Refrigerant compressor room temperature measurement and control utilizing frequency converter's built-in logic

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Sähkö- ja automaatiotekniikka		Tiivistelmä
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Ilmanvaihtojärjestelmiä tarvitaan ilman vaihtamiseen ja lämmön poistamiseen tiloissa, joissa on lämpöä tuottavia järjestelmiä. Tämän projektin tavoitteena oli suunnitella ja luoda ilmanvaihtojärjestelmä, jota säädetään pelkästään taajuusmuuttajan sisäänrakennetulla logiikalla. Muita projektiin liittyviä ominaisuuksia oli hätätuuletus joka aktivoituu painonapista sekä kaasun tason nousemisesta tietyn pisteen yli. Järjestelmän tuottamat hälytykset lähetettiin käyttäjälle GSM:n kautta. Projekti sisälsi sähkö- ja automaatiosuunnittelussa käytettäviä prosesseja ja se rakennettiin, ohjelmoitiin ja testattiin onnistuneesti.

Työn tilaaja oli Suomen Teollisuuskylmä Oy, ja he mahdollistivat projektin rakennuksen ja dokumentoinnin tulevia taajuusmuuttajien parametrointeja ja ohjelmointeja varten.

Avainsanat taajuusmuuttaja, PID-säädin, nopeussäätö.
Sivut 30 sivua ja liitteitä 3 sivua

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Electrical and Automation Engineering		Abstract
Author	Samu Purhonen	Year 2023
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Ventilation systems are needed to change air and remove heat from spaces containing systems that generate heat. The aim of this project was to design and implement a ventilation system which would be adjusted by a variable frequency converter and its built-in logic. Other components included into the project were emergency ventilation activated with a button or gas level reaching a certain point. Alarms generated by the system were sent to the operator via GSM. The project involved electrical and automation design processes and was also successfully built, programmed and tested.

The commissioner of the work was Suomen Teollisuuskylmä Oy and they enabled me to build and document this project for future references on parametering and programming of a VFD.

Keywords PID-controller, speed control, variable frequency drive,.
Pages 30 pages and appendices 3 pages

Contents

Appendices

1 Introduction

The purpose of the work was to create a system which controls the temperature of an industrial refrigeration room utilizing a frequency converters built-in logic, without adding any additional automation parts. The main target for the project was to choose, parameterize and program a variable frequency drive to read an analogue signal of a temperature sensor and adjust a blower motor to keep the room temperature at a certain point. Important aspects included in the project were gas detection for emergency ventilation and alarms transmitted via GSM. The finished system was designed to be testing equipment which would be ready to be implemented in the future.

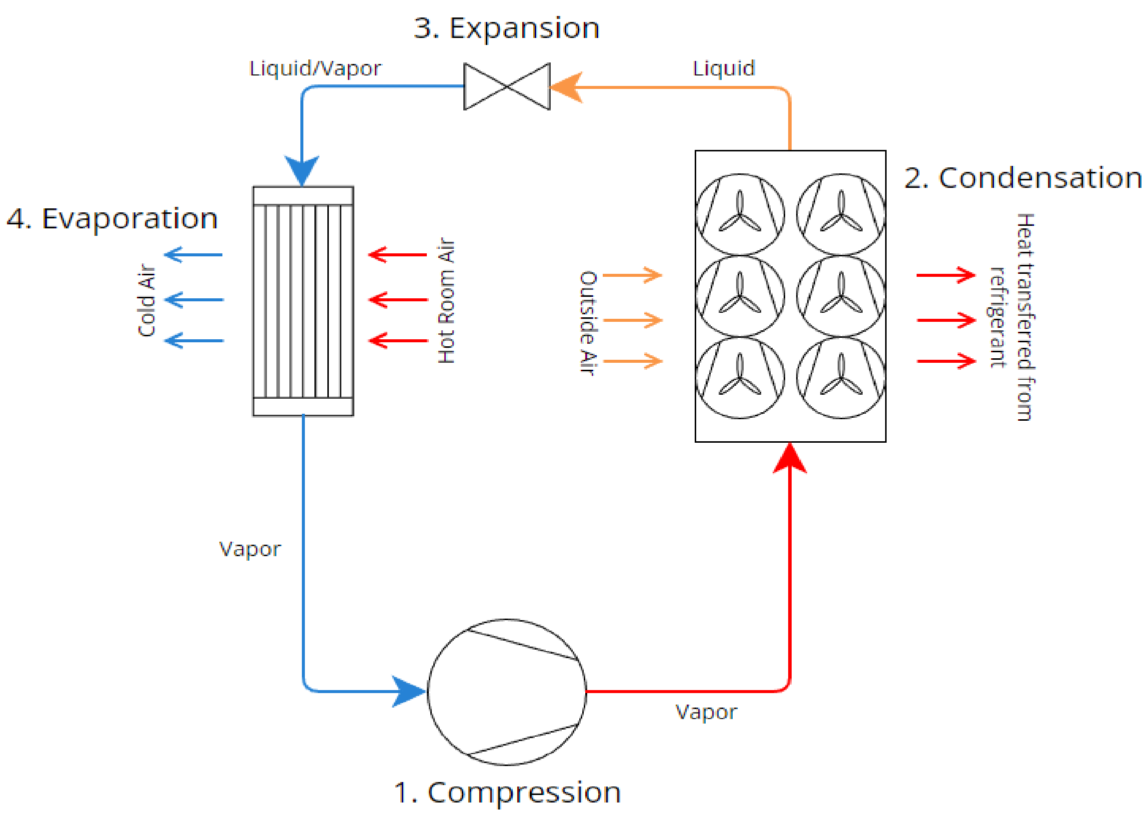
In chapter two, the principles of industrial refrigeration are explored. In chapter three variable frequency drives' working principles are studied and also different manufacturers are considered. Chapter four includes the electrical and automation design of the system aswell as the choosing of the relevant components. In chapter five the system is built and tested, and in chapter six the conclusion and results are presented.

The commissioner of the work is Suomen Teollisuuskylmä Oy, which is a Finnish company founded in 2011. It specializes in industrial refrigeration systems and heat pumps, offering full lifecycle services from designing and installation to commissioning and servicing.

2 Industrial Refrigeration

Refrigeration technology is used in many areas of industry with the main objective of maintaining a needed temperature in a certain area. Cold storages, process- and food industries and artificial ice rinks are the most common fields of industry that use refrigeration technologies, altough refrigeration is a very wide field of technology with countless of different uses. Most often refrigeration systems are based on condensation and evaporization of a refrigerant in which heat is removed from- or added into a system by doing work. In Figure 1 the basic principle of a refrigeration system is shown.

Figure 1 Basic Refrigeration System.



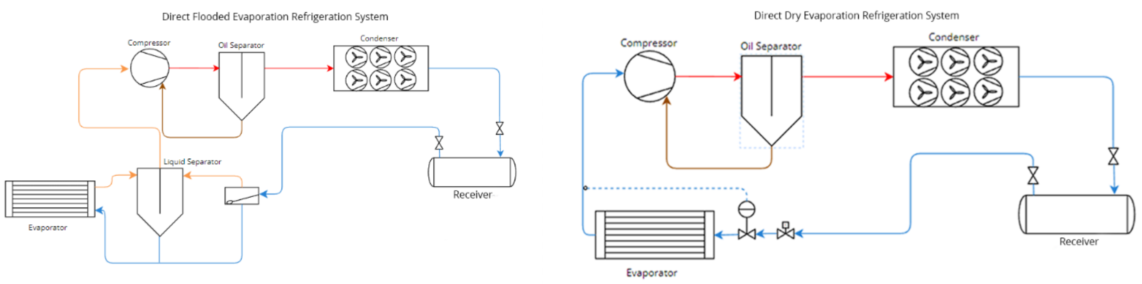
1. Compression of a refrigerant, hot refrigerant vapor leaves for condensator.
2. Heat in the refrigerant is transferred to the environment. Refrigerant vapor condenses into a liquid.

3. High pressure refrigerant liquid is expanded into low pressure liquid/vapor. The expansion valve controls the amount of refrigerant injected into the evaporator by measuring the refrigerant temperature after the evaporator.
4. Cold refrigerant liquid/vapor is used to cool an area by blowing hot room air through the cold refrigerant in an evaporator binding the heat in the room air into the refrigerant. Refrigerant evaporates into gas and is sucked into the compressor.

To make the process as energy efficient as possible in industrial use, it can be scaled and optimized by adding components such as accumulators, heat exchangers, economizers and control valves. Different types of industrial refrigeration plants include direct- and indirect systems as well as pump circulated- and two-stage systems.

