NOVIA
UNIVERSITY OF APPLIED SCIENCES

Electrical heater for charge air conditioning on a research engine

Henrik Wasberg

Bachelor's thesis

Electrical Engineering

Vaasa 2012

BACHELOR'S THESIS

Author:	Henrik Wasberg
Degree Programme:	Electrical Engineering, Vaasa
Specialization:	Electrical Power Engineering
Supervisor:	Matts Nickull

Title: *Electrical heater for charge air conditioning on a research engine*

Date: 29.3.2012 Number of pages: 42 Appendices: 4

Summary

This thesis work has been done for Wärtsilä, Testing & Performance (T&P). T&P belongs to R&D and the work was done in Waskiluoto Validation Center, which is an engine laboratory. The work has been to plan, dimension and install an electrical heater for the charge air conditioning system on a research engine. To be able to accurately regulate the load to the heater, a control cabinet also needed to be installed. The control cabinet is controlled from the PLC system.

The electrical heater is located after the existing liquid heaters and the heater is dimensioned to meet the process requirements. The PLC and Morphee systems are programmed for controlling the heater. Morphee is the user interface for the operator of the engine and it provides the engine operator with an easy, understandable user interface.

The electrical heater will be used in certain tests which need high charge air temperatures. It will also be used when the engine is started in order to faster achieve the wanted charge air temperature and save time. The result is a well working electrical heater for the charge air conditioning system, which has good regulation possibilities and is quite easy to use.

Language: English

Key words: charge air, electrical heater, power control

EXAMENSARBETE

Författare:	Henrik Wasberg
Utbildningsprogram och ort:	Elektroteknik, Vasa
Inriktningsalternativ:	Elkraftsteknik
Handledare:	Matts Nickull

Titel: *Elektrisk värmare för laddluftkonditioneringssystem till en utvecklingsmotor*

Datum: 29.3.2012 Sidantal: 42 Bilagor:4

Abstrakt

Detta ingenjörsarbete har gjorts åt Wärtsilä, Testing & Performance (T&P). T&P hör till R&D och arbetet utfördes vid Waskiluoto Validation Center, som är ett motorlaboraturium. Arbetet gick ut på att planera, dimensionera och installera en elektrisk värmare för laddluftkonditioneringsystemet till en utvecklingsmotor. För att kunna reglera effekten noggrant till värmaren behövs också ett kontrollskåp som regleras från PLC-systemet.

Den elektriska värmaren är installerad efter de befintliga vätskevärmarna och är dimensionerad enligt processens behov. PLC och Morphee systemet är programmerade att kontrollera och styra värmaren. Morphee är användargränsnittet för användaren till motorn och är programmerad och planerad att ge en enkel och klar användning av den elektriska laddluftvärmaren.

Den elektriska värmaren kommer att användas vid tester som behöver höga temperaturer på laddluften och dessutom kommer värmaren att vara i användning när motorn startas upp, för att snabbare uppnå önskad laddluftstemperatur och därmed spara tid. Resultatet för arbetet var en bra fungerande elektrisk värmare för laddluften. Den har bra reglermöjligheter och är rätt lätt att använda.

Språk: engelska

Nyckelord: laddluft, elektrisk värmare, effektstyrning

OPINNÄYTETYÖ

Tekijä:	Henrik Wasberg
Koulutusohjelma ja paikkakunta:	Sähkötekniikka, Vaasa
Suuntautumisvaihtoehto:	Sähkövoima
Ohjaaja:	Matts Nickull

Nimike: *Sähköinen ahtoilman lämmitin kehitysmoottorin ilmastointijärjestelmälle*

29.3.2012 42 sivua 4 liitettä

Tiivistelmä

Tämä opinnäytetyö on tehty Wärtsilälle, Testing & Performance yksikölle (T&P). T&P kuuluu R&D:hen ja työ on suoritettu Waskiluoto Validation Centerissä, joka on moottorilaboratorio. Työhön kuuluu suunnitella, mitoittaa ja asentaa sähköinen ahtoilman lämmitin kehitysmoottorille. Jotta tehoa pystyttäisiin tarkasti säätämään lämmittimelle, tarvitaan säätökaappi, jota ohjataan PLC-järjestelmän kautta.

Sähköinen ahtoilman lämmitin on asennettu nykyisten nestemäisten lämmittimien jälkeen ja mitoitettu prosessin tarpeisiin. PLC-ja Morphee-systeemit on ohjelmoitu valvomaan ja ohjamaan lämmitintä. Morphee on käyttäjälle tarkoitettu moottorin käyttöliittymä ja ohjelmoitu ja suunniteltu aikaansaamaan helppo ja selkeä käyttö sähköisestä lämmittimestä.

Sähköista ahtoilman lämmitintä tullaan käyttämään jatkossa testeissä, joissa tarvitaan korkeaa ahtoilman lämpötilaa ja startattaessa, että saataisiin haluttu ahtoilman lämpötila nopeammin ja säästettäisiin aikaa. Opinnäytetyön lopputulos on hyvin toimiva sähköinen ahtoilman lämmitin, jolla on hyvät säätömahdollisuudet ja jota on suhteellisen helppo käyttää.

Kieli: englanti

Avainsanat: ahtoilma, sähköinen lämmitin, tehonsäätö

Table of Contents

Abstract

Abstrakt

Tiivistelmä

Abbreviations

Appendices

Heater dimensioning calculations

Control cabinet wiring diagram

Heater and control cabinet installation drawing

Earth dimensioning

Abbreviations

SCE	Single Cylinder Engine
LFO	Light Fuel Oil
HFO	Heavy Fuel Oil
LNG	Liquefied Natural Gas
SCR	Silicon Controlled Rectifier
PLC	Programmable Logic Controller
NO	Normally Open
NC	Normally Closed
DO	Digital Output
AO	Analogue Output
AI	Analogue Input
DI	Digital Input
SG	Spark Ignited
DF	Dual Fuel
CR	Common Rail
RFI	Radio Frequency Interference

1 Introduction

The thesis has been made for Wärtsilä, Testing & Performance (T&P). T&P belongs to the Research & Development department and the work was done in Waskiluoto Validation Center, which is an engine laboratory. Wärtsilä provide lifecycle power solutions to enhance the business of their customers, while creating better technologies that benefit both the customers and the environment. In the Research & Development activities, the objective is to achieve a leading position in engine and propulsion technology, specifically in the areas of environmental technology, reliability, lifecycle costs and automation. /1/

The work was done to a research engine which uses charge air produced by large electrically driven compressors. The charge air heating system consists of two heaters before the engine but these two heating sources do not give the amount of heat that is needed in certain tests.

1.1 Background

The problem with the current system setup is that the temperature going into the engine is too low. The temperature level is not high enough and need to be warmer in some tests. It is important to be able to accurately control the charge air temperature, because it has a big impact on the engine performance. The heating system is not efficient enough to reach high temperatures and it also takes too long a time to reach them when the system is starting up. When the engine test cell was built, it was already planned for an electrical charge air heater but the heater was never installed. In the main electrical room there was already a place reserved for the heater fuses.

1.2 The problem with the current system

There are two existing heaters located before the engine today. One of them utilizes district heating water from Eteläpohjanmaan voima, which is a coal-fired power plant. The other heater uses waste heat from the air compressors. However, these two heating sources do not give high enough temperatures for the charge air. The temperature after the heaters decreases in the charge air pipe and the 7 m^3 air tanks, before it reaches the engine and especially when the engine is started up. The air tank and the charge air pipe are insulated and they are made to withstand high pressure levels, as they are built of thick steel and have a high thermal capacity. At startup the heat energy will first heat up the pipes and tanks and then the wanted charge air temperature is reached and this takes time. The problem is also that the received temperature is too low at the engine in certain tests.

1.3 Scope of the work

To solve the problem an electrical heater, as well as a power control cabinet are installed as it was planned when the test cell was built. The electrical heater will be located after the existing heaters and the heater has to be dimensioned to meet the process requirements. Both the PLC and the Morphee systems need to be programmed to control the heater. Morphee is the user interface for the operator of the engine and will be programmed to be able to control the heater and provide the engine operator with an easy, understandable user interface to the engine. Alternative heater control setups will be tested in order to find one, which works best for the process and which is easy to use.

1.4 Targets for the thesis

The targets of the work are to plan, dimension and install a heater for charge air, including the control system. The control cabinet will control the heater power and the temperature set point can be changed remotely by the operator through Morphee. Information about the real temperature after the heater will also be moved to Morphee where the operator gets an easy overview of the process. A fast reacting differential pressure sensor will also be installed above the heater in order to detect when the heater can be safely activated. Electrical drawings will be made for the control cabinet and other required connection boxes. The control system for the heater has to be configured and required programming in PLC and Morphee has to be done to get the heating system to work.

2 The research engine

The research engine is a Single Cylinder Engine (SCE) and its main purpose is to function as a tool for combustion development. As the engine only has one cylinder, there is more space for engine instrumentation and fuel costs are also reduced. The engine has been designed and built to be flexible and it is possible to set up the engine as conventional diesel, spark ignited gas, dual fuel, and common rail. Also new concept setups can easily be made on this engine. The SG setup is running on LNG and has a spark plug which ignites the LNG mixture. The DF setup allows running on both diesel and gas. In gas mode a small amount of pilot diesel is needed in order to ignite the gas. CR is a setup which uses high pressure fuel rail, which connects all the cylinders of the engine. /2/

2.1 Engine cooling system

The engine is using a low-temperature cooling system and has an exchanger for its own high-temperature cooling system to cool down the engine. The high-temperature cooling system is also used as preheating for the engine before start. The high-temperature cooling system is using a district heater to warm the water and a frequency-controlled water pump to get easy control of the High Temperature (HT) water pressure. The preheating of oil is also done with a district heater and a pneumatic backup system is ensuring that the engine always has lubrication, in case of a blackout or a pump breakdown. There are separate lube oil tanks when operating on diesel or gas and also a balance oil tank for balancing shaft lubrication. /2/

2.2 Control system

The control system of the engine is a complex system with many programs sharing information with each other. The heart in the control system is the user interface Morphee which is programmed to communicate with all the PLCs in the test cell, which are needed to operate the engine. The engine control is special because it is the only one in the engine laboratory using Morphee as the test-bed automation. A common Wärtsilä engine is operated from the in-house developed WOIS and this system only enables the operator to perform basic engine control tasks. /2/

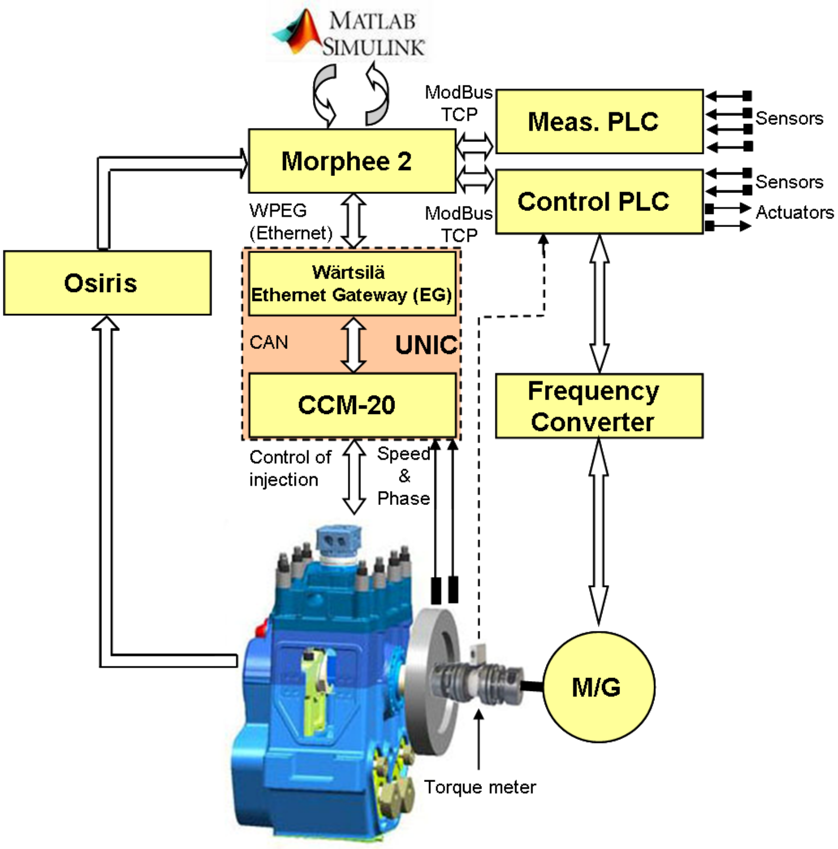


Figure 1. Engine control. /2/

2.2.1 PLC

In the engine test cell there are three PLC cabinets which use the Modicon Premium PLC system. A big majority of the sensors and actuators are connected to the PLC system in the test cell. The sensors and actuators located on the engine are not connected directly to the PLC, instead they are connected to the UNIC system, which is the control system for the fuel injection system on this research engine. /2/

2.2.2 UNIC

The control system which controls the fuel injectors is UNIC. This control unit is connected to Morphee. Fuel injection parameters and measurements from the engine are communicated between Morphee and UNIC. /2/

