.
- Breaker control from connected device possible.
- Breaker position indication for connected device through signals.
- Visualization of the systems relation indicated by synchro scope.

The planning and drawing of the synchronizing cabin was completed and the synchronizing tester could be ordered through a subcontractor. The test cabin is still under construction, leaving the cabin tests incomplete.

The reader is referred to the attachments for further clarifications.

6 Discussion

This thesis covers a wide area. Everything from figuring out how transformers and frequency drivers works together, best solution, approach, how E^3 works, and how to build a test cabin from scratch. The size of the work for this thesis felt overwhelming in the beginning but in the end, the experience gained has made it worth it.

I received the thesis in the autumn of 2018 and had a lot of time to spend on it. In the beginning of this thesis work I spent most of the time studying the existing synchronizing tester and figuring out which components to use in the new improved version. By discussions and advice from Mr. Tony Bäck the suitable components and solutions was achieved. As time went by my hours became more and more limited. Busy school schedule and lot of service work from the employer. I was employed part time.

At the beginning of 2019 I put aside the work and focused fully on finishing my thesis. Most of the time was spent on learning and understanding how the drawing program E^3 worked. In January 2019 was the first time I opened E^3, spending hour after hour studying old projects and old drawings, I finally begun to get a hold of how the program worked.

The planning and designing of the synchronizing tester started in early January, and I put a great number of hours into designing of the tester. Because of lack of experience and skills regarding E^3. The learning process has mostly been achieved by trial and error.

When the finalizing of the drawings was done a meeting with the subcontractor was scheduled. Discussing the drawings and design of the synchronizing tester with the subcontractor gave us a new viewpoint of the cabin design. A few modifications were done and a new design of the cabin was drawn.

Drawings and material list was sent to the subcontractor to be quoted. After receiving their quotation an investment decision from ABB's side had to be accepted. Investment decision accepted and the synchronizing tester could be ordered.

The synchronizing tester is untested. The tester is still under construction by the subcontractor. I am satisfied with the drawings and functions designed at the moment. The drawings are made so it is easy to do modifications later if problems occur. The test cabin is also built in a way so it is easy to use, no complicated instructions are necessary. The cabin is however built as neat and small as possible, so if any extensions or modifications to the cabin are preferred problems could occur.

I have learned a lot working on this thesis. The process of planning, designing, coming up with a solution and getting it working has been rewarding. To do something with no experience, having to learn it and finally being comfortable with the subject has been a useful journey and experience. It has also improved my ability to discuss the subject with others to get a different point of view and therefore a better solution.

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List of Appendices