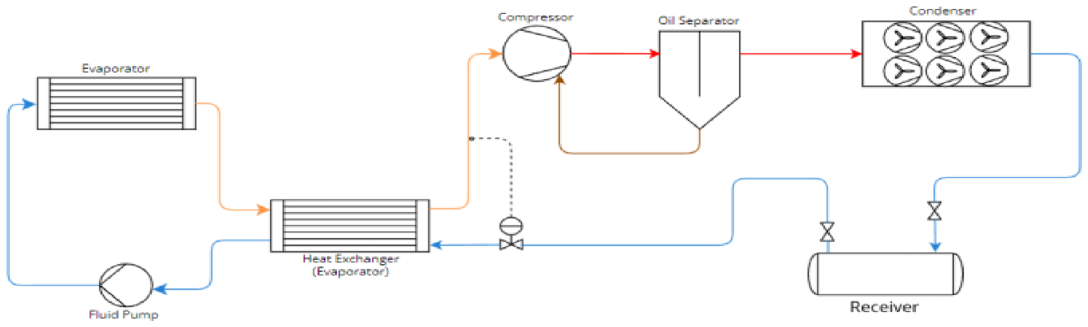
Direct systems are divided into dry evaporation and flooded evaporation systems (Figure 2). In dry evaporation the refrigerant completely vaporizes in the evaporator and in flooded evaporation the refrigerant passes through the evaporator in liquid form. (Alijoki & Aittomäki, 2012, pp. 269-270)

Figure 2 Direct Evaporation Refrigeration System Principles (Alijoki & Aittomäki, 2012, p. 269)



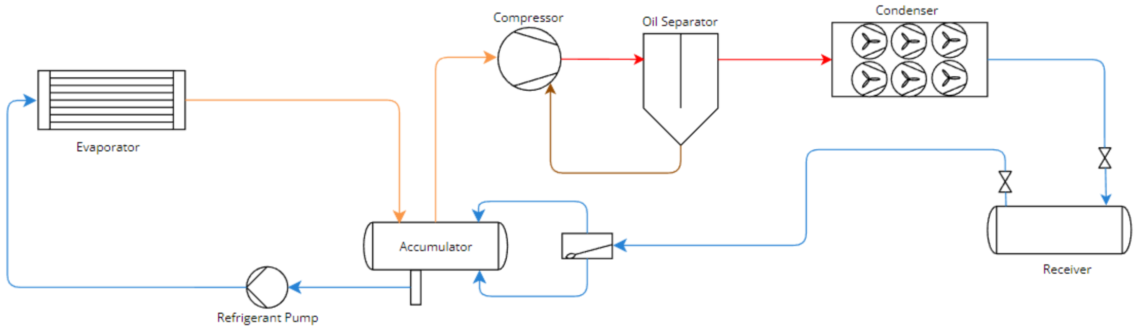
Indirect systems use the main refrigerant to absorb heat from a heat transfer fluid in a heat exchanger, which is circulated in evaporators to cool the space. Indirect systems prevent the leakage of hazardous refrigerants to areas outside the machine room and has multiple other positive aspects such as precise control and relatively easy maintenance. (Alijoki & Aittomäki, 2012, p. 270)

Figure 3 Indirect Refrigeration System Principle (Alijoki & Aittomäki, 2012, p. 270)



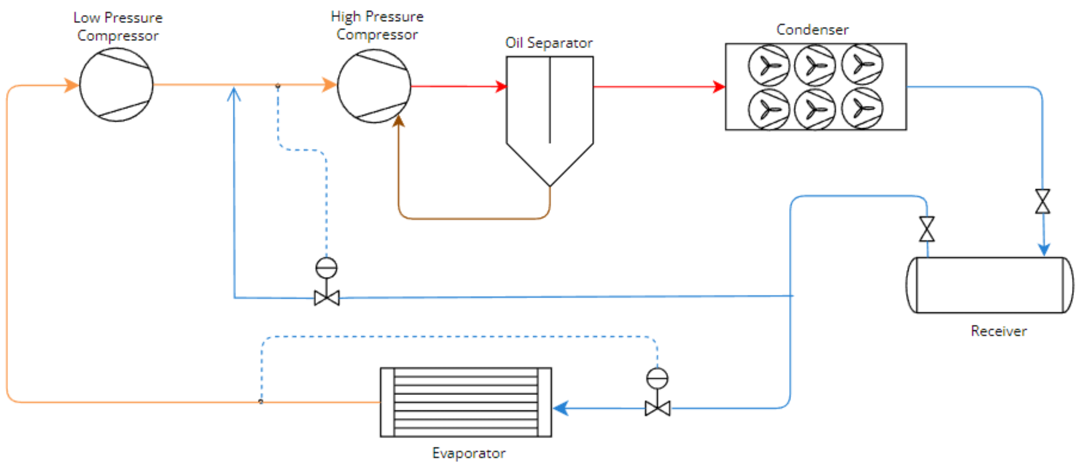
Pump circulated systems use refrigerant pumps to circulate liquid refrigerant in the evaporators. As only some of the refrigerant is vaporized, it must be separated from the liquid with a liquid separator, from which the vapor is sucked into the compressor and liquid is pumped into the evaporators. (Alijoki & Aittomäki, 2012, p. 274)

Figure 4 Pump Circulated Refrigeration System Principle (Alijoki & Aittomäki, 2012, p. 274)



Two-stage systems (Figure 5) divide the refrigeration process into low-pressure and high-pressure sides, each having own compressors. The low-pressure compressor sucks cold low-pressure refrigerant vapor from the evaporator and compresses it into an intermediate pressure. Liquid refrigerant from the receiver is injected to the vapor cooling it for the high-pressure compressor which compresses the cooled refrigerant vapor into condensation pressure. (Alijoki & Aittomäki, 2012, pp. 276-277)

Figure 5 Two-Stage Refrigeration System Principle (Alijoki & Aittomäki, 2012, p. 276)



Refrigerants must have certain thermodynamic, chemical and physiological characteristics to be viable for use in refrigeration technologies. High evaporation temperature, small viscosity and good thermal conductivity are needed attributes in a refrigerant as these increase the efficiency of the system. Physiological aspects of a good refrigerant are non-toxicity to environment and living things as well as the ability for leaks to be easily detected. Non-flammability is also a wanted attribute in a refrigerant especially in large plants or in air conditioning use. Most common refrigerants used in industry are NH_3 (Ammonia) and CO_2 (Carbon Dioxide). Ammonia and carbon dioxide are natural refrigerants which possess great characteristics to be used as a refrigerant. Ammonia has a high evaporation temperature, low viscosity and good thermal conductivity, it is relatively cheap, and leaks can be easily detected since ammonia has a distinctive smell even at low and safe concentrations. However ammonia is extremely harmful to the environment and humans, being fatal at concentrations of more than 2000 ppm, and is also flammable in high concentrations. Carbon dioxide is used for its non-toxic and non-flammable characteristics. CO_2 systems operate at very high pressures as the pressure of CO_2 at 30°C is 72 bar, so the condensation pressure can reach more than 100 bar. Different HFC refrigerants such as propane, butane and propylene are used in smaller applications such as commercial refrigeration systems. (Aittomäki, 2012, pp. 102-127)

Refrigerants used in refrigeration technologies are often hazardous to the environment and people, so the European standard EN 378-1 divides different refrigerants into safety classes based on their flammability and toxicity. The Total Equivalent Warming Impact (TEWI) is used to calculate the greenhouse effect of refrigerants. CFC- (Chloro-Fluoro-Carbon) and HCFC- (Hydro-Chloro-Fluoro-Carbon) refrigerants are especially harmful to the environment as they contain chlorine. The chlorine in the refrigerant harms the ozone layer when released into the atmosphere, accelerating global warming. The Montreal Protocol on Substances that Deplete the Ozone Layer was agreed on in Montreal, 1987 restricting the use of harmful refrigerants. (Aittomäki, 2012, pp. 102-127)

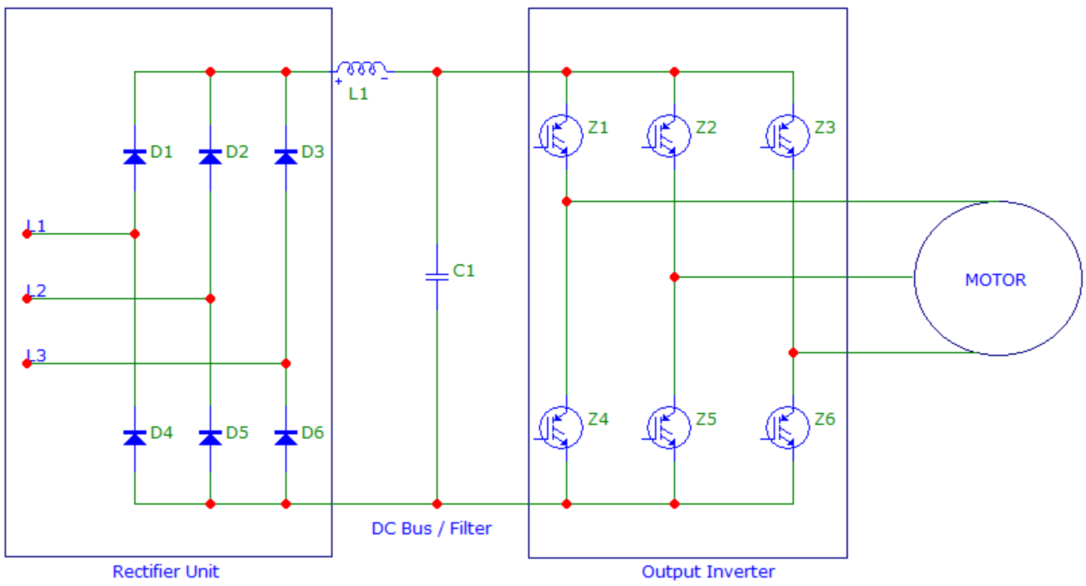
Solutions such as refrigeration containers are manufactured to create portable refrigeration systems, which can be used as temporary cooling equipment. The containers include everything a refrigeration system needs from a compressor to piping and instrumentation. A ventilation system is also needed to remove the heat generated by the heat losses of the compressor, piping, pumps and lighting as well as for emergency ventilation in case of a refrigerant leak.

3 Variable Frequency Drives

Variable frequency drives (VFDs) are used in controlling the speed of electric motors in many different industries. VFDs are a more energy efficient and equipment friendly option for old motor starting systems such as soft starters, star-delta starters or Direct On Line (DOL) starters. The use of VFDs increases the lifespan of rotating components in electric motors and saves energy since the motors operational speed can be adjusted.

The VFDs consist of three main components, a rectifier unit, a DC bus and an inverter unit. One phase or three phase AC supply voltage is converted to rough DC voltage through the rectifier unit, and the DC voltage is then filtered by the DC bus. The DC bus filters out harmonics which are generated in the conversion from AC voltage to DC voltage. The inverter unit converts DC back to AC by using very fast Insulated Gate Bipolar Transistors (IGBTs), which switch on and off creating pulses. The pulses create a sinusoidal waveform and with pulse width modulation (PWM), different frequencies can be achieved, aswell as the correct voltage- to frequency ratio can be maintained. The switch frequency in modern VFDs is around 3KHz to 4KHz, and a larger switch frequency increases the resolution of the output sine wave but also increases the heat generated inside the VFD (Aditya, 2013). Figure 6 illustrates the internal circuit of a variable frequency drive.