2.2.3 Morphee

The operator interface of the engine is Morphee which adjusts engine parameters and controls the engine and measurements. The program is programmed to be able to control all different engine setups and has contact with PLC, UNIC and fast measurements (Osiris). The Morphee has several algorithms, for example fuel consumption calculation from three different fuel scales and an algorithm that gathers measurement data from all subsystems (emission, smoke meter, opacity meter, fast measurements, UNIC, PLC and more) into a file for engine performance evaluation. /2/

2.2.4 Engine modes

The engine has five control modes in use to facilitate the engine running and provide a safer operation of the engine. These control modes are Emergency Stop, Rig off, Standby, Run and Combustion. When the motor is at stop, the mode is Rig off and all auxiliary units are shut off, so it is safe to leave the engine. When the engine is ready for getting starting, the mode is standby, and this allows preheating of lube oil and high-temperature cooling water. The generator is started in Run mode and is used as a motor. The electrical motor rotates the engine and when changing to Combustion mode the fuel injection is enabled. In the combustion mode, the electrical motor also starts to work as a generator and produces electricity to the grid through the Vacon frequency converter. /2/

```
16:45:26.768 - Campaign:Entr...:      0"000 -- Deviation from reference alarm: PT601 = 0.075 bar < 0.1 bar
16:45:26.768 - Campaign:Entr...:      0"000 -- Deviation from reference alarm: PT601_2 = 0.088 bar < 0.1 bar
```

SPEED SETPOINT 730.000 RPM

0h00'00"

TIME BEFORE STANDBY 0 h 0 min

SPEED 730.000 (rpm)

POWER 2.60 (kW)

PLC TORQUE -2.160

HBM TORQUE -2.975

TIMING (deg CA) 200.0 | 0.0

DURATION (usec)

SPEED (RPM) 729.00 | 729.00

POWER (kW) 2.60

TORQUE (kNm) Filtered 0.034 | Offset 3.058

RAIL PRESSURE (bar) 0.00

M S 1000.0 | 0.00

BMEP (bar) 0.13

PC023 - CA Pressure stage 1 (bar) 7.00

PC024 - CA Pressure stage 2 (bar) 0.20

PC025 - CA Temperature control (°C) 40.00

PC021 - CA Humidity control (%) 0.00

PC026 - EGR Pressure control (%) 0.00

PC027 - EGR Flow control (%) 0.00

PC028 - Counter pressure control 1 (bar) 0.00

PC029 - Counter pressure control 2 (bar) 0.00

Figure 2. Morphee engine control. /1/

There is an emergency stop circuit in the engine test cell. If something goes wrong, the engine can be stopped quickly by pressing an emergency stop button. Buttons for the emergency stop are located in the test cell and control room. When the buttons are pushed, the engine will automatically go to emergency stop mode and the frequency converter is forced rapidly to ramp the rotational speed to zero. /2/

2.3 Charge air system conditioning

The engine is equipped with a charge air conditioning system which uses electrically driven compressors to produce the charge air. The charge air has free adjustment of pressure, temperature and humidity in order to cover a lot of different engine operating points. The charge air system consists of many sensors and valves, which control the air. The most important sensors for engine performance are flow meter, temperature and humidity sensors, which measure the real value that the engine receives. /2/

2.3.1 Compressors

The main components of the charge air conditioning system are the two 250 kW electrically driven screw compressors, which supply the engine with charge air. The compressors' maximum work pressure is 10 bar and they manage to produce 38.7 Nm^3/min each. The compressors are cooled with water and the water is then used to heat the charge air. The pressure after the compressors is 10 bar and is adjusted down to the wanted pressure with two valves. The last control valve for the charge air is located after the third 7 m^3 tank and before the heaters. There are also valves which adjust the air flow through the air dryer, cooler and heaters. /2/

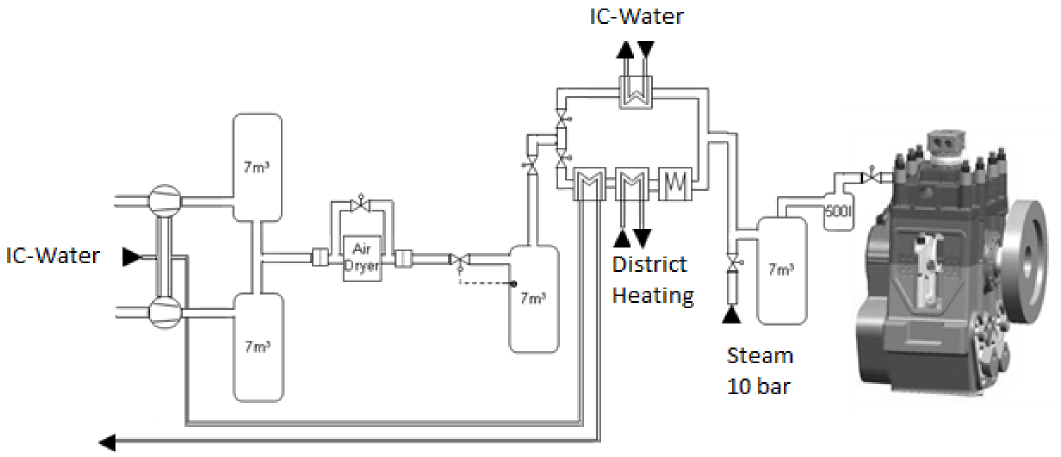


Figure 3. The charge air conditioning system. /2/

2.3.2 Air tanks

There are five air tanks in the system in order to provide the engine with the correct air pressure and flow characteristics. The first two tanks are located after the compressors and they are 7 m^3 each. The tanks after the compressors are buffer volume for the compressors. The third tank is also 7 m^3 and located before the heaters and cooler, and this tank removes pressure fluctuations caused by the compressors. In this tank the pressure is still high but in the fourth 7 m^3 tank the pressure is lower and the wanted charge air pressure has been achieved. The fifth tank is a buffer tank located just before the engine. The buffer tank is also the smallest 0.5 m^3 and it works with the fourth tank to bring an air volume reserve close to the engine in order to achieve similar gas exchange dynamics as on a production type of engine. /2/

2.3.3 Humidity in the charge air

The charge air conditioning system has free adjustment of air humidity. There is an air dryer which works with air pressures up to 14 bars. There is also a steam feed line to the test cell that allows the addition of 5-30 g water/kg dry air. The steam is mixed into the air before the last 7 m^3 tank. The main purpose of the steam system is to enable simulation of tropical running conditions. /2/

2.3.4 Sensors in the process

In the charge air conditioning system there are several sensors measuring temperature, pressure, flow and humidity. The sensors in the charge air system are cabled to three PLC cabinets, depending on where the sensor is located. The sensors are giving an analogue signal to the PLC cabinets and are connected to an analogue input terminal. Some sensors must have a transducer or amplifier to get an analogue signal (mA or V) that the PLC manages to handle.

The sensors measuring temperature in the process are of the PT100 or thermocouple type. The PT100 sensor can be connected with 2-4 wires. The 2-wiring connection is not used, because the measurement accuracy is poor when the wire resistance is not considered in the measurement. The sensors are connected with 3 wires and with this connection the accuracy is much better and the transducer considers the resistance in the wires to the sensor. The PT100 needs a transducer to be able to connect it to the AI on the PLC. This module changes the signal to an analogue signal accepted by the PLC. The resistance in the PT100 is 100 Ω at 0 °C and the resistance is rising with higher temperature. Thermocouple sensors measure higher temperatures than PT100 and this sensor also needs a transducer before it can be connected to the PLC. The thermocouple sensor gives a mV signal created when two metals are connected to each other. The measuring point is there where the two metals are connected and, depending on the metals, the sensor measuring range changes. /3/

Figure 4. PT100 and a dip-switched configurable transducer. /4/

The pressure is measured with gauge pressure sensors with mA output and the sensor adjusts the current in the wire depending on the pressure. These sensors are connected with two wires.

Relative humidity is measured in two separate locations in the charge air system. The first place is directly after the air dryer and is measured by a Vaisala sensor. The Vaisala humidity sensor also measures temperature at the same spot in order to make relative humidity measurements possible. The other humidity meter is located before the small air tank before the engine. This last place of measuring humidity is comparable to the humidity of the air in the combustion chamber.

2.3.5 Cooler and temperature control

There is a cooling possibility for the charge air. A charge air cooler is installed in parallel with the heaters and the air flows through the heaters, and the cooler is controlled in order to reach a desired charge air temperature in the receiver. The control of the charge air temperature at the engine is adjusted with two valves that adjust how much air is flowing through the heaters and cooler. The valve is adjusted from the PLC and the wanted temperature is set by the operator in Morphee. The real temperature is measured before the engine and a PID regulator is controlling the valves to ensure that the desired receiver temperature is obtained. /2/

2.3.6 Heaters

The heating system initially consisted of two heat exchangers. As heating source one heater uses district-heating water from Eteläpohjanmaan voima, which is a coal-fired power plant. The district-heating water pressure is too high for the heater, so that an intermediate circuit is needed in order to get the correct pressure levels. The other heater is using waste heat from the air compressors. /2/

Figure 5.The charge air cooler and heaters in the test cell.

3 Electrical heater and control cabinet

It has been determined that an electrical heater will be installed after the existing liquid heaters to ensure a higher charge-air operating temperature. The electrical heater will also be handy in the startup of the engine as it enables a faster received charge air temperature. The process requirements have to be considered when the heater is dimensioned and the heater will be dimensioned to have a 200 °C charge air. To manage to regulate the power to the heater, a control cabinet is also needed to control the power accurately.

3.1 Heater dimensioning

The engine is made flexible and it is possible to set up the engine with 26 to 40 cm cylinder diameters. When dimensioning the charge air heater, this has to be taken into consideration. The heater will be dimensioned for two different cylinder diameters in order to determine the maximum heater power for each setup and which heater would suit the process best. In the current system the heaters manage to heat the charge air up to about 70-80 °C. The charge air pipe system is made to withstand a maximum temperature of 200 °C, therefore the heater will be dimensioned according to this. This means that the temperature has to increase with 130 °C to get the desired 200 °C receiver temperature. The most frequently used cylinder configuration in the engine is the W32 and therefore one heater dimensioning is done for this cylinder configuration. The other dimensioning is done for the biggest cylinder that the engine is done for, which is the W40 configuration. When calculating the heating power needed for each cylinder configuration, information about the air flow is needed. The W32 has an air flow of 3330 kg/h (500 kW/cylinder) and the W40 has an air flow of 7992 kg/h (1200 kW/cylinder). The heating power needed for both cases is calculated according to the formula 3.1.1 on the next page. /2/, /5/

$$Q = mc_p\Delta\mathrm{T} \qquad (3.1.1)$$

Q = *Heating power [W]*
m = mass [$\frac{Kg}{s}$ *]*
c_p= *specific heat (capacity) [* $\frac{J}{Kg \cdot C^{\circ}}$*]*
ΔT= *temperature change [°C]*

The calculations for the heater dimensions are attached in Appendix 1 for both cylinder configurations. The heating power needed for the W32 cylinder was calculated to 122 kW and for the W40 cylinder to 292 kW. It has been decided that the heater is an Osram Sylvania and the heater dimension was chosen from their range. A 192 kW heater with a three-phase power supply was selected. The heating power is lower than the effect needed for the W40 but the next size would have been 400 kW. The most used cylinder configuration in the engine is W32 and W34 and for this purpose the 192 kW heater will be sufficient.