Figure 6 Variable Frequency Drive Internal Circuit. (Rahman et al., 2019, pp. 47-48)



In the commissioning of a variable frequency drive, it must be parameterized. In parameterization, the motor plate information, the minimum and maximum rotational speeds and acceleration and deceleration rates are inserted using the VFDs operational panel. These are necessary information the VFD needs to operate, but modern VFDs have many other parameters that can be changed according to the operational conditions of the electric motor.

3.1 ABB

ABB is well-known and widely used as a manufacturer of variable frequency drives. ABB offers general purpose VFDs that range from 0.37kW to 500kW and industrial VFDs that range from 0.55kW to 150MW. ABB ACS880 for industrial use offers a power range of 0.55kW to 3 200kW, which allows the use of them for almost any industrial low voltage motor. ABB VFDs can be ordered as floor- or wall installed, with different frame sizes and IP classes depending on the power class and operational conditions. (ABB, 2013)

ABB ACS880 supports all the most used fieldbus protocols, such as Profibus, Profinet, EtherCat and MODBUS TCP, altough separate accessory cards must be used. The stock model of ACS880 includes two analog inputs, two analog outputs, six digital inputs, two digital I/O and three relay outputs, however ACS880 has three accessory card slots which can be used for fieldbus modules, additional I/O modules or safety modules. All ACS880 VFDs are equipped with the same standard software which control system is already optimized for most common electric motors such as induction-, permanent magnet-, servo-, and pace reluctance motors. The VFD can be connected to PC with USB or RJ45 connection and it allows the parameterization and configuration of the VFD using ABB Drive Composer software, aswell as the programming of the VFD with ABB Automation Builder software. Automation Builder enables the operator to choose from five programming languages to create an own application program. (ABB, 2013)

3.2 Vacon

Vacon is a finnish company founded in 1993 and it has focus on manufacturing and developing variable frequency drives. Vacon Oy was bought in 2014 by Danfoss which is now selling the VFDs of Vacon.

Vacon offers variable frequency drives for power classes ranging from 0.25kW to 4MW for voltage of 400V and up to 12 000kVA for voltage of 10kV. Options for different industries and operational conditions are many – VACON 20 is an option for general purpose, smaller motors such as pumps, fans and HVAC purposes, VACON 1000 and 3000 are created to be used with medium voltages from 2.2kV to 11kV, and VACON 100 Industrial is created for industrial use and it is offered in power ranges of 0.55kW to 800kW. (VACON, 2016)

VACON 100 Industrial can be ordered as wall- or floor installed and with three additional accessory cards such as additional I/Os, safety modules or fieldbus modules. It also supports the most commonly used fieldbus protocols, Profinet, Profibus, EtherCat and Ethernet/IP. VACON 100 Industrials standard I/Os include two analog inputs, six digital inputs, one analog output, one thermistor input and three relay outputs, many of the I/Os are possible to be configured to meet the requirements of operation for the motor. VACON 100 is possible to be connected to PC and configured using VACON Live software, it is also possible to create own control configurations by taking advantage of the versatility of parameters and PID control possibilities. (VACON, 2016)

3.3 Danfoss

Danfoss Drives is the manufacturer of VLT series VFDs and are mostly specialized in HVAC applications. Danfoss VLT drives have five different low voltage models, each optimized for its own type of motor application. VLT Micro Drive FC51 is a general purpose VFD for smaller motors ranging from 0.18kW to 22kW. For HVAC and refrigeration purposes VLT FC102 and FC103 are dedicatedly created for the control of compressors, pumps and fans in harsh conditions, and FC301, FC302 and FC360 VFDs are for industrial use with power ranges of 0.25kW to 1.4MW. Danfoss VLT drives can be ordered in different frame sizes and IP classes. (Danfoss, n.d.)

Danfoss VLT HVAC FC102 stock model is equipped with six digital inputs, two analog inputs, two digital outputs, one analog input and two relay outputs, which all of them are programmable. Modbus RTU is standardly built-in but with additional accessory cards most common fieldbus protocols such as Profinet, Profibus DP and Ethernet/IP are supported. The VFD can be ordered to include accessory cards for different fieldbus protocols, additional I/Os, relay extensions or safety features. Danfoss VFDs are equipped with a control panel from which it can be parameterized and programmed, altough connection to PC is possible. The software created for Danfoss drives is VLT Motion Control Tool (MCT) 10 which enables parameterization, commissioning and programming of the VFD using PC. (Danfoss, n.d.)

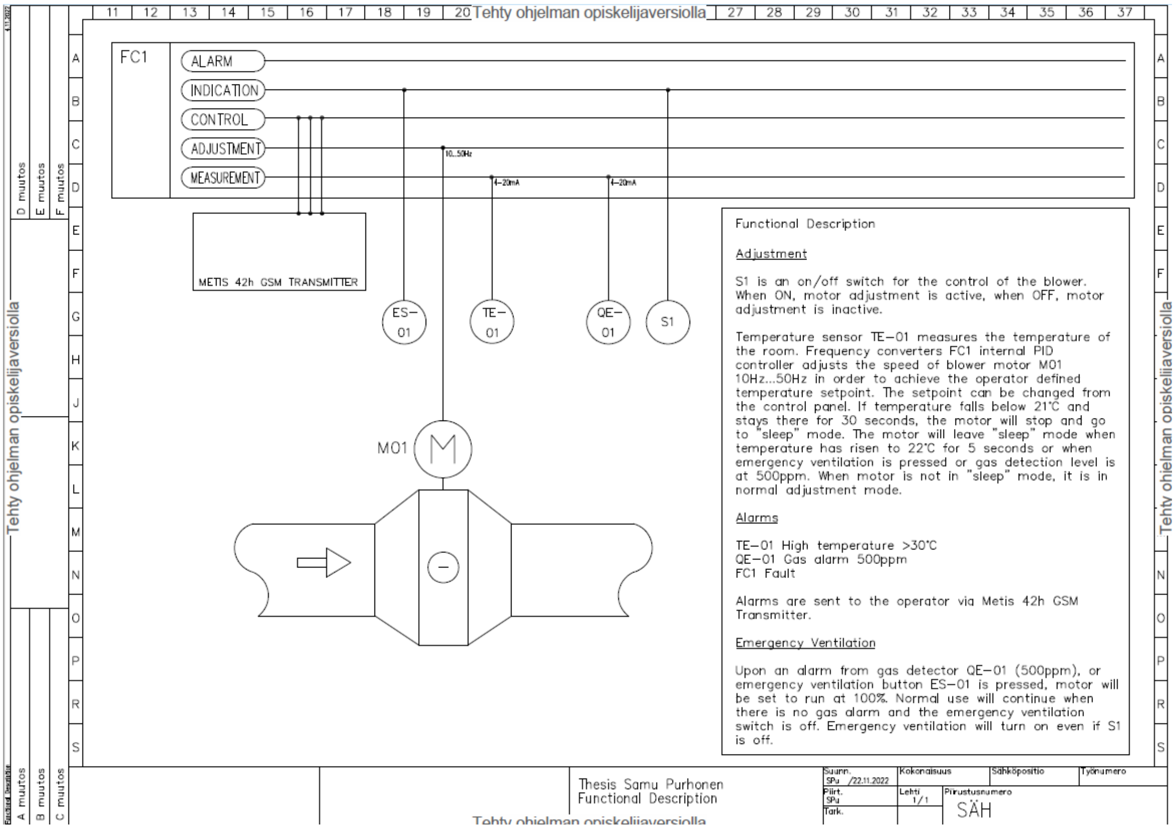
4 Electrical and Automation Design

The design part of the project was started with assessing the functional requirements and components needed, from which a functional description and a functional diagram were created. The variable frequency drive adjusts the motor speed using its internal PID controller. The exact types and models of components were chosen after a functional diagram was created, as the needed components, instruments and the number and types of I/Os could be taken into account from the diagram. As the project was test equipment with the main target of achieving the motor control using only the variable frequency drives logic, the blower, motor and VFD are not dimensioned for any specific situation.

4.1 Functional Diagram & Description

A functional diagram is a simplistic drawing of the system, allowing assessment of the system I/Os and functionality. The functional description describes how the system should work in every situation and gives a base for starting the designing of automation.

Figure 7 Functional Diagram & Description



S1 is an on/off switch for the control of the blower. When ON, motor adjustment is active, when OFF, motor adjustment is inactive. Temperature sensor TE-01 measures the temperature of the room. Frequency converters FC1 Internal PID controller adjusts the speed of the blower motor M01 10…50Hz in order to achieve the operator defined setpoint.

The setpoint can be changed from the control panel. If temperature falls below 21°C and stays there for 30 seconds, the motor will stop and go to "sleep" mode to prevent unnecessary cooling during cold weather. The motor will leave "sleep" mode when temperature has risen to 22°C for 5 seconds or when emergency ventilation button is pressed, or gas detection level is at 500ppm. When motor is not in "sleep" mode, it is in normal adjustment mode. High temperature alarm, gas alarm and the VFD fault alarm are sent to the operator via the GSM transmitter. Emergency ventilation adjusts the motor speed to 100%. An alarm from the gas detector or if the emergency ventilation switch is switched ON triggers emergency ventilation. Normal use will continue when there is no gas alarm and the emergency ventilation switch is switched OFF. Emergency ventilation must turn on even if switch S1 is off.

From the functional diagram it is seen that the variable frequency drive FC1 must have at least two analogue inputs for the gas detector and room temperature sensor, two digital inputs for the emergency ventilation button and motor control switch, and three outputs for the follow-up alarms sent via the GSM transmitter. The adjustment of motor speed will happen by changing the output frequency of the VFD, adjusted by the internal PID controller.