3.2 Power control

To be able to control the load to the heater, a control cabinet is ordered together with the heater. Osram Sylvania had two kinds of control methods and four or six SCRs adjusting the load in their range. The control of the heater is done by SCRs, which are semiconductor rectifiers that have the added feature of controllability. The SCRs are capable to conduct or block current in the forward direction, depending on the gate signal. The SCR always blocks the current in the reverse direction like a diode and therefore every phase has to consist of two SCRs connected back to back. One SCR conducts the positive period and the other the negative period. /6/

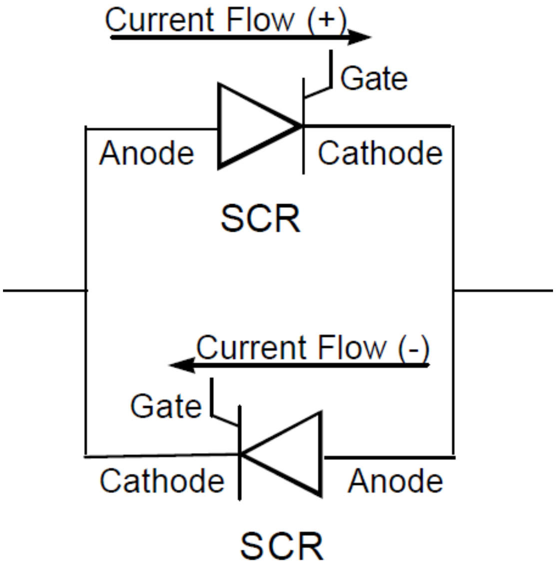


Figure 6. Back to back connected SCRs /5/

The SCR consists of an anode, a cathode and a gate. The current flows from anode to cathode when a trigger signal reaches the gate. The SCR stops conducting when the gate is turned off and the voltage over the SCR reaches zero. The gates on the SCR are connected to a control circuit, which are synchronized with the line frequency. The SCRs are not perfect conductors and all SCRs exhibit some voltage drop over the component. A general voltage drop that is used is 1.5 V and with big currents the cooling of the SCR has to be properly done to keep the SCR within the operating temperature range. /6/

3.2.1 Phase-angle control

The first control method for controlling the load to the heater is a Phase-angle control. The phase angle is adjusted by the SCRs and it also controls the current to the heater. The Phase-angle control is accurate and tight but this method allows fast current change when the SCRs are turned on. This fast current change happens two times per sine period and this causes noise and Radio Frequency Interference (RFI). RFI causes degraded radio communication, disrupts computer operations and gives interference in the measurements. /6/

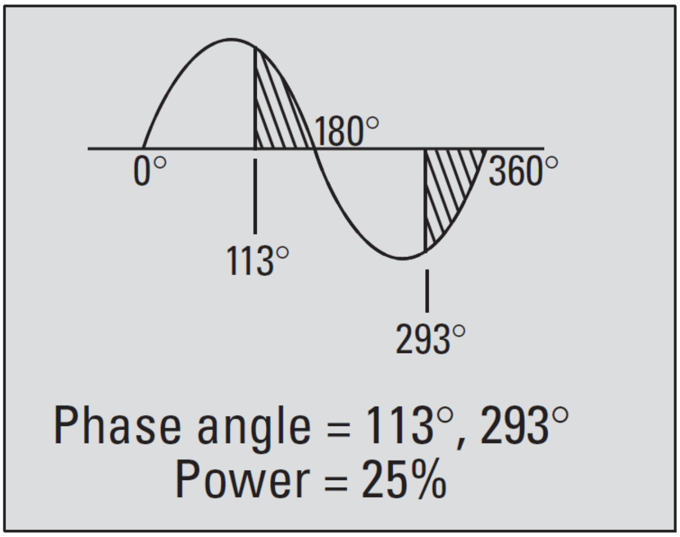


Figure 7. Phase-angle control./6/

Phase-angle control used in three-phase power controllers can be Δ or Y connected. The control method requires that every leg is controlled and therefore the number of SCRs used is six. A hybrid connection is also possible where one SCR is replaced with a diode in every leg. The control is suitable for all types of loads and has a soft start that allows a smooth increasing of the load. The control method also gives harmonic waveforms which destroy the 50 Hz sine wave. /6/

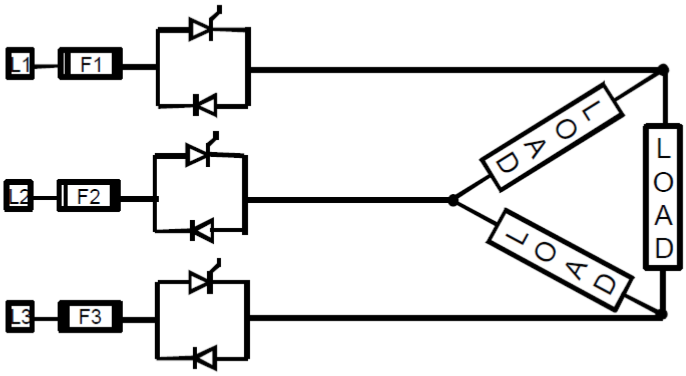


Figure 8. Three-leg delta hybrid connection. /6/

3.2.2 Zero-cross control

The second method to adjust the load is to use Zero-cross control, which allows the SCR to gate when the AC voltage is zero. The SCR will remain on until the voltage across the SCR drops again to zero. The load to the heater is controlled with the amount of cycles when the sine wave is on or off. Zero-cross control of a three-phase load can be done by controlling two or three legs. The control with two legs uses only four SCRs and the third phase is connected straight to the grid. The control with three legs uses six SCRs and the load can be connected Δ or Y. /6/

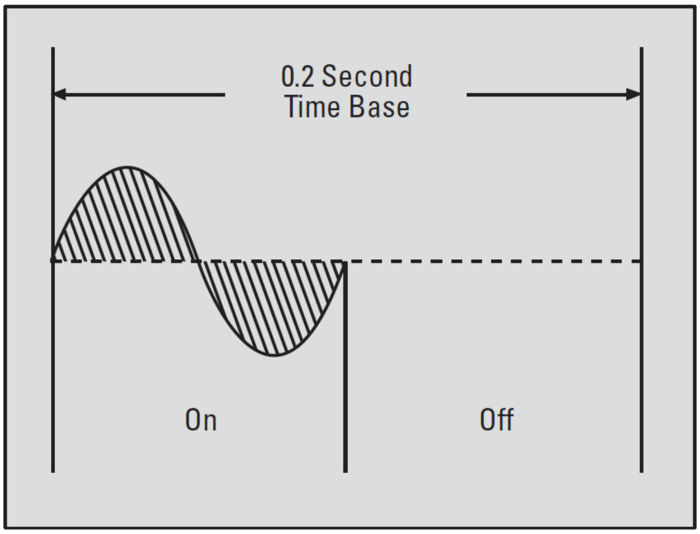


Figure 9. Zero-Cross control. /7/

The control method is quieter than the Phase-angle control because the SCRs turn on and off when the current is zero. The control method does not cause as much RFI when the SCRs are allowed only to gate when the current is zero. The lifetime of the heater is also extended when fast current changes are not possible. One disadvantage of the Zero-cross control is that it suits only resistive loads. /6/

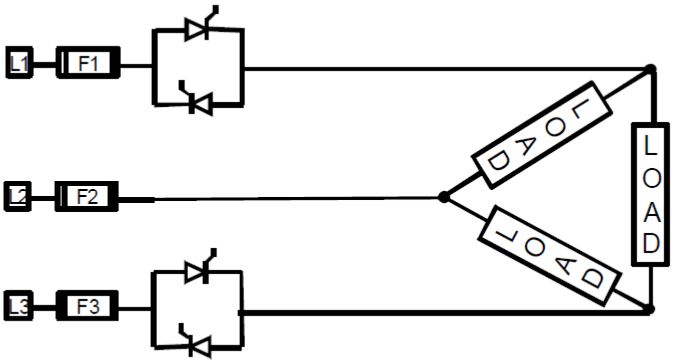


Figure 10. Two-leg Δconnection*. /6/*

3.3 Selected control cabinet

The control method was selected for the Zero-cross control because the load is resistive and this method does not cause as much RFI as the phase angle control. For a laboratory environment, keeping RFI on a low level is of a certain importance. The reliability is also better than that of the Phase-angle control as it consists of fewer components and as the SCR turns on when the voltage is zero. The Phase-angle control does not have any big benefits compared to the Zero-cross control and a common rule is that the Zero-cross control is used if possible.

There are two models with Zero-cross control which suit the heater, ZF2 and ZF3. Both models are three phase, 350-500 A, but the ZF2 is 2-leg/4SCR and the ZF3 is a 3-leg/6SCR. The heater current is 277 A in this case. This is of course lower than 350 A, but the next smaller model is rated 225 A so that is not an option. The difference between the ZF2 and the ZF3 is that the ZF3 is controlled by three legs and the ZF2 is controlled by two legs but both work well and fulfil requirements in terms of functionality. The model taken was the ZF3 because Osram Sylvania recommended it. /8/

Optional functions were added to ensure safety and easy control of the heater. Heaters over 90 A are all standard-equipped with a thermostat that shuts down the heater if it is too warm. The switching contact of the high limit temperature alarm indication is connected to a contactor where NO or NC can be chosen. In the control cabinet there is also an alarm for the over-current trip, which controls the current through the SCRs and, like a fuse, it shuts down the heater and gives an alarm when the current is too big. The SCR over-current trip indication works as the high-limit temperature alarm with a switching contact in the control cabinet where NO or NC can be chosen. /8/

Figure 11. The control cabinet installed.

4 Cables and fuses

The electrical installation of the heater system has to meet the regulations that are used in Finland. The cable dimensions and installation directives are taken from the SFS 600 manual (Low-voltage electrical installations and safety at electrical work). The SFS 600 manual is published by the electric and electronic branches' standardization organization SESKO r.f. The SFS 600 manual consists of the standard SFS 6000, which deals with low voltage installations and the standard SFS 6002, which is about the electrical safety and building regulations and the operation of electrical installations. /9/

4.1 Main supply

The control cabinet for the heater needs 3 phases to work and does not need any neutral wire. The fuses in the main central were chosen for 3 x 315 A gG because the heater current is 277 A and the next-size fuses were chosen. The cable has to be dimensioned for the weakest point where it is installed. The cable shelves in the compressor room where the control cabinet is located were full, therefore new shelves were made from the main electrical central. The factor relevant for the situation must be used if the temperature where the cable is installed is another than 25 °C. Another factor must be used if more than one cable is installed on the same cable shelf or if the cables are installed next to each other. The factor used changes the final load capacity of the cable needed and will result in a larger or smaller cable area if the temperature at the installation is over or less than 25 °C. In this case the main power supply will be the only one installed on the cable shelf. The temperature where the cable is installed will not rise higher than 25 °C. Due to this it was not necessary to take other cables and temperatures into account. /9/

The cable dimension was taken from the SFS 600 manual. First the minimum load capacity of the 315 A fuse was taken from Table B.52-1. The load capacity was 348 A. The cable installation method was taken from Table A.52-1 and when the cable is installed on a cable shelf, the reference installation method is E (multi-conductor cable freely in the air). There were no factors to consider for the cable and the cable was chosen according to the load capacity in Table A.52-4 for copper and Table A.52.5 for aluminium. The cable's maximum load capacity was chosen from a table and from the column with three loaded conductors. The copper cable was chosen for 185 mm² with a maximum load capacity of 386 A. If an aluminium cable is used, the area must be 240 mm² and a maximum load capacity of 350 A. A copper cable was chosen because the 185 mm² copper cable is thinner than the 240 mm² aluminium cable and has a smaller bending radius. It will be much easier to install in the control cabinet and in the main central. The decision was to use a copper cable, MCMK 3x185+95, which has three phase conductors of 185 mm² each and an earth around all the phases which are 95 mm². /9/

4.2 Heater supply

The heater has double three-phase Δ connected heater elements inside. Each of the heater elements has a rated electrical power of 96 kW. The heater power supply requires six cables to be installed from the control cabinet to the heater and they should be heat resistant. The heater current is calculated in each conductor to be 139 A (96000W/ (√3·400V). The protection of the over current is done by six 175 A fast fuses located in the control cabinet. /9/

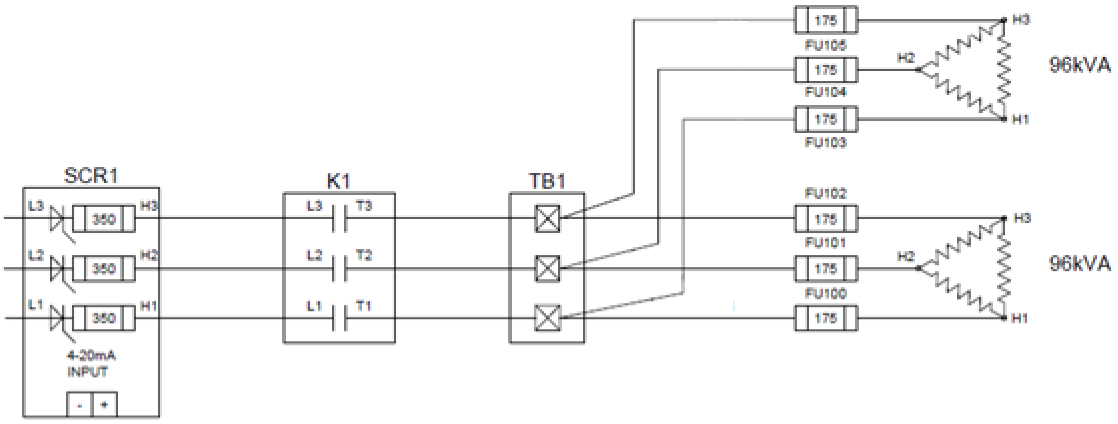


Figure 12. Connection of the heater elements.

The cables were dimensioned according to the SFS 600 manual and the installation method was first taken from Table A.52-1. The cables will be installed on a new cable shelf which was installed between the heater and the control cabinet. The reference installation method is F (Single cables touch each other in the air). Two three-phase circuits were installed on the same cable shelf so the relevant factor has to be considered. The relevant factor was taken from Table A.52-21 for perforated shelves and cables touching each other. The relevant factor was 0.91 for two three-phase circuits, and the finishing load capacity was calculated to 153 A (139 A / 0.91=152.7 A). The cable dimension was chosen from Table A.52-6, which is for PEX-or EPR-insulated cables. A 35 mm² copper cable with a maximum load capacity of 183 A was chosen. /9/

The cables connected to the electrical heater have to be heat resistant in order to protect the conductors. Different kinds of insulation material are used in cables to give specific operation temperatures. PVC cables withstand a temperature of 70 ˚C and the next step is PEX and EPR cables which withstand a temperature of 90 ˚C. The EVA rubber withstands a temperature of 110 ˚C but in this electrical heater installation the cables have to be very resistant against heat. The silicon rubber withstands a temperature of 180 ˚C and resists oil, alcohol and acidic conditions. The selected cable is a Sif/GL 35 mm², whose insulation is made of silicone rubber and has a layer of glass fiber yarn braid. /9/

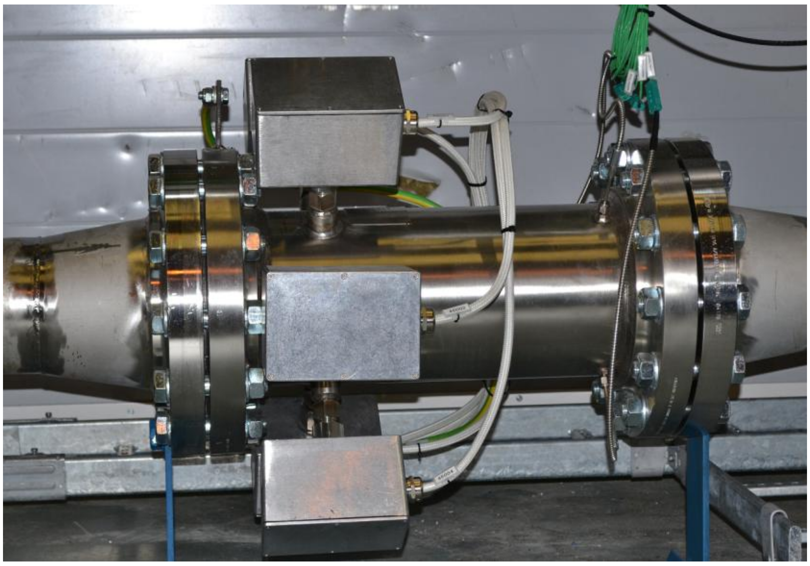


Figure 13. The heater installed.

4.3 Earthing

The earthing has to be connected with the heater and the control cabinet. The control cabinet is connected with one 95 mm² copper earth conductor from the main central, which is included in the same cable as the main power supply. The heater is connected with an earth from the potential equalization rail in the main central. The earth from the potential equalization rail is calculated to be 32.9 mm² according to the formula 4.3.1. The calculations are enclosed in Appendix 2. A 50 mm² copper cable was chosen as heater cables because it was the next available size. The cable was also spliced in a T-connection and connected to the earth in the control cabinet. A grounding terminal had to be welded on the heater because the heater manufacturer had left this undone. The grounding of the heater enables safety operations in case something breaks in the heater and the heater becomes conductive. Leaving out the ground terminal in the heater design is a clear deficit. /9/

$$A = \frac{\sqrt{I^2 \cdot t}}{k} \tag{4.3.1}$$

A= Cable area [mm²]
I = Fault current [A]
t = operating time [S]
k = Factor for cable

The control cabinet was not equipped with any earth terminal when it arrived and the connection terminals were custom made for the 95 mm² cable and the 50 mm² earth cable was directly connected to the mounting plate with a cable lug. The control cabinet consisted of a door and sides, which were conducting but they were not earthed in the cabinet. The door and sides were separately connected to the mounting plate in the control cabinet with 16 mm² copper cables.

4.4 Signal cables

To be able to control the heater, a signal cable is installed between the PLC cabinet and the control cabinet in order to give information and feedback between the cabinets. A Jamak cable with six pairs was selected in order to route all required signals between PLC and heater cabinet. The cable choice was a Jamak 8X(2+1)X0.5 and this cable has eight pairs inside and every pair consists of two conductors. The cable also has a shield around every pair and a shield around all the pairs, to protect against interferences. For the differential pressure sensor the selected cable was a Jamak 2X(2+1)X0.5 because the sensor requires only one pair and the cable was in stock. The other pair in the cable is a spare.

The thermocouple sensors in the heater were of type K. Each of the thermocouple types requires a different cable and here a cable for the K type was selected. The thermocouples from the heater were spliced and two of the thermocouple signals were installed to the control cabinet and the third to the PLC cabinet for a configurable temperature transducer. The transducer was DIP switched to work as K type, cold junction compensation was set on, the start temperature was set to 0 °C, the end temperature to 250 °C and the output was also configured. The thermocouple signals for the control cabinet manage to handle the mV signal from the sensors.

4.5 Drawings

Making drawings for the heater installation was also a part of the thesis work. The heater was supplied with drawings made according to USA-standard. To make the drawings easy to understand and later facilitate troubleshooting, the drawings were made more user-friendly. The new control cabinet drawing was made in AutoCAD 2009 and all components and connection terminal blocks were included in the drawing. The signal cables to the control cabinet were also marked on the drawing. The drawing is included in Appendix 3. A second drawing was made to facilitate the installation of the heater and the control cabinet. This drawing is easier to understand as all the cables and connection clamps are marked in the drawing, in order to get the heater to work as desired. The drawing is included in Appendix 4.

The drawings for the PLC cabinet were also made. All cables which were installed were also given a cable number in each end according to the system which is used at the plant. The cables coming from the PLC cabinet BAP041 were given a number of 41 000 and cables from the control cabinet, NGE041 were given a number of 46 000. The main supply for the control cabinet was coming from the main central BCK041 and therefore it got a number of 40 000. The cable numbers were also included in the cable list of the plant.

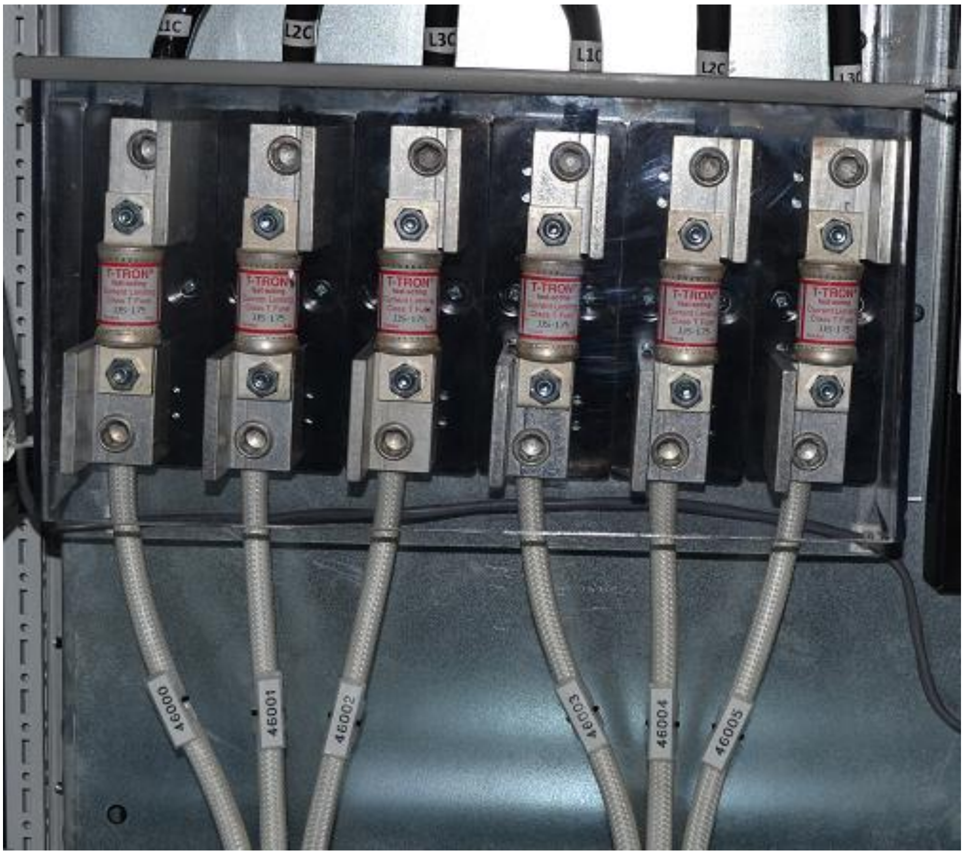


Figure 14.Cable markings on the heater cables in the control cabinet.

5 Control of the heater

The heater is controlled from the user interface Morphee. The PLC is also an important component in the control system, which helps Morphee and external devices to communicate with each other. The temperature setpoint for the electrical charge air heater is set from Morphee in °C and through the PLC to a 4-20 mA signal accepted by the Gefran 1600 controller. The process value is measured by thermocouple sensors and the heater power is controlled in order to reach the desired setpoint. The process temperature is controlled by the Gefren PID controller and gives a signal to the SCR unit which adjusts the current to the heater.

It is possible to control the heater remotely or manually. If manual control is used, a contact is added after the transformer in the control cabinet, switching out the remote control device. In this case the heating system is planned to be remotely controlled only and a jump lead is replaced instead of the contact.

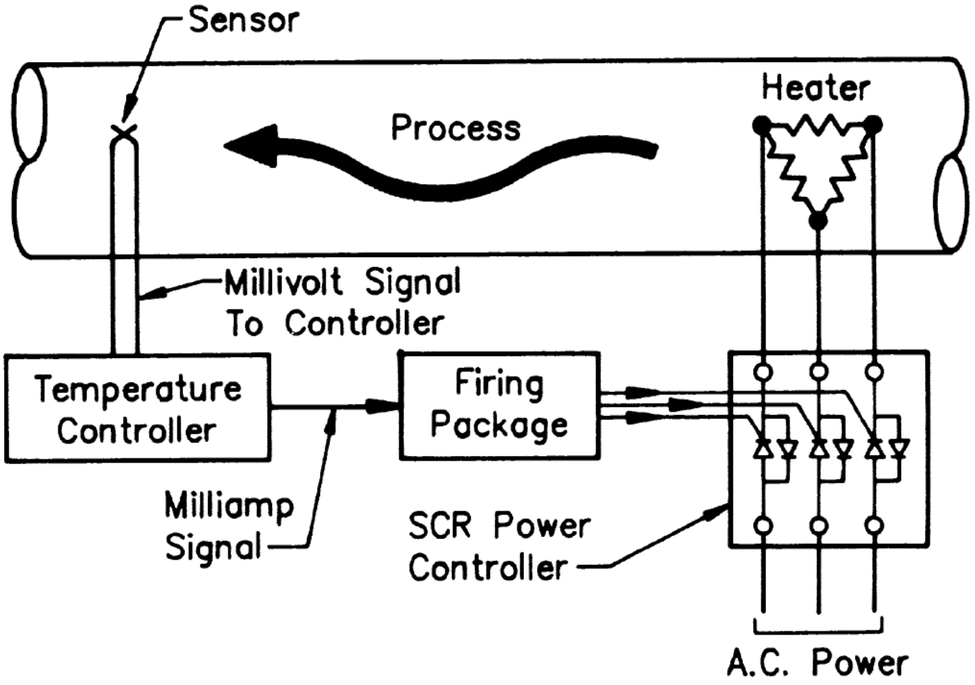


Figure 15. Process of controlling the temperature (only one Δ connected heater element in the picture). /6/

5.1 Air flow protection

An important safety protection for the heater is the air flow protection which prevents the heater from overheating. Osram Sylvania recommended installing a differential pressure sensor above the heater in order to control the air flow through the heater. The pressure above the heater according to Osram Sylvania has to be over 25 mbar. A Siemens sitrans differential pressure sensor was chosen. The measure range of the Siemens pressure sensor was twice as big as needed and the sensor was rescaled to 0-30 mbar. The sensor linearity was tested and calibrated.

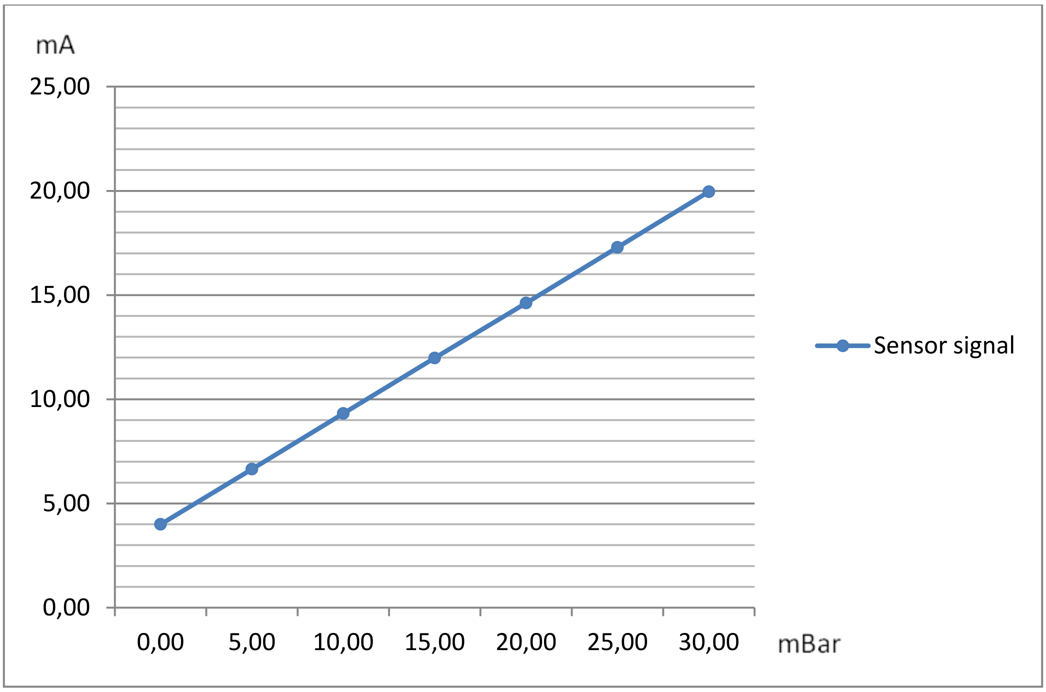


Figure 16. The differential pressure sensor scaled and tested.