4.2 Control System

Over 90% of industrial process controllers are Proportional-Integral-Derivative (PID) controllers. The main purpose of a PID controller is to achieve a setpoint value for some process variable by reacting to feedback and manipulating a variable, in this case the motor speed. The P part of PID is proportional to the instantanious error, I part is proportional to the integral of the instantanious error and D part is proportional to the derivative of the instantanious error, together the PID controller can take into consideration the past and the present errors, and also try to predict the future error. (Knospe, 2006, pp. 30-31)

In the project an internal PID controller of the variable frequency converter is used to control the motor speed. The PID controller needs certain variables from which it performs calculations to obtain the needed motor speed for reaching the wanted temperature, these include a setpoint, a process feedback value which in this case is temperature, gain, integration time and derivation time, and the output of the controller must also be scaled to appropriate minimum and maximum levels in respect to the minimum and maximum motor speeds. Gain, integration time and derivation time are used to adjust the aggressiveness of control, gain adjusts how fast the controller reacts to changes in feedback, integration time adjusts on how far from the past the controller calculates the error in feedback, and derivation time adjusts on how far into the future the controller predicts.

$$u(t) = K_c(e(t) + \frac{1}{K_i}\int_0^t e(t)dt + K_d e'(t)) \quad (1)$$

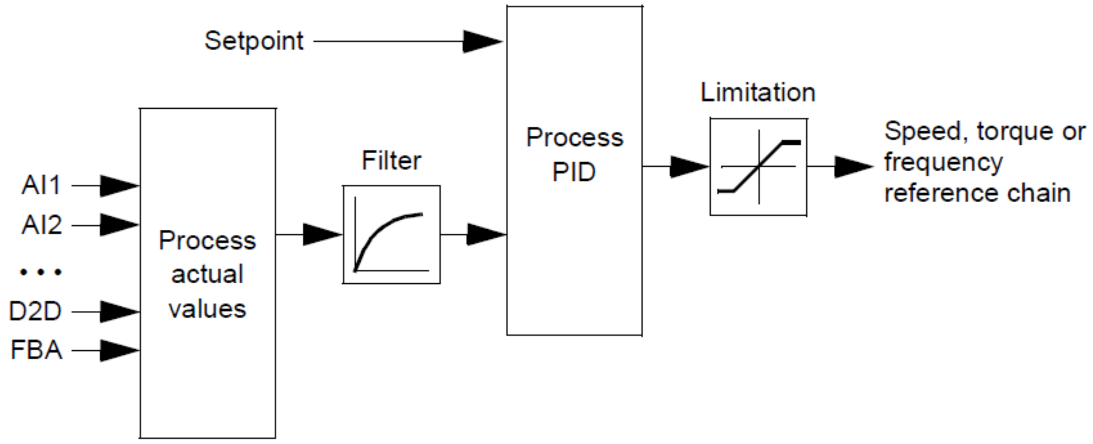
An ideal form of a PID controller is characterized in Equation 1, in which e is the difference between the setpoint and process value, K_c is proportional gain, K_i is integral time and K_d is the derivative time. Increasing the proportional gain makes the controller more aggressive, as does decreasing the integral time. The derivative part of the controller is sensitive to noise in the signal, which often leads to the derivative part to not be used in industrial control (Vandoren, 2016). The general effects of changing the different parameters are shown in Figure 8.

Figure 8 General Effects of Parameter Changes in a PID Controller (Technology Robotix Society, 2019)

Parameter	**Rise time**	**Overshoot**	**Settling time**	**Steady-state error**	**Stability**[11]
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No effect in theory	Improve if K_d small

Figure 9 illustrates a simplified PID process control diagram which is in use on the ABB ACS880 PID control macro.

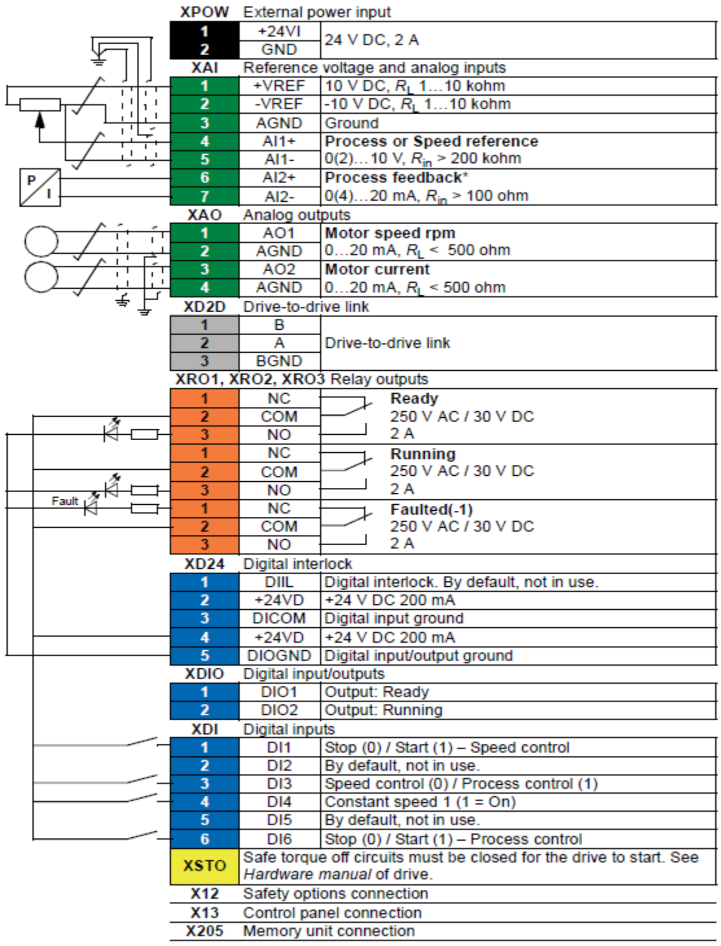
Figure 9 ACS880 Process PID Control (ABB, 2014, p. 38)



4.3 Components

Variable frequency drive for the project was chosen to be an ABB ACS880-01-04A0-3+B056+E200. When ordering an ABB variable frequency drive different options are possible to be specified in the ordering code. “-01” refers to the method of installation and possible special features, which is wall-mounted with no special features in this case. “-07” would refer to a cabinet mounted option, “-17” to a cabinet mounted VFD which brakes in to the electrical network, creating energy savings as the energy from the braking of the motor is injected into the electrical network. “-37” would refer to a low-harmonic version of a cabinet mounted VFD. The next part of the ordering code “-04A0” refers to the amperage of the drive, in this case it is 4.0 Amperes. “-3” refers to the operating voltage which for this drive is 400V, the VFD is also available in 230V, 500V and 690V and the ordering codes would be “-2”, “-5” and “-7” respectively. Extra option +B056 refers to the IP rating of the VFD, B056 is classified as IP55. +E200 is an option for the EMC-class and in this case the VFD has an EMC class of C3, which corresponds to an industrial environment and the power drive system is rated less than 1000V. Figure 10 displays the default connections for the VFD when a PID application macro is in use. All digital inputs and outputs aswell as the relay outputs are possible to be programmed if needed, so no additional I/O accessory cards are required.

Figure 10 ACS880 Default PID Macro Connections. (ABB, 2014, p. 64)



As the project is test equipment, the VFD is not dimensioned for any specific motor. The motor used in this project is a small three-phase motor manufactured by VEM Motors for testing purposes. An EMC safety switch by Katko was chosen to be put near the motor.

Temperature sensor and transmitter RT350-HTB230 manufactured by Nokeval was chosen for the room temperature measurement. RT350 is a Pt100 resistance thermometer, which has a resistance of 100Ω at temperature of 0°C and as the temperature rises the resistance also rises. This resistance can be read and converted to temperature by RTD compatible accessory cards or alternatively a transmitter which calculates and converts the resistance to a 4-20 mA signal. HTB230 is a transmitter to which the Pt100 is connected, and the mA signal is connected to the VFD for process value reading.

Gas sensor SX-482 by Sensorex is manufactured for detecting ammonia, which is the most commonly used refrigerant in portable refrigeration container systems. The sensor uses 24VDC as supply voltage, and has an output of 4-20mA in the range of 0-1000ppm.

Alarms are sent through a Metis 42h GSM Transmitter. The transmitter uses 24VDC as supply voltage and has four alarm loops, each loop is possible to be configured to send a certain message to a certain SMS number. It also has an alarm relay, two remotely controllable relay outputs, one output for status information and a possibility to connect a temperature sensor for monitoring high and low limits. Emergency ventilation button is a "push to break"-type button, MCP-3A-Y000FG-FI with a SY2G surface-mounting box, manufactured by Schneider Electric. S1 switch used for switching process control on and off is a normal 0/1 switch.

Table 1 Component List

TAG	**DEVICE**	**MANUFAC.**	**MODEL**
TE-01	Room Temperature Sensor	Nokeval	RT350-HTB230
QE-01	Gas Sensor	Sensorex	GAM-5/180
M01	Motor	VEM Motors	K21R 63 G 2
FC1	Frequency Converter	ABB	ACS880-01-04A0-3+B056+E200
METIS	GSM Transmitter	METIS	42h
ES-01	Emergency Ventilation Button	Schneider Electric	MCP-3A-Y000FG-FI + SY2G
S1	Adjustment Control Switch	Sälzer	P220-61001-076M1
Q1	EMC Safety Switch	Katko	KUM 316 1V M2EMC 2XM25MEMC
T1	230VAC / 24VDC Transformer	Mascot	230VAC/24VDC/3A;70W
X1	Installation box		380x280x130

4.4 Electrical Design

Electrical design for this project was made in CADS. The supply power for the variable frequency drive and transformer are brought from an external source. The operating voltage for the gas detector and GSM transmitter come through a 230VAC to 24VDC transformer which is located inside the installation box. The box also contains terminal blocks, circuit breakers and tube fuses from which the 400V, 230V and 24VDC is distributed to the components. The VFD creates electromagnetic interference which must be taken into account by using shielded EMC cables, an EMC safety switch and EMC cable sealing clamps in the VFD circuit, as they are a part of reducing the effects of high-frequency electromagnetic interferences. The gas sensor is connected to AI1 and the temperature transmitter is connected to AI2, which is the input for the process variable when using a PID application macro. Cables for measuring instruments should be shielded and the shield grounded to minimize the effects of outside interference on sensitive measurements.