The differential pressure sensor is connected to the PLC cabinet and ensures a safe operation of the heater. If too small an air flow flows through, the heater will cause a shut off of the main contactor K1 in the control cabinet. The control circuit of the contactor K1 will be currentless and the load to the heater is disconnected.

5.2 Analogue signals

The Gefran 1600 controller has two analogue outputs, one 4-20 mA, which gives the measured temperature after the heater to the PLC and Morphee. The other analogue output from the controller is also 4-20 mA, but it is connected to the SCR unit and adjusts the load to the heater. The setpoint temperature for the controller is sent from the Morphee and the PLC scales the temperature to a 4-20 mA signal. /10/

5.3 Digital signals

Digital signals in this installation are mainly used for alarm signals or on/off buttons from the control cabinet or the PLC. A digital run/stop signal is connected to the PLC in order to make it possible to put the heater on and off. In the series with the run/stop contact there is an SCR overcurrent trip and high limit alarm which shuts down the heater by opening the control circuit of the contactor K1. The alarms will be activated if the heater is too warm or if too big current flows through the SCR unit. An emergency stop circuit and low air flow contacts were also planned to be installed in series with the contactor K1 controlling circuit in the control cabinet. These two contacts were not installed as in the drawing and it was not necessary to install them directly in the control cabinet, because the heater will not be dangerous if an emergency stop activates. /7/

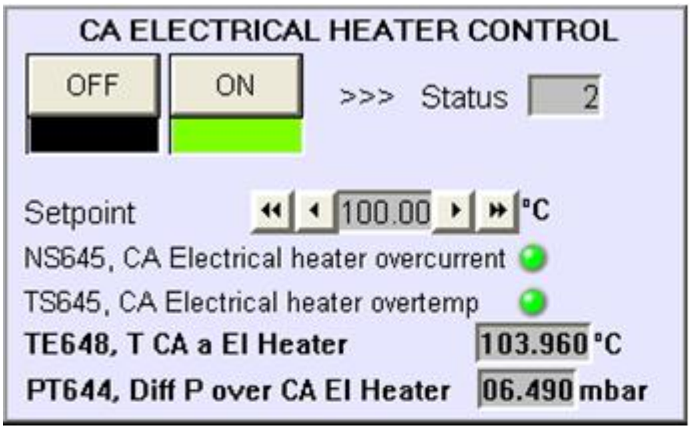
Figure 17. Athena controlling the high limit of the heater.

When an alarm is activated from the SCR over current trip or high limit alarm, the heater will be shut down and an alarm trip will be transferred to the Morphee through the PLC. Two digital inputs are used in the PLC to detect the alarm. The contacts are normally closed in the control cabinet but will be opened when a fault is detected and give an alarm to Morphee. The alarm has to be reset before the heater can be used again. The SCR over current trip has a button in the control cabinet by which the alarm is reset. Athena, which controls the heater temperature, had a possibility to reset the alarm from Morphee through the PLC. A remote reset alarm was not implemented for safety reasons. A manual reset was preferred to be installed in the control cabinet. /7/

Figure 18. A PID regulator switch and a high limit reset have been added in the control cabinet’s door.

5.4 PLC and Morphee

The PLC and Morphee were programmed to work with the control cabinet and to transfer information between them. The analogue inputs in the PLC have to be scaled right in order to display the right differential pressure above the heater and give the right process temperature. The PLC was programmed so that it is possible to put on the heater only in run or higher mode and when the heater has an air flow through it. The wanted temperature is set in Morphee when the heater is activated and the information is transferred to the PLC. The PLC sends the setpoint to the PID controller in the control cabinet, if manual control is chosen. The process temperature is also displayed in Morphee and this temperature is coming from the TE648, which is a PT100 sensor. The alarm indications from the control cabinet are transferred to Morphee and display red when an alarm is activated and green otherwise. The differential pressure sensor value is also displayed in Morphee and this information in Morphee gives an easy overview of the process.



Status 2

Setpoint 100.00 °C

NS645, CA Electrical heater overcurrent ●

TS645, CA Electrical heater overtemp ●

TE648, T CA a El Heater 103.960 °C

PT644, Diff P over CA El Heater 06.490 mbar

Figure 19. Charge air electrical heater control in Morphee.

6 Inspections

Before the heater system is taken in use a system inspection is needed to ensure safe operation. The SFS 600 manual defines required measurements and required measurement results in order to pass the tests. The measurements are done with an Amprobe installation tester. A visual inspection is also done to ensure that the installation is done by the standards and that everything looks okay.

6.1 Earth conductivity

An earth conductivity test is done to ensure that the earth cable is connected properly. The earth conductivity is measured for the control cabinet and the heater. The Amprobe installation tester is used to measure and one end is connected at the potential equalization rail in the main central and the other at the heater or in the control cabinet. A long cable is used to measure the distance between the two points and the meter is deducting the resistance of its own cables which it uses. The final value the meter gives is the resistance between the heater or the control cabinet and the potential equalization rail. The continuity was measured to 0.01 Ω for both the heater and the control cabinet and it means that the earth is properly connected and thus passed the test. /9/

6.2 Cable impedance

The impedance is measured for the main power supply and the power supply to the heater. The measurement is done to see how well the voltage-providing wires and connections are isolated to the earth. When the main power supply was measured, the cable was dead. The main switch had to be off in the control cabinet in order to protect the sensitive electronics from damages. All phases had to be connected with each other. One measuring wire from the meter was connected to the phases and the other wire to the earth in the control cabinet. The impedance was measured to >199.9 MΩ. This result is well below the limit and passed the test easily because the limit is 1 MΩ. The heater power supply was measured as the main power supply and all phase wires were connected with each other. The measuring wires were connected to the earth and the phases. The impedance was measured to 10.5 MΩ and it passed the test well as the limit is 1 MΩ. /9/

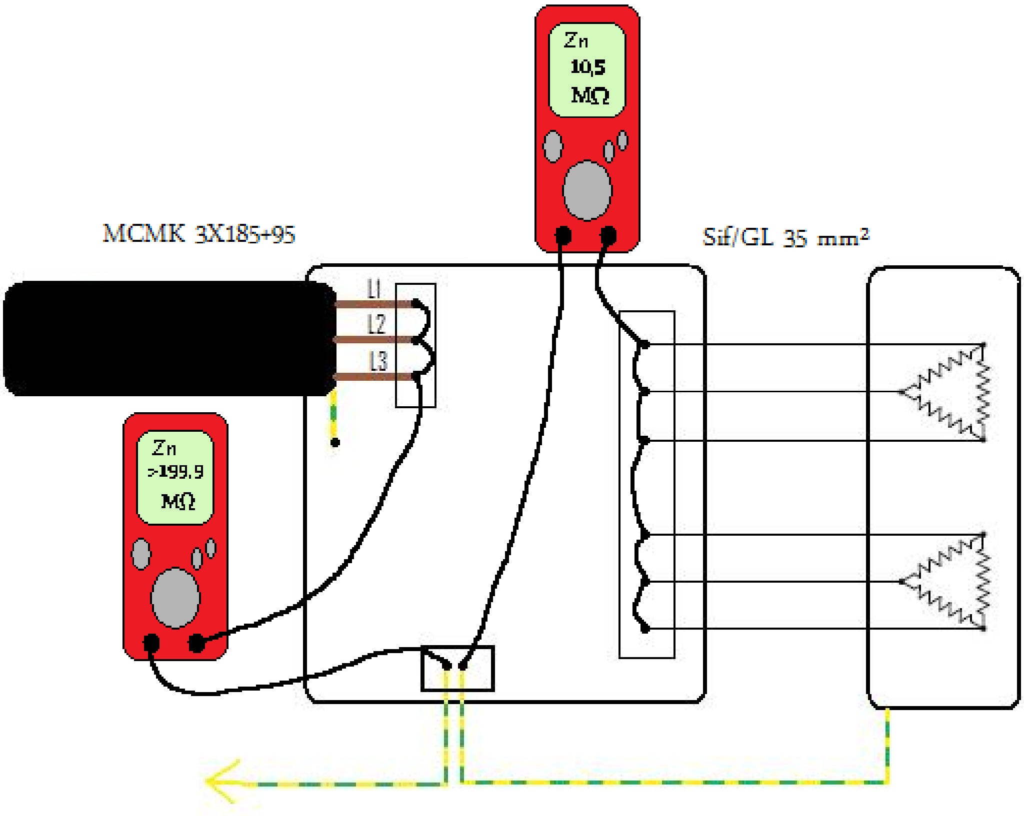


Figure 20. Impedance measurement connections.

6.3 Short circuit current

The short circuit current is measured for the main supply, and the fuses have to be replaced in the main central and the main switch switched on. The meter is connected between two phases in the control cabinet. The meter measures the current flowing through the meter and also the voltage drops. The meter then calculates the short circuit current. The short circuit current was measured to 6.66 kA between two phases and it passed the test because a 315 A fuse must have a short circuit current which is at least 2.3 kA. /9/

7 Commissioning and testing

After the inspection had been done the heating system was ready to be tested and adjusted. The high limit alarm was adjusted in the Athena to 200 °C in the control cabinet to prevent the heater from overheating. The temperature sensors were scaled in the Gefran controller to 0-750 °C and the control setpoint was scaled to 0-200 °C. The process temperature from the Gefran controller was scaled to 0-200 °C in the PLC. The Gefran PID controller had default settings for the heater and they were checked and some of them were changed.

When the testing started there was a problem to get the heater on and after troubleshooting a problem with the main K1 contactor in the control cabinet was found. The voltage above the contactor was too small because of a voltage drop in the cable to and from the DO in the PLC. To solve the problem a smaller contactor was installed in the control cabinet. This contactor controls the control circuit of the contactor K1.

7.1 Heater control strategies

The heater system was delivered as a ready-to-use concept, with the Gefran PID controller controlling the heater power. First the testing is done with the Gefran controller and the controller is adjusted as well as possible. A second control method will also be tested. In this method the PID controller is programmed in the PLC, replacing the Gefran PID controller. A switch is installed in the control cabinet and it chooses which PID controller is used. A pair in the Jamak cable is taken in use to transfer the signal from the PLC PID regulator to the SCR unit through the switch which chooses the controller.

7.2 Testing the heater and the control cabinet

When the testing started the Gefran controller was adjusted so that the signal to the SCR unit can only be maximum 10 % on. When the signal is 10 % on, the maximum heat power is 19.2 kW (0.1·192 kW). The P part of the PID controller was the first to be set when the testing started and it was given in %. When the P part was set to a large value the gain was low and with a small P value, the gain was high. The P value was first set “large” to get a slow heating response and increased until the heating response was fast enough. The I and D parts were given in minutes and the I part was added to remove stationary control error. The D part was not added because it seemed to work properly without it. The D part is used in processes with large dead times and in this case the air flow in the pipe is fast and the temperature sensor is close to the heater element and therefore the dead time is short.

When the PID regulator had been adjusted, a test was done with different receiver pressures to get various air flows through the heater and different dynamics in the process. The regulator worked properly with 1, 2, 3, and 4 bar receiver pressures, but a fault was detected when step responses were tested. When the heater is switched off from Morphee and the K1 disconnects the load from the heater, the PID controller continues giving full signal to the SCR unit because the PID controller tries to keep the setpoint. This causes a big current and heat peak when the heater is switched on again (Figure 21). The controller then gives a maximum signal to the SCR unit for a short time before the PID reacts and decreases the heater power. The problem was corrected in the PLC so that the temperature signal will be connected and disconnected at the same time as the on/off signal to the control cabinet controlling the main K1 contactor.

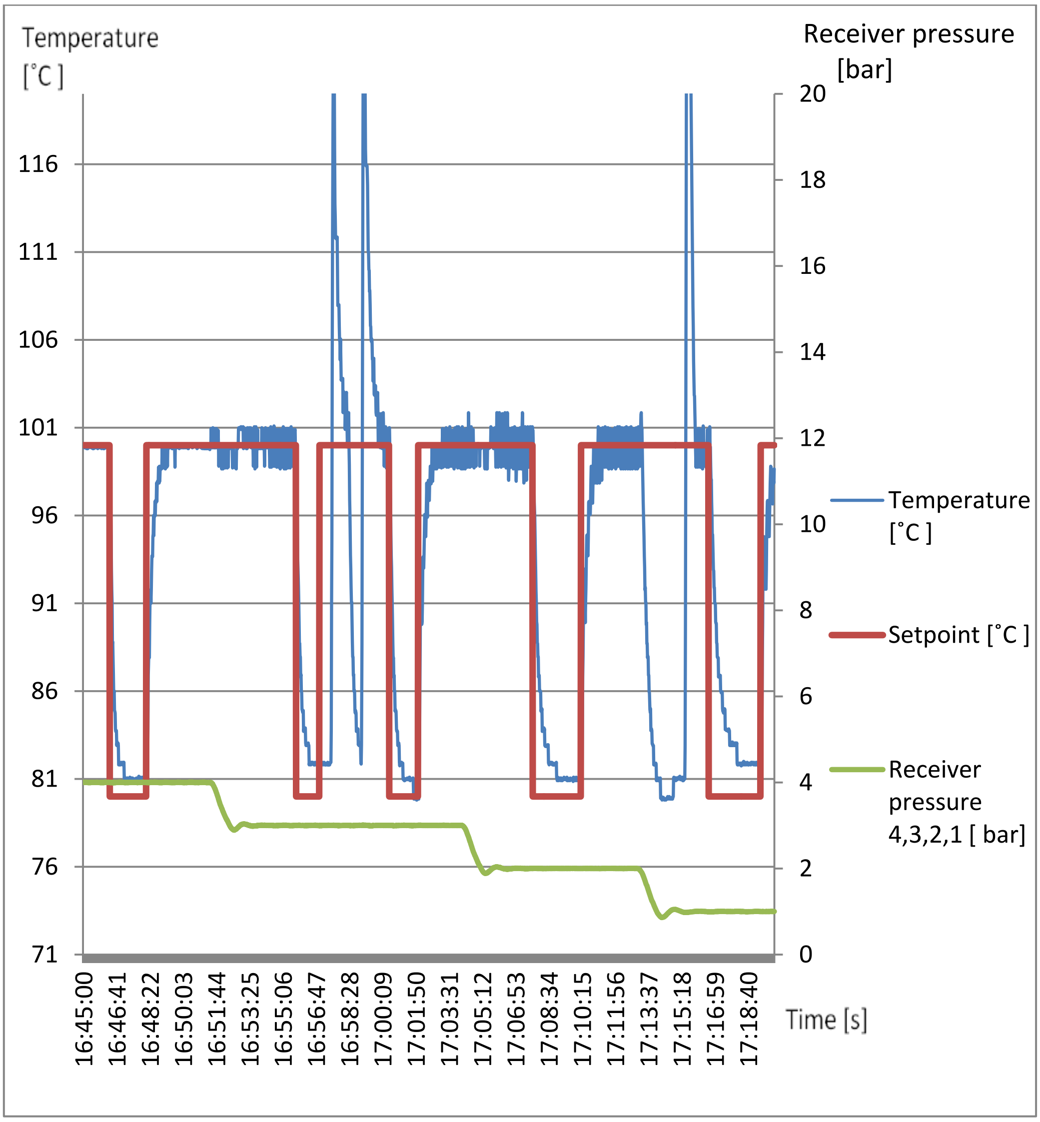


Figure 21. Step response tested with different receiver pressures.

The filter function was also tested in the Gefran PID controller in order to look for the best filter for the incoming temperature signal. The default setting for the filter was 0.1 and it was changed to 1 to see how it behaves. When the filter was changed to 1 it was not as stable as before and the filter worked best when a low value was used. Step responses were also tested with the parameter 0 and it worked best with this. The filter parameter was set to 0.

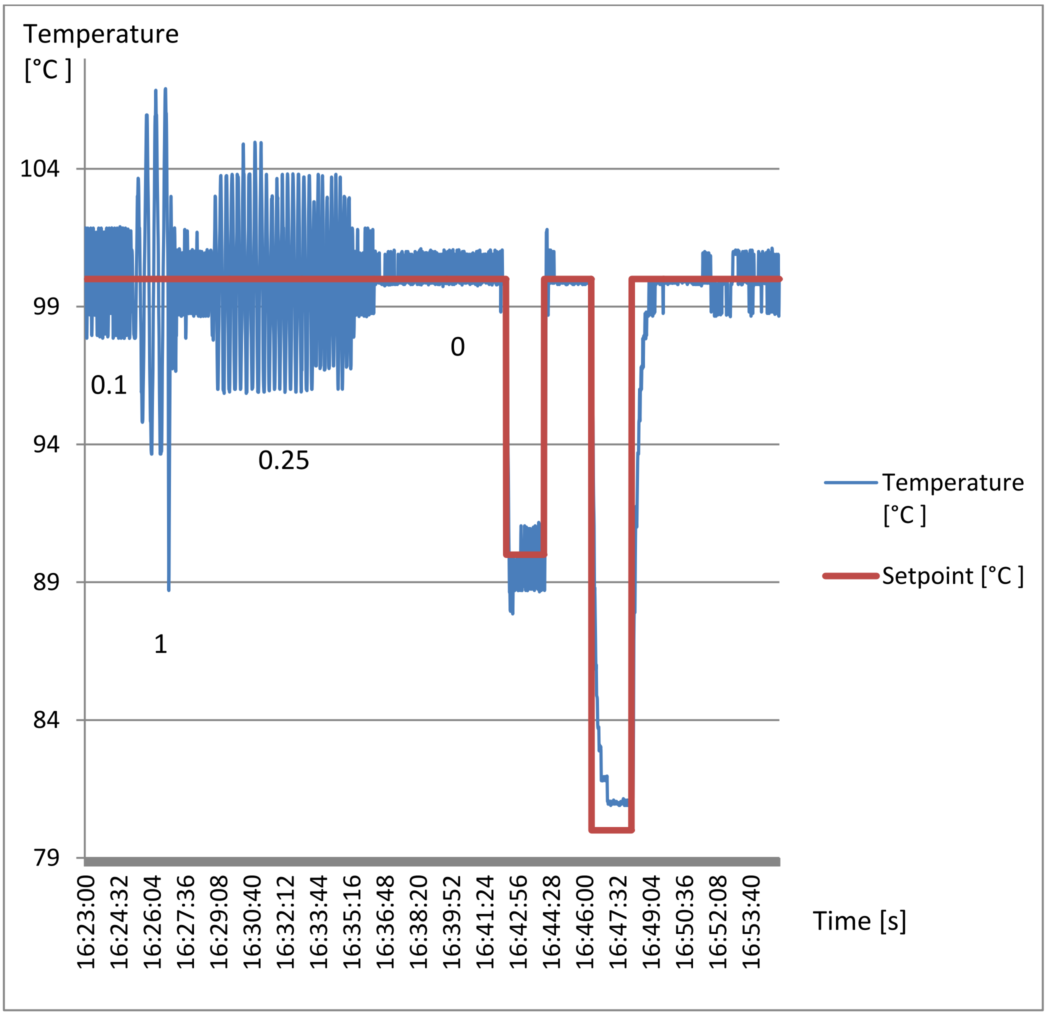


Figure 22. Filter function tested with different parameters (0.1, 1, 0.25 and 0)

7.3 Testing with a PID regulator programmed in the PLC

The second test is done with the PID controller programmed in the PLC and using the PLC PID signal straight to the SCR unit. All other devices in the control cabinet are in use except the Gefran PID controller signal. In the PLC there are pre-programmed PI and PID regulator blocks to use in the tests. The real temperature in the process is taken from the TE648 and it is a PT100 located after the electrical heater. The PT100 is scaled in the PLC to 0-160°C. In case the temperature rises higher than 160°C, it will cause problems but the heater will not be used with such high temperatures in the beginning. First a PI regulator was tuned in for the process to be as good as possible. However, it was seen that the temperature sensor was too far away from the heater and a significant dead time was created in the process. It was not possible to use the PI regulator in the process and the only choice was to try with a PID regulator which takes the dead time into account.

The PID regulator was adjusted as well as possible but oscillations were still created and the regulator was unstable. The dead time was too big and it is not possible to adjust the PID regulator well because of the location of the PT100 sensor. The alternatives were to move the PT100 closer to the heater or take in use the thermocouple sensor in the heater and use this as the process temperature. The decision was to use the thermocouple sensor because it was easily done and will also work well.

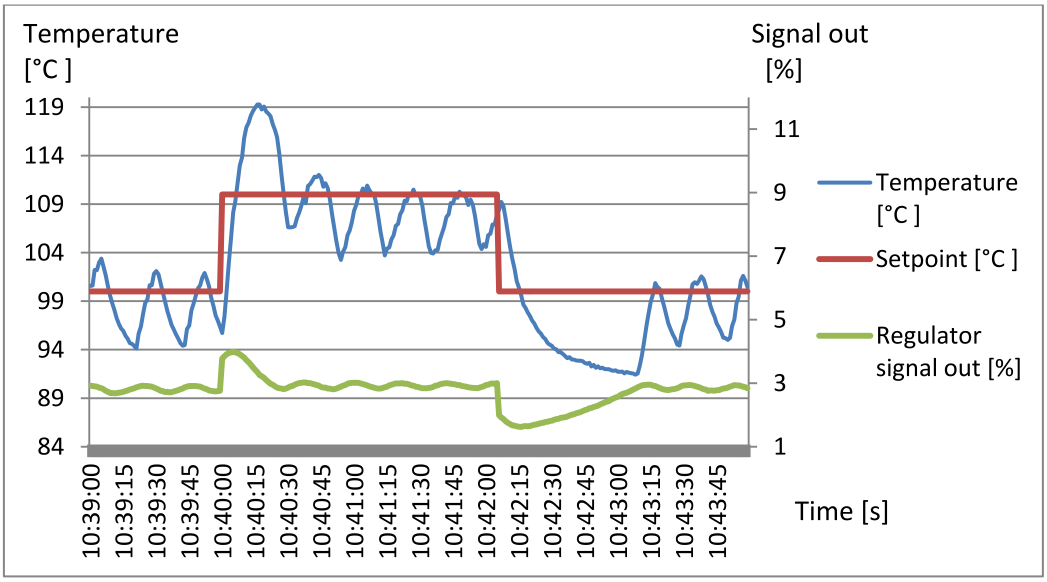


Figure 23. PID regulator adjusted in the PLC when the PT100 is used.

When the thermocouple sensor was used as the process value, it immediately worked much better. As the thermocouple sensor gives an mV signal, it is sensitive to interferences. Therefore the signal is filtered in the PLC. The adjustment of parameters in the PI regulator was much easier when the dead time was nearly non-existent and the D part was not needed. Step responses were done with different PI parameters to optimize the PI-parameters for the process.

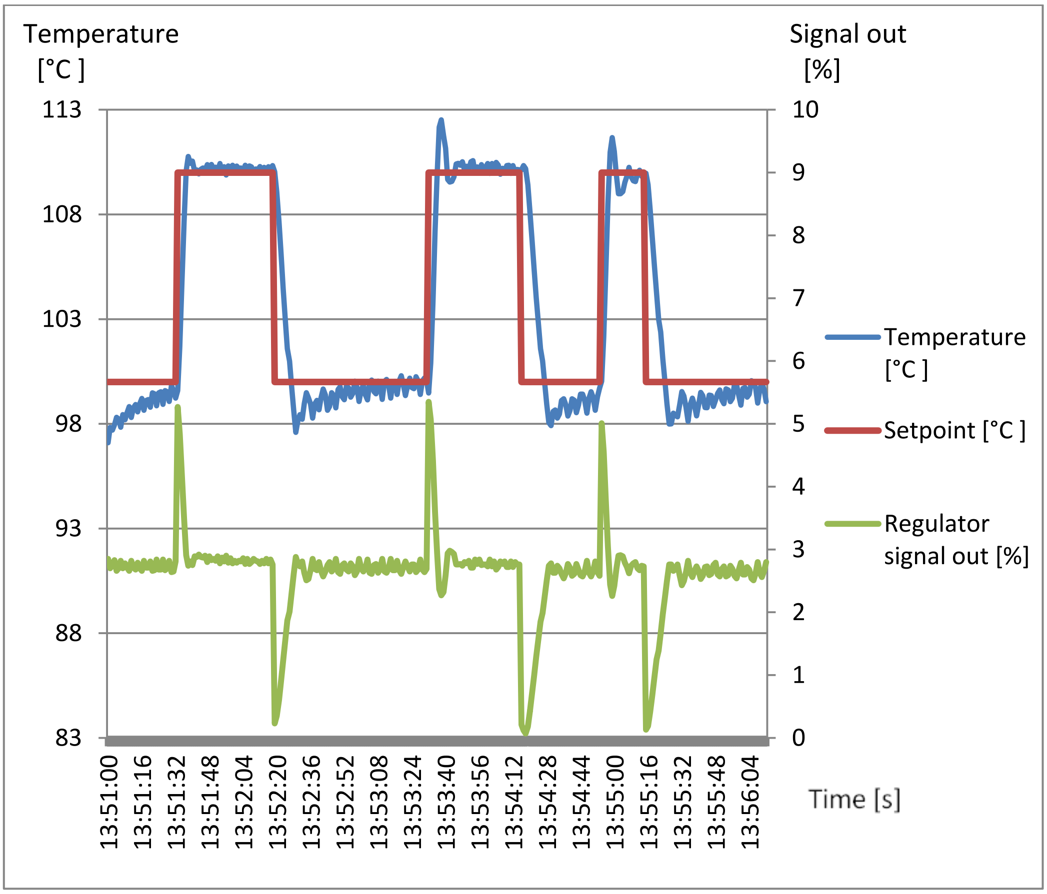


Figure 24. Different parameters in the PI regulator (First step response P=0.25 and I=20, second and third step response P=25 and I=30)

The final PI parameters were tested with different receiver pressures to get different air flow dynamics in the process. During these tests the engine setup is SG and with this setup the charge air pressure enables a maximum receiver pressure of 3 bar. The receiver pressure was tested with 3, 2 and 1 bar. Big step responses were also tested to ensure that the regulator will work with large setpoint changes.