Figure 11 Electrical Diagram 1

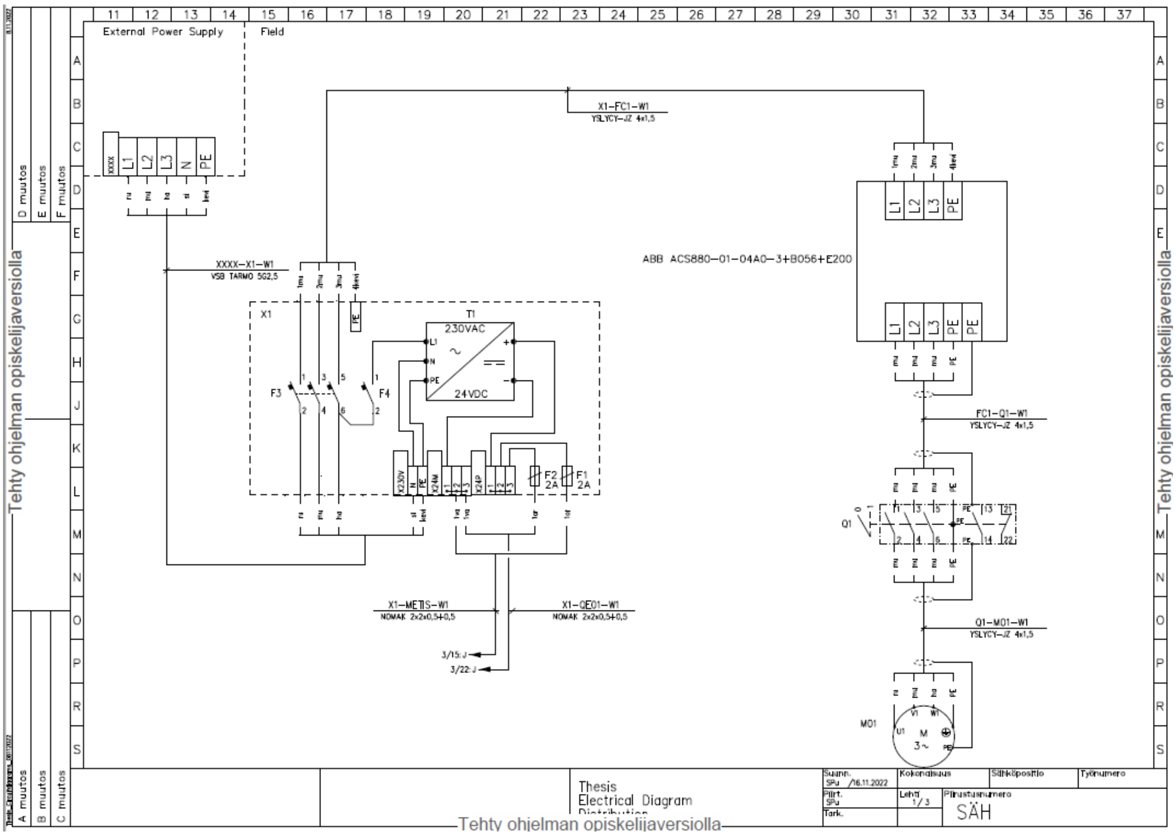


Figure 12 Electrical Diagram 2

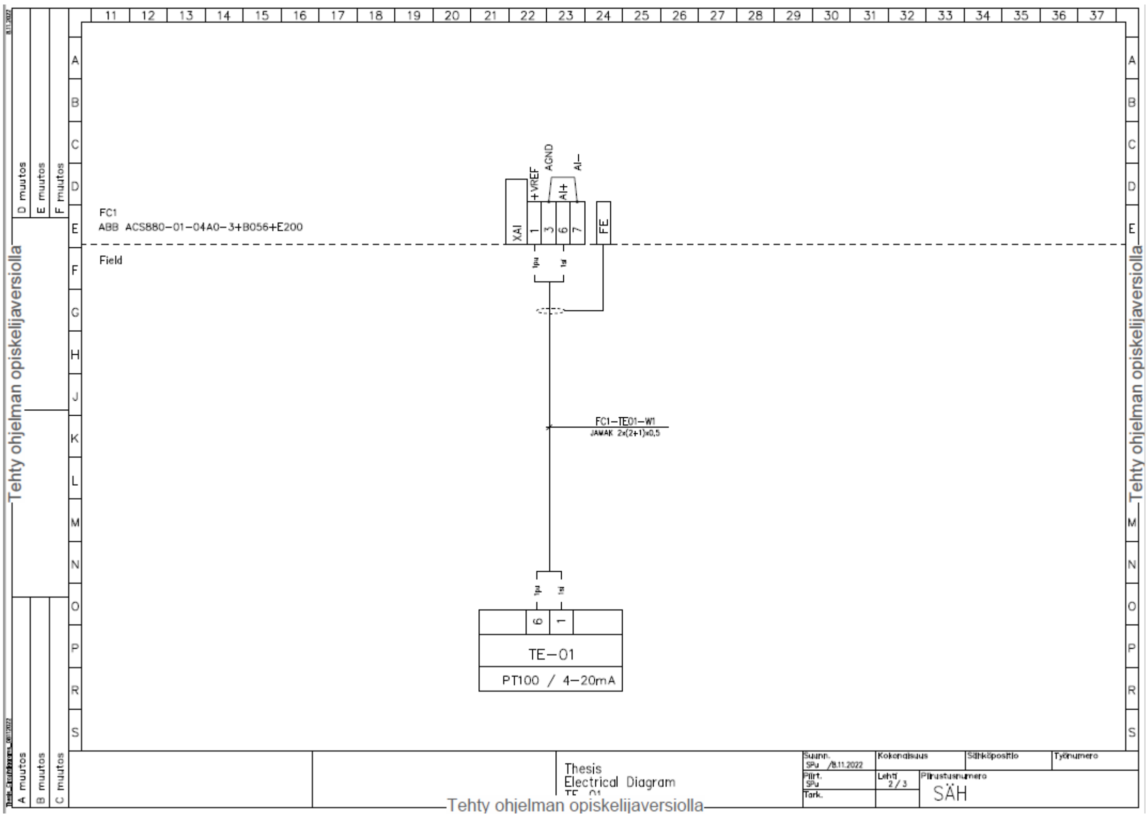
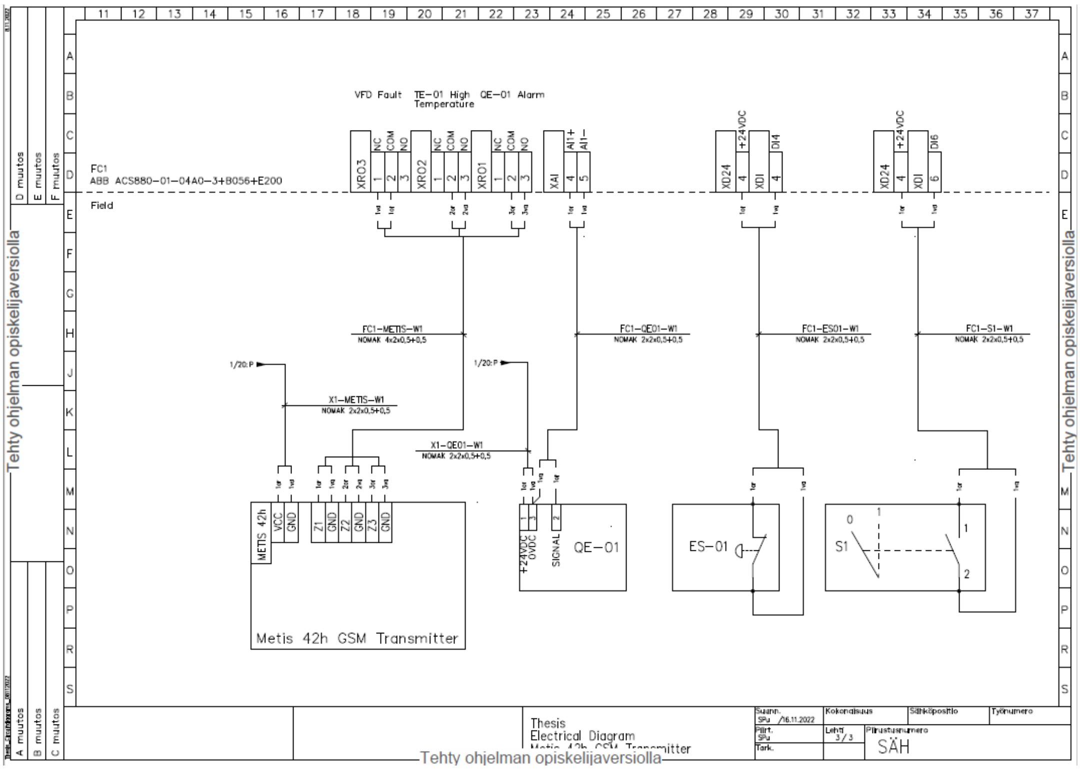


Figure 13 Electrical Diagram 3



Alarms are sent to the GSM transmitter through the programmable relay outputs XRO1, XRO2 and XRO3. Gas detector, emergency ventilation button ES-01 and the adjustment control switch S1s contacts take 24VDC supply voltage from transformer T1, ES-01 and S1 are connected to digital inputs DI4 and DI6 respectively, DI4 is an input for choosing a constant motor speed and DI6 is the input for choosing process control to be on or off.

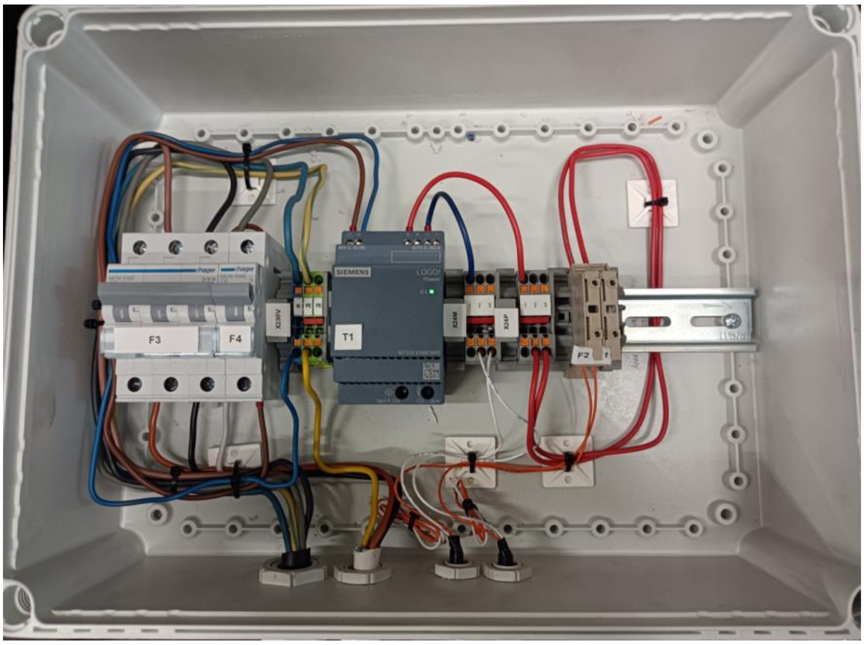
5 Building and Testing

Building of the project begun with allocating a space for the test equipment. It was decided to be made in the maintenance hall of Suomen Teollisuuskylmä Oy located in Tampere.

5.1 Physical Assembly

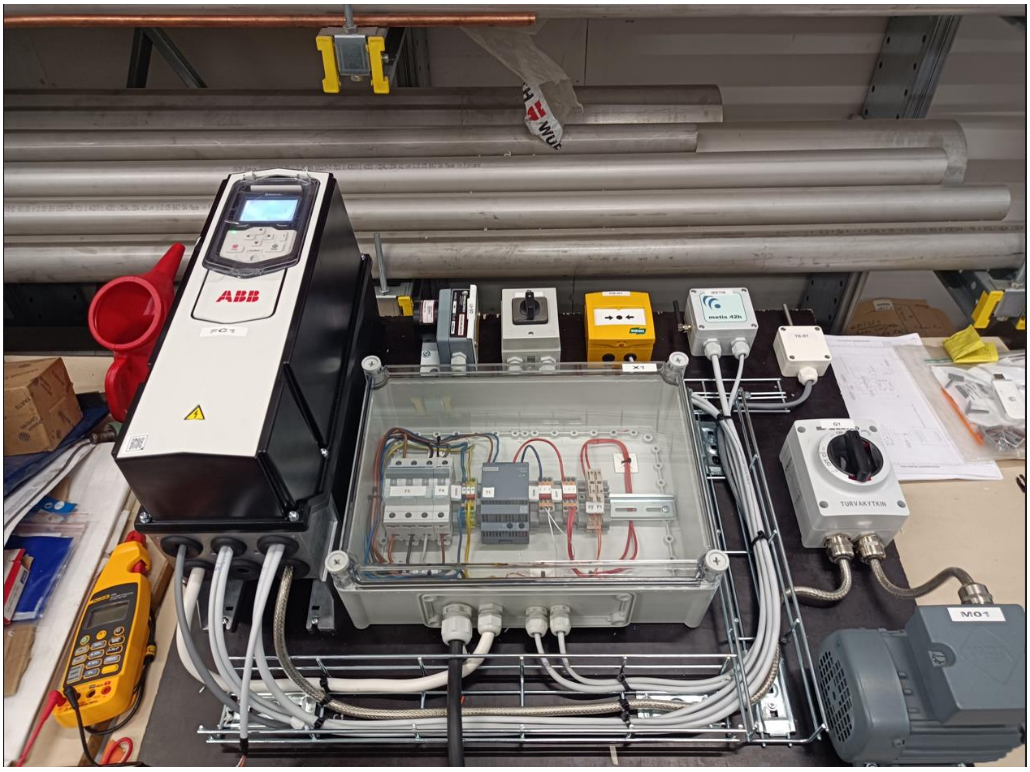
The space requirements for the project were not large as the equipment could fit on a $1m^2$ piece of plywood, on which the components were fastened with wood screws. As seen in Figure 14, the installation box X1 houses the protective devices, transformer, terminal blocks and pipe fuses for the distribution of voltages to the VFD, gas sensor and the GSM transmitter. The size of the installation box X1 was determined by assembling the relevant parts on a piece of DIN-rail which then was connected to a fitting installation box.

Figure 14 Installation Box X1



All components were fitted on the plywood and cable routes designed to be pleasant to the eye. All cabling and connections were finished before powering up the VFD for the first time.

Figure 15 Full System



5.2 Setup of the VFD

Once an ABB VFD is powered up for the first time, it needs to be set up and commissioned to be used with the motor. Once powered on, the commissioning is possible to be made using the drives own assistant on the control panel or by using ABB Drive Composer software. In the commissioning, the language, units, time, voltages and the basic motor data are given to the VFD, the basic motor data includes the information on the motor plate such as nominal voltage, current, power and cos ϕ. Minimum and maximum speeds and torques and the maximum current are also given to the VFD, there is also a possibility to check the direction of rotation of the motor during it.

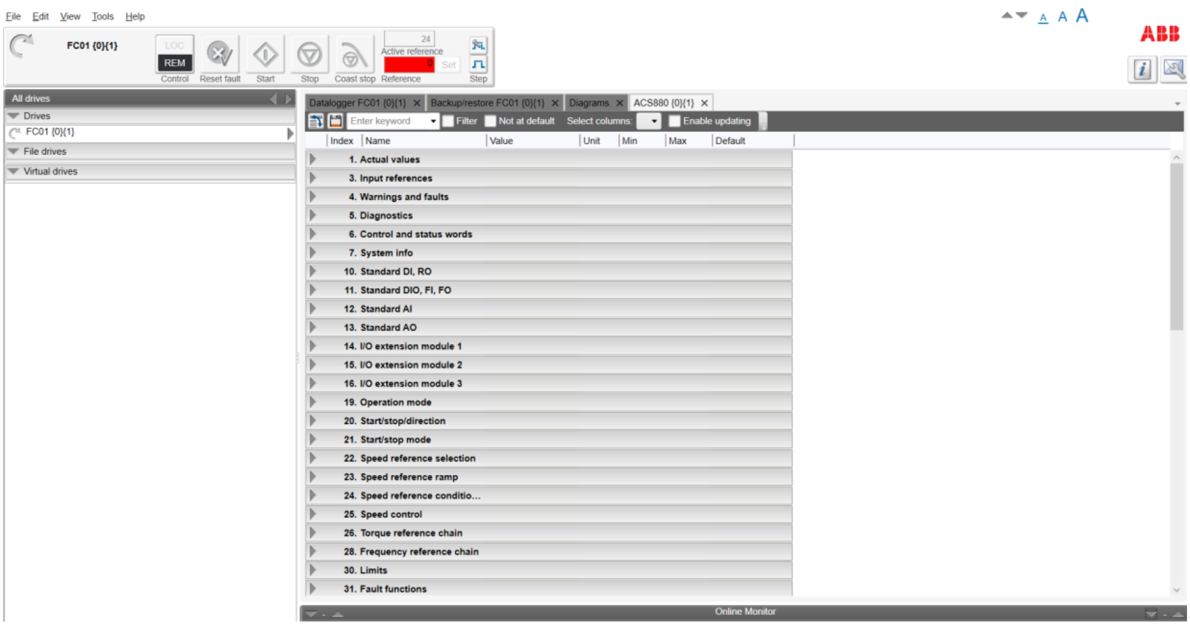
Once the commissioning is complete, the motor can be run manually in local control mode in which it is possible to set a fixed speed reference and run the motor using that speed. It was made sure the VFD and motor are working by running the motor with different speeds, and the parameterization and programming begun to achieve the needed operational demands.

5.3 ABB Drive Composer and Parameterization

The parameterization was done using ABB Drive Composer software for which the connection between the VFD and computer was created using the mini-USB port of the control panel. ABB Drive composer enables the parameterization and programming of the VFD using a PC. Features included in the software are datalogging, easy parameterization, adaptive programming using function blocks or PAWN-language, backupping and restoring parameters and monitoring. The software also allows the user the simultaneous monitoring and control of a network of VFDs.

The first step towards achieving the operational demands was activating and parametering the PID control macro. Parameters can be changed in the Drive Composer by double-clicking a parameter and changing its value by either using the drop-down menu or typing in the wanted value. The parameter window is shown in Figure 16.

Figure 16 ABB Drive Composer Parameter Window



By activating the PID control macro by changing parameter 96.5 to “PID-CTRL”, the default values of certain parameters are changed to be as shown in Table 2.