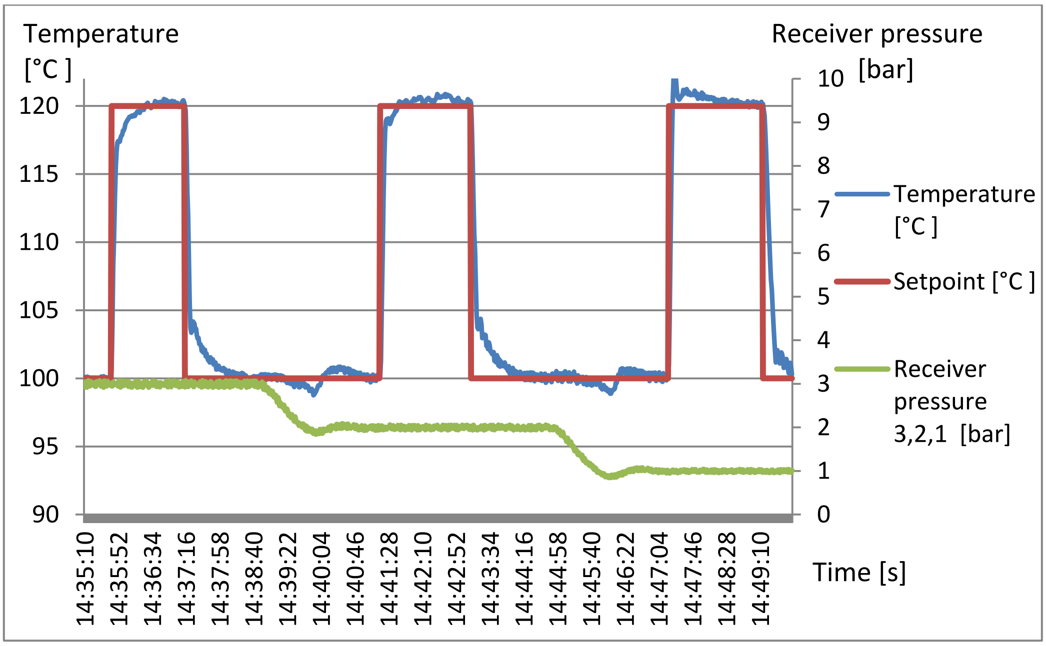


Figure 25. Step responses with different receiver pressures.

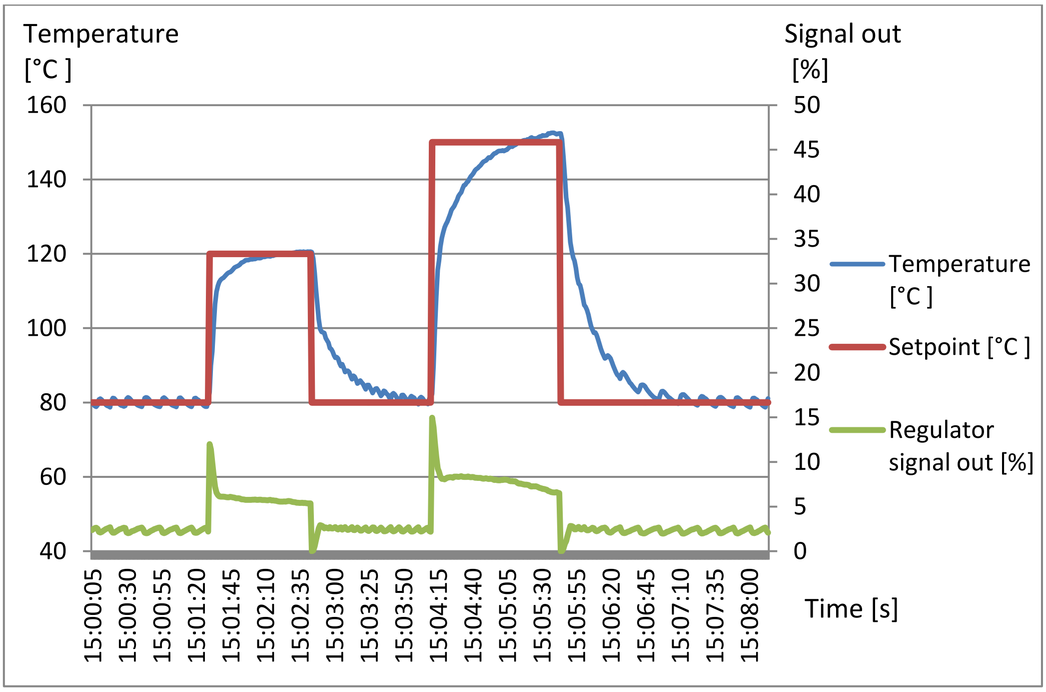


Figure 26. Large step responses

7.4 The final setup

It is possible to control the heater from two different controllers but the PI controller in the PLC will be used in the future. The PLC PI regulator enables easy control and change of the heating process as the regulator is adjustable from the control room. The Gefran PID controller worked very well but almost all of the PID regulators in the test cell are programmed in the PLC. The signal from the PLC PID regulator to the SCR unit was set to be maximum 20 % on and it allows a maximum heating effect of 38.4 kW (0.2·192 kW). The heating effect is adjustable from the control room if more heating effect is needed.

The limit of the differential pressure sensor was also changed. The recommended differential pressure above the heater is 25 mbar but as the charge air also flows through the cooler side, the air flow through the heater is reduced. The differential pressure limit above the heater was reduced to 3 mbar and will shut down the heater in case the differential pressure is less than this during normal operation of the heater.

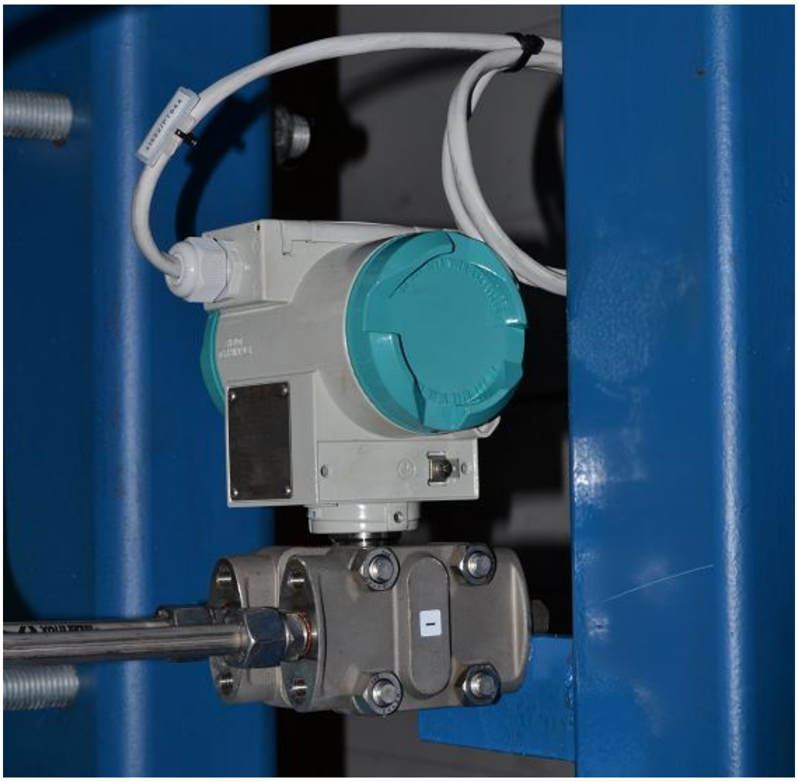


Figure 27. The differential pressure sensor.

8 Conclusions

The electrical heater started to work according to the expectations and has a good controllability of the charge air temperature. The heater also worked well during the start-up of the engine when the high temperatures are received faster. The use of the electrical heater also made it possible to reach the desired higher temperatures. The heater was dimensioned large as the W32 cylinder configuration is the one that is mostly used. A 192 kW heater was selected and it will not be used at max power when the W32 cylinder configuration is run. The calculated heating power for the W32 cylinder configuration was 122 kW to get the desired 200 ˚C. If the W40 cylinder configuration is used, the heating power will not be enough to reach the desired 200 ˚C but this cylinder configuration will probably not be used. The heating power was limited to 38.4 kW from the PLC PID regulator, which gives out max 20 %. The charge air temperature was tested up to 150 ˚C.

Figure 28. The electrical heater insulated and finished

The control cabinet dimensions are quite small for the purpose they were made for. It was difficult to install the main power supply when the cable was so large and the cabinet small. The control cabinet had to be modified with terminals for the grounding cables. These were missing and that can be dangerous if the ground is not connected. The grounding terminals were difficult to add due to the small size of the cabinet.

When the heater was taken into use a safety-related issue was noticed. The rig saver stops the charge air flow to the engine if a serious fault is detected in the test cell. The heater can have problems to withstand the high temperature if the rig saver is activated and the charge air flow through the heater stops. With a small heating power used, this will not be a problem but if the heater is operating at full power this may cause a heater failure. The minimum differential pressure above the heater was also reduced to 3 mbar from the manufacturer’s recommendation 25 mbar. The decreased differential pressure will not be a problem because the 3 mbar still indicates an air flow through the heater. When the electrical charge air heater is used, the operator should know how to use it and special care has to be taken.

9 Discussion

The work has been interesting to do and the electrical charge air heater has its advantages and disadvantages. The heater is fast to use and it enables full heating power directly at the start up of the engine, which is good. At the same time the heater can be sensitive to heat shocks if the air flow stops instantly. As the work progressed, an idea of using a silicone oil heater was also discussed. How would it work to have 200 °C silicone oil circulating through a heat exchanger heating the charge air? The liquid heating system would have been slower to reach the high temperatures but if the rig saver had been activated, the liquid heater would have been more durable against heat shocks. In my opinion the electrical heater for the charge air was a good choice, because it enables full heating power directly at startup of the engine and it is a clear benefit. An operation instruction manual was also made for the electrical charge air heating system to guide the operator.

Future work to the electrical charge air heater system is related to protection against possible heat shocks caused by the rig saver. This is not necessarily to be done if the heater is not allowed to work at full heating power. If the heater is allowed to work at full power, it is recommended to install a bypass pipe with a valve directly after the electrical heater. The bypass pipe leads out the heated air if the rig saver is activated and the air flow stops through the heater.

The work has taken me quite a long time to finish, as my duties were first to dimension and plan the heater system and then to install it. I have learnt a lot about power controllers, how they work and what kind of methods are available for controlling the SCRs. The commissioning of the heater system was an educative phase of the work when the PID regulators were adjusted and tested. I have had a great support from Wärtsilä throughout the work and I would like to thank everybody who helped me.

10 List of sources

/1/ Wärtsilä Corporate presentation 2011. Power Point document.

/2/ Nysand, S. (2011). *SCE Engine, auxiliaries, automation and control*. Power Point document for Wärtsilä internal use.

/3/ Connection Technology.
http://www.soclair.ch
(Read 10.12.2011).

/4/ Configurable transducer picture.
http://www.onlinecomponents.com
(Read 5.3.2012).

/5/ Mäkelä, M. Soininen, L & Tuomola, S. (2002).*Technical formulas* 2002. Tammertekniikka.

/6/ Roman, A. & Heiligenstein, A. (2002). *SCR Power Theory Training Manual*.

/7/ OMEGA. *SCR 19/39 Power Controllers Instruction Manual*
http://www.omega.com. (Read 12.12.2011).

/8/ Ise, Inc. *Installation, operation and maintenance manual*.
http:iseinc.com (Read 12.11.2011).

/9/ Standards Association SFS r.y. (2008).
Low-Voltage electrical installation and safety at electrical work 2008.
Helsinki.

/10/ Gefran. (2005). *Installation and operation manual,* 1600/1800 controller.