Table 2 PID Control Macro Default Parameters (ABB, 2014)

Parameter		PID control macro default
No.	Name	
12.30	AI2 scaled at AI2 max	1500.000
19.11	Ext1/Ext2 selection	DI3
20.01	Ext1 commands	In1 Start
20.04	Ext1 in2	Off
20.06	Ext2 commands	In1 Start
20.08	Ext2 in1	DI6
22.12	Speed ref2 selection	PID
22.14	Speed ref1/2 selection	DI3
22.22	Constant speed sel1	DI4
23.11	Ramp set selection	Acc/Dec time 1
31.11	Fault reset selection	Off
40.07	PID operation mode	On
40.08	Feedback 1 source	AI2 scaled
40.09	Feedback 2 source	AI2 scaled
40.11	Feedback filter time	0.040 s
40.16	Setpoint 1 source	AI1 scaled
40.35	Derivation filter time	1.0 s

Ext2 commands make the VFD start when Ext2 in1 is active. Speed reference is selected to be adjusted by the PID output, and constant speed is selected through DI4. Feedback sources are changed to AI2 scaled. The default PID macro was needed to be further parameterized to match the design and connections of the project. Table 3 shows more of the changed parameters accompanied with short explanations of the functions of the particular parameters.

Table 3 Changed Parameter Values

Index	Name	New Value	Unit	Default	Comment
10.24	RO1 source	Adaptive program	NoUnit	Ready run	RO1 trigger selection, trigger comes from the adaptive program
10.27	RO2 source	Adaptive program	NoUnit	Running	RO2 trigger selection, trigger comes from the adaptive program
12.15	AI1 unit selection	mA	NoUnit	V	Selects AI1 to use mA signal
12.17	AI1 min	4	mA	0	Low limit for mA signal, in this case 4-
12.18	AI1 max	20	mA	10	High limit for mA signal, in this case 4-
12.20	AI1 scaled at AI1 max	1000	NoUnit	1500	AI1 value when signal is 20mA. AI1 min value is default 0.
12.29	AI2 scaled at AI2 min	-50	NoUnit	0	AI2 value when signal is 0mA
12.30	AI2 scaled at AI2 max	50	NoUnit	100	AI2 value when signal is 20mA
19.11	Ext1/Ext2 selection	EXT2	NoUnit	DI3	Operation mode selection, in this project EXT2 is constantly used.
20.02	Ext1 start trigger type	Level	NoUnit	Edge	Ext1 is in use when Ext1 in1 source is 1.
20.03	Ext1 in1 source	Not selected	NoUnit	DI1	Ext1 in1 source is not selected since we are always in Ext2 mode
20.07	Ext2 start trigger type	Level	NoUnit	Edge	Ext2 is in use when Ext2 in1 source is 1.
20.08	Ext2 in1 source	Adaptive program	NoUnit	DI6	Ext2 in1 source is controlled by the adaptive program
20.12	Run enable 1 source	Selected	NoUnit	DI5	Run enable 1 source is always selected
22.22	Constant speed sel1	Adaptive program	NoUnit	DI4	Constant speed 1 is selected by the adaptive program
22.26	Constant speed 1	2820	rpm	300	Constant speed 1 is given a value, in this case the maximum speed
23.12	Acceleration time 1	5	s	20	Acceleration time
23.13	Deceleration time 1	5	s	20	Deceleration time
30.11	Minimum speed	600	rpm	-1500	Minimum speed
30.12	Maximum speed	2820	rpm	1500	Maximum speed
31.36	Aux fan fault function	Warning	NoUnit	Fault	Choosing of a warning or a fault from auxiliary fan error
40.7	Set 1 PID operation mode	On	NoUnit	On when drive is on	Set PID operation mode to be always On
40.9	Set 1 feedback 2 source	AI2 scaled	NoUnit	Not Selected	PID controller feedback source is chosen to be AI2 scaled value (scaled
40.12	Set 1 unit selection	PID user unit 1	NoUnit	%	Feedback unit selection, the unit can be assigned from the VFD settings
40.14	Set 1 setpoint scaling	28	NoUnit	100	At what value the PID output must be maximum
40.15	Set 1 output scaling	2820	NoUnit	1500	Scales PID maximum output to the motor maximum speed
40.16	Set 1 setpoint 1 source	Control panel	NoUnit	Internal setpoint	Setpoint 1 is possible to be changed from the control panel
40.26	Set 1 setpoint min	19	NoUnit	0	Minimum allowable setpoint
40.27	Set 1 setpoint max	40	NoUnit	32767	Maximum allowable setpoint
40.31	Set 1 deviation inversion	Inverted (Fbk -Ref)	NoUnit	Not Inverted (Ref-Fbk)	Deviation is inverted, PID calculates the deviation from Feedback-Setpoint rather than Setpoint-Feedback. This allows the controller to increase motor speed when temperature rises.
40.33	Set 1 integration time	10	s	60	Integration time
40.36	Set 1 output min	600	NoUnit	0	Minimum PID output speed
40.37	Set 1 output max	2820	NoUnit	1500	Maximum PID output speed
40.41	Set 1 sleep mode	External	NoUnit	Not Selected	Sleep mode will activate by an external event
40.42	Set 1 sleep enable	Adaptive program	NoUnit	Not Selected	Adaptive program controls sleep mode off or on
40.44	Set 1 sleep delay	0	s	60	Delay for entering sleep mode, timer function is in the adaptive program
95.1	Supply voltage	380...415 V	V		Value changed in the setup assistant
96.1	Language	English	NoUnit	Not selected	Value changed in the setup assistant
99.6	Motor nominal current	0,8	A	0	Value changed in the setup assistant
99.7	Motor nominal voltage	400	V	0	Value changed in the setup assistant
99.8	Motor nominal frequency	50	Hz	0	Value changed in the setup assistant
99.9	Motor nominal speed	2820	rpm	0	Value changed in the setup assistant
99.10	Motor nominal power	0,25	kW	0	Value changed in the setup assistant
99.11	Motor nominal cos ϕ	0,7	NoUnit	0	Value changed in the setup assistant

The PID controller was hard to configure as the test equipments motor speed did not have have a direct effect on the room temperature. The PID controller was roughly tuned to showcase the operation, and to illustrate how the adjustment is working in real time the monitoring feature of ABB Drive Composer was used. In a real environment the PID controller should be more carefully tuned to increase energy efficiency and to ensure operation.

5.4 Adaptive Programming

It was noticed that the functional demands could not be achieved with only parameters, so adaptive programming was utilized to create an application that runs by the VFD PID control macro. The environment in the ABB Drive Composer for adaptive programming includes most common function blocks and different input and output possibilities. At most 20 function blocks can be used in the program, and the program can also be saved and downloaded for further use in other similar drives. While creating and editing the application program, the drive can not run, and after the program is complete it can easily be uploaded to the drive.

Figure 17 Adaptive Programming Environment

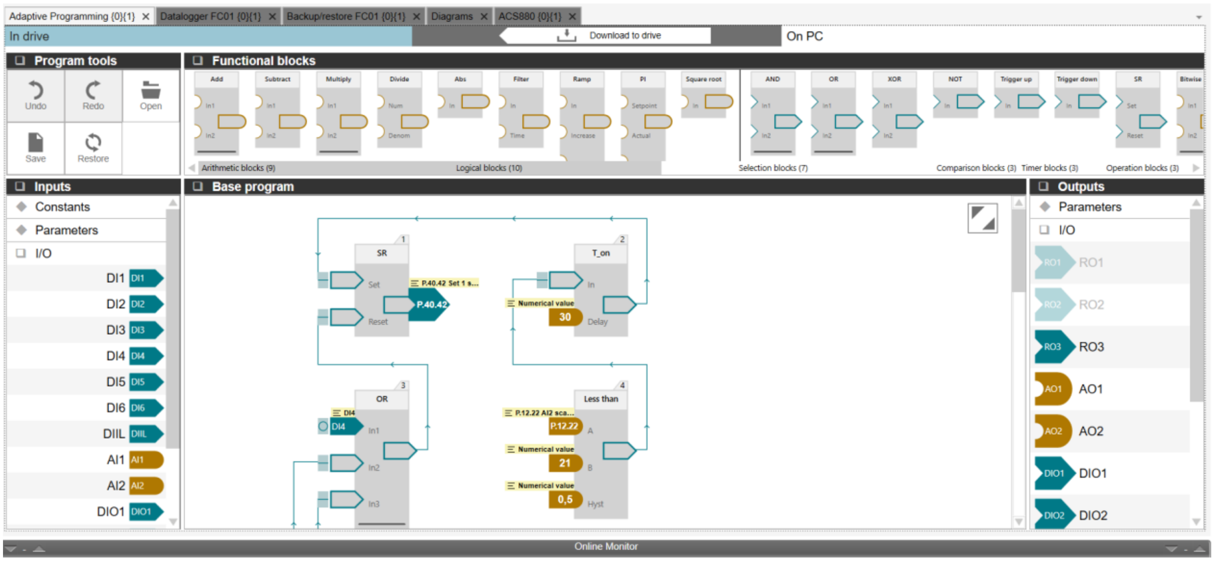
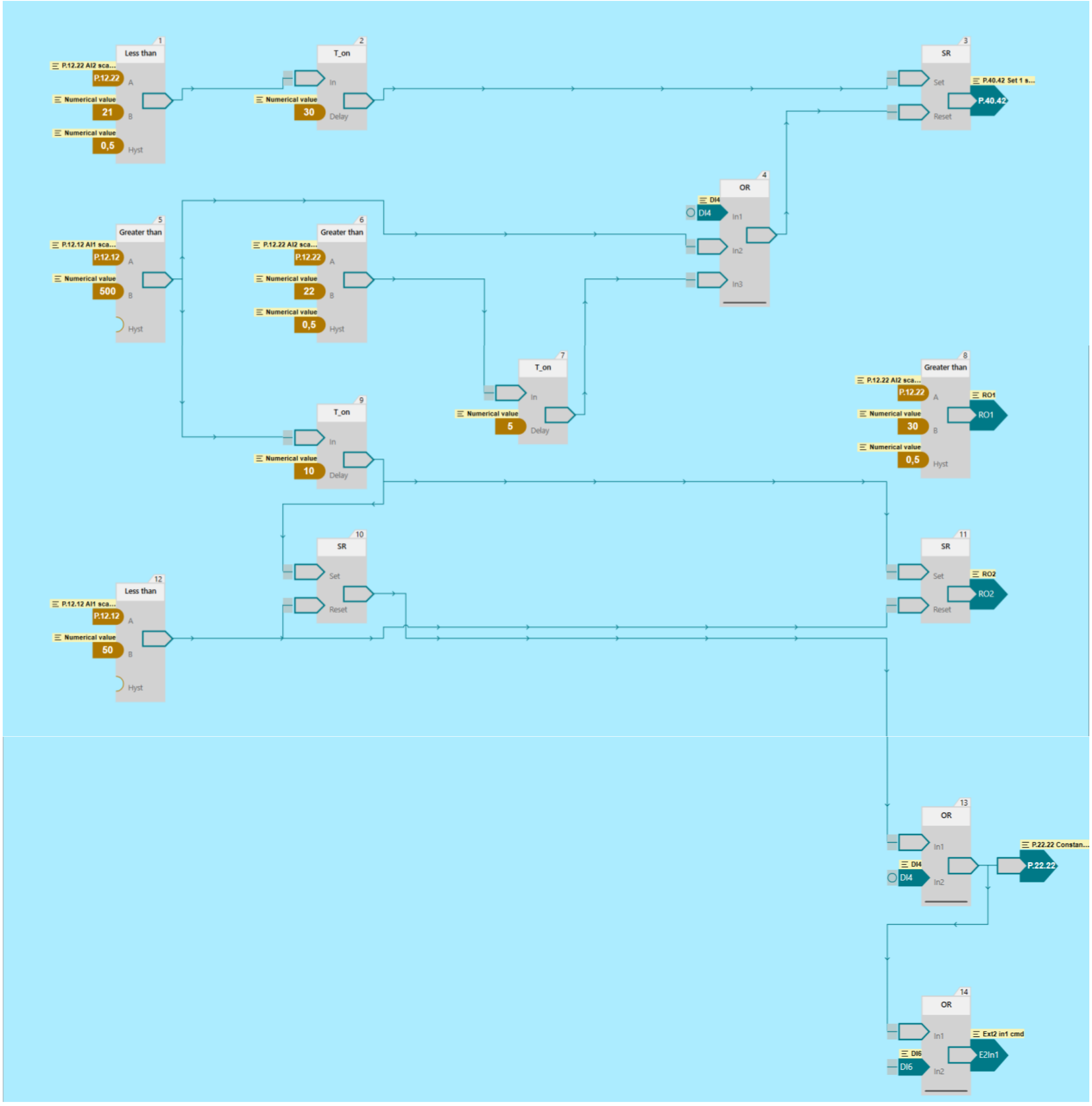


Figure 18 Adaptive Program



Function block 3 activates sleep mode when the temperature has been below 21°C for 30 seconds, and sleep mode is deactivated by the temperature being above 22°C for 5 seconds, DI4 being deactivated or the gas level is greater than 500ppm. Function blocks 8 and 11 are controlling the RO1 and RO2 relay outputs which trigger the alarms. Function block 13 sets the motor to run at a constant speed when DI4 is deactivated or the gas level has been greater than 500ppm for 10 seconds. When gas level falls below 50ppm, function block 12 disables the constant speed through block 10, constant speed will be disabled if emergency ventilation button is also not active. Function block 14 keeps Ext2 active if switch S1 is enabled, and also allows the emergency ventilation to turn Ext2 on even if S1 is disabled.

5.5 Metis GSM Transmitter

The Metis GSM transmitter is possible to be programmed by sending text messages in a certain format and also by using metisSoft software. In this project the metisSoft software was used and the settings changed are shown in Figure 19. The connection between Metis and PC is done with a mini-USB cable.

Figure 19 MetisSoft Settings

5.6 Testing

All elements of the project were tested one by one, ensuring that the system operates according to the functional description. Values such as the temperature, gas level, motor speed and PID output were monitored in ABB Drive Composer. The system testing began with ensuring the PID control was working by heating up the PT100 thermometer and seeing if the controller starts to increase the speed of the motor, and cooling the PT100 to see if it decreases it. The sleep function was tested by cooling the temperature to the sleep setpoint in which it stopped the motor, the motor did not continue to run before the temperature reached the setpoint for exiting sleep.

Figure 20 Adjustment Graph

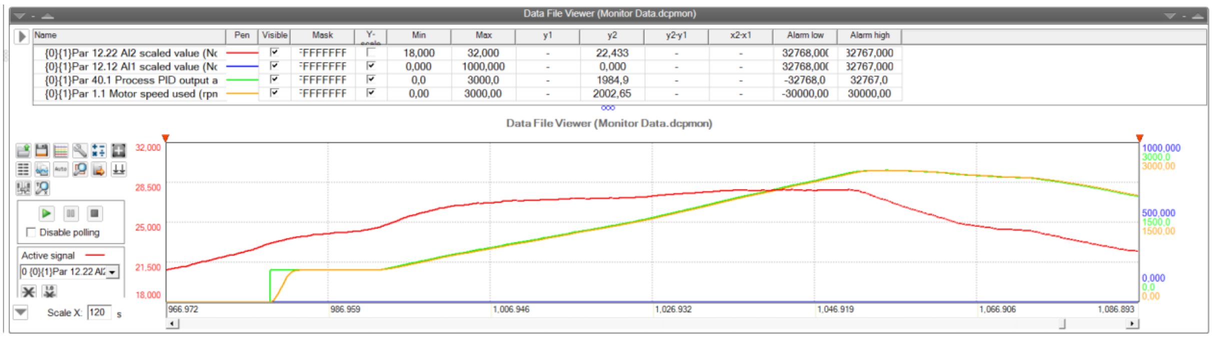
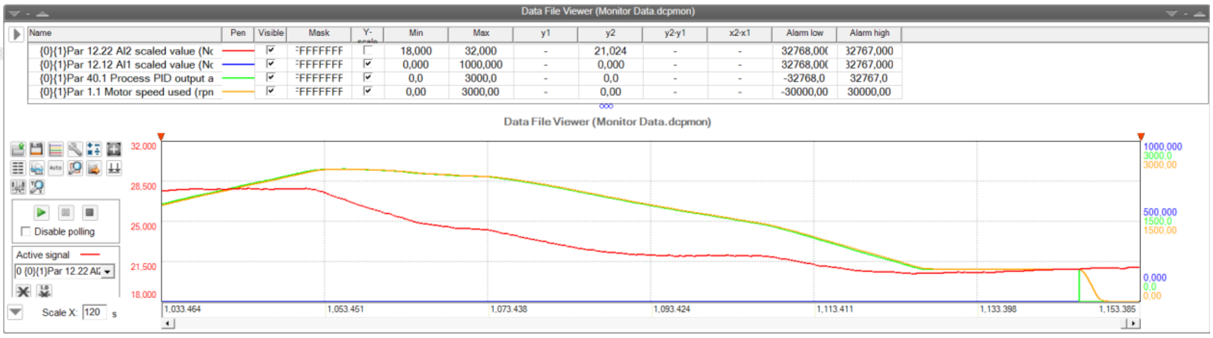


Figure 21 Adjustment Graph 2



Figures 20 & 21 illustrate how the system was in sleep mode and as the temperature rose, it exited sleep mode and the PID controller started adjusting motor speed. Once the temperature fell below 21°C and stayed there for 30 seconds, sleep mode was activated again.

The function of switch S1 was tested and if the drive was not in emergency ventilation mode, it always stopped the motor. The emergency ventilation was tested in conjunction with S1, as it must turn on regardless of the switch position. The emergency ventilation button set the motor speed to maximum and so did the gas sensor while above 500ppm regardless of the position of S1. The emergency ventilation did not stop unless the emergency ventilation switch was off and the gas level below 50ppm. The emergency ventilation also made the VFD exit sleep mode.

Figure 22 displays how the system reacted to the gas level rising. The gas sensors 4-20mA signal was simulated using a Fluke 773 Milliamp Process Clamp Meter as releasing ammonia to the sensor was not an option in the maintenance hall. Once the gas level had risen above 500ppm and after a set delay, motor speed was set to run at maximum. Figure 23 shows the system leaving sleep mode when emergency ventilation button was pressed and increasing the motor speed to maximum following the acceleration ramp. Once the emergency ventilation button was reset the system activated sleep mode and decreased motor speed according to the deceleration ramp.

Figure 22 Emergency Ventilation Operation

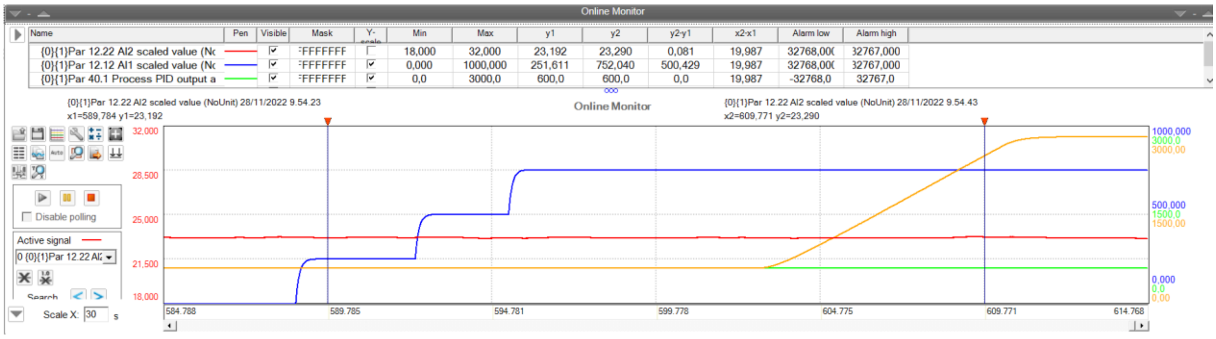