Heater dimensioning APPENDIX 1

The maximum temperature with the current setup 70 °C

Max desired temperature 200 °C

W32(500 kW/Cyl) = 3330 kg/h Air

W40(1200 kW/Cyl)=7992 kg/h Air

The effects are calculated according to: $Q = mc_p\Delta\mathrm{T}$

W32: $Q = 0.925\frac{kg}{s} \cdot 1010\frac{J}{\mathrm{kg{\cdot}°C}} \cdot (200 - 70)\ \mathrm{°C}$

$Q = 121.5\ \mathrm{kW}$

W40: $Q = 2.22\frac{kg}{s} \cdot 1010\frac{J}{\mathrm{kg{\cdot}°C}} \cdot (200 - 70)\ \mathrm{°C}$

$Q = 291.5\ \mathrm{kW}$

Earth dimensioning APPENDIX 2

The area is calculated according to: $A = \frac{\sqrt{I^2 \cdot t}}{k}$

A= Cable area [mm²]

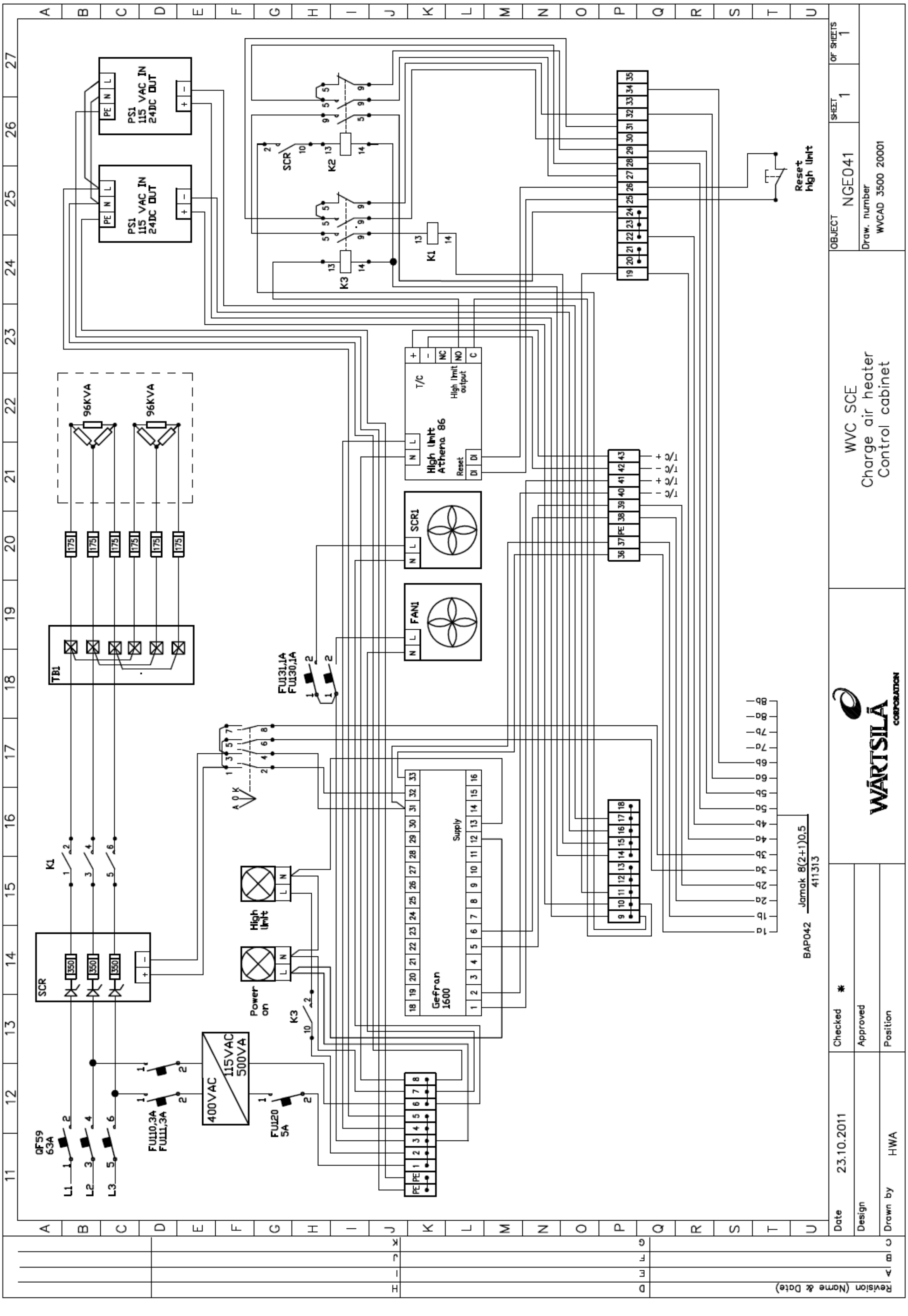
I = 6660 A (Fault current: measured)

t = 0.5 s (operating time: gG fuses)

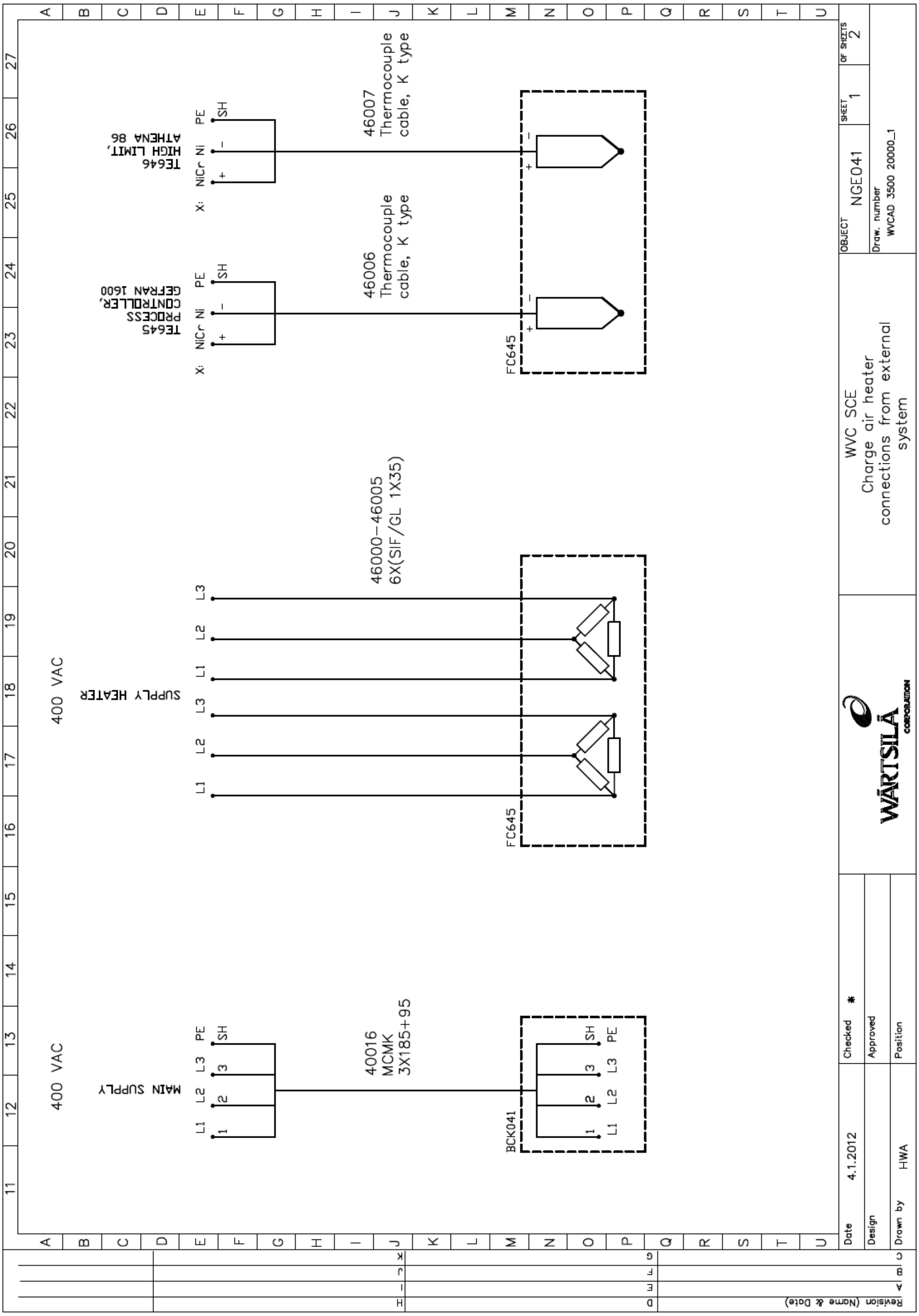
k = 143 (Factor for cable: SFS 600, table A54.2 for PVC 70 ˚C and copper)

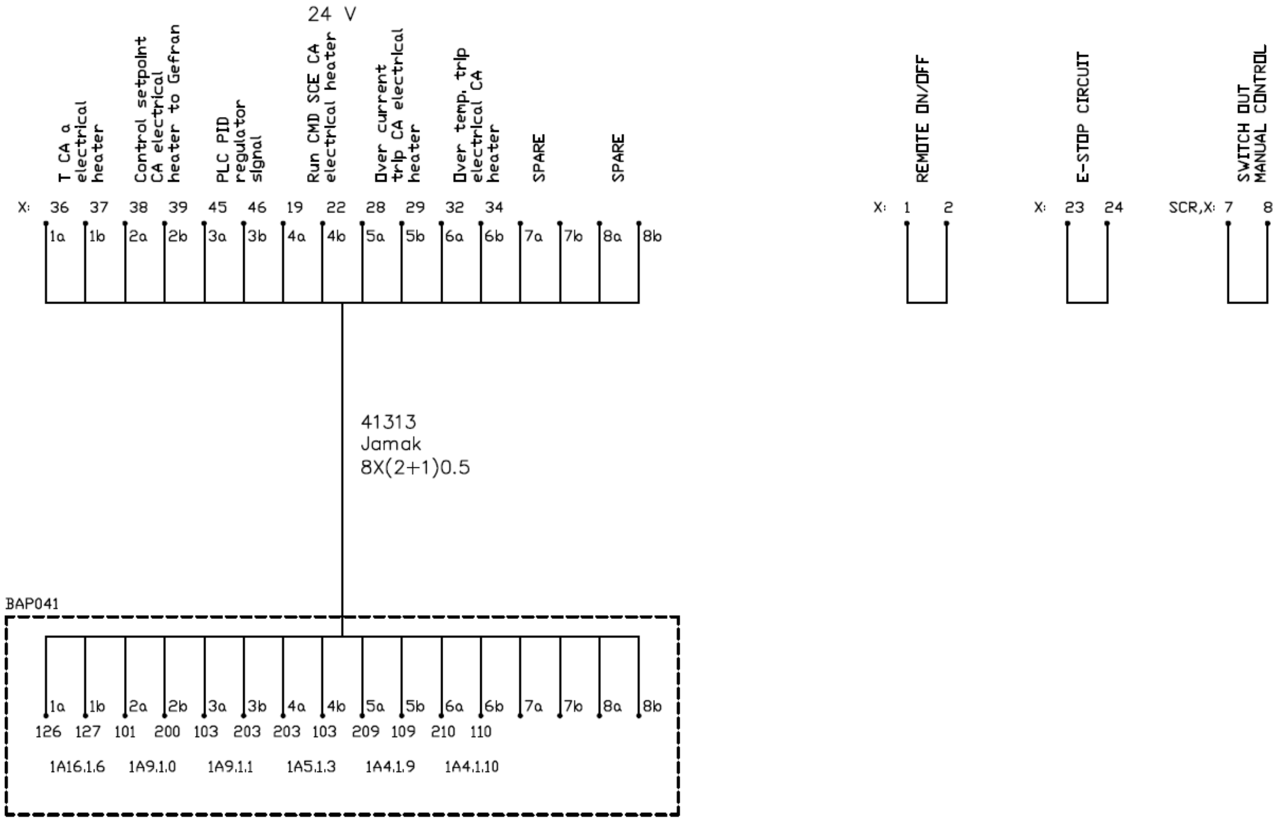
$$A = \frac{\sqrt{6660^2 \cdot 0.5}}{143} = 32.9\ mm^2\ Copper\ cable$$

APPENDIX 3


WVC SCE
Charge air heater
Control cabinet
OBJECT NGE041
Draw. number WVCAD 3500 20001
SHEET 1
OF SHEETS 1
Date 23.10.2011
Design
Drawn by HWA
Checked *
Approved
Position
Revision (Name & Date)
WÄRTSILÄ CORPORATION
PS1 115 VAC IN 24DC OUT
PS1 115 VAC IN 24DC OUT
96KVA
96KVA
TB1
SCR
QF59 63A
FU110,3A FU111,3A
FU120 5A
400VAC
115VAC 500VA
K1
K2
K3
SCR1
FAN1
High limit Athena 86
T/C
High limit output
Reset
Gefran 1600
Supply
Power on
High limit
FU131,1A FU130,1A
Reset High limit
BAP042
Jamak 8(2+1)0,5 411313
L1
L2
L3

APPENDIX 4


400 VAC
MAIN SUPPLY
L1 L2 L3 PE
1 2 3 SH
40016
MCMK
3X185+95
BCK041
400 VAC
SUPPLY HEATER
L1 L2 L3 L1 L2 L3
46000–46005
6X(SIF/GL 1X35)
FC645
TE645
PROCESS
CONTROLLER,
GEFRAN 1600
X: NiCr Ni PE
+ – SH
46006
Thermocouple
cable, K type
TE646
HIGH LIMIT,
ATHENA 86
46007
Thermocouple
cable, K type
FC645
WVC SCE
Charge air heater
connections from external
system
WÄRTSILÄ
CORPORATION
OBJECT NGE041
SHEET 1
OF SHEETS 2
Draw. number
WVCAD 3500 20000_1
Date 4.1.2012
Checked *
Design
Approved
Drawn by HWA
Position
Revision (Name & Date)



Revision (Name & Date)

Date	5.1.2012	Checked	*	WÄRTSILÄ CORPORATION	WVC SCE Charge air heater connections from external system
Design		Approved			
Drawn by	HWA	Position			

OBJECT	SHEET	OF SHEETS
NGE041	2	2

Draw. number
WVCAD 3500 20000_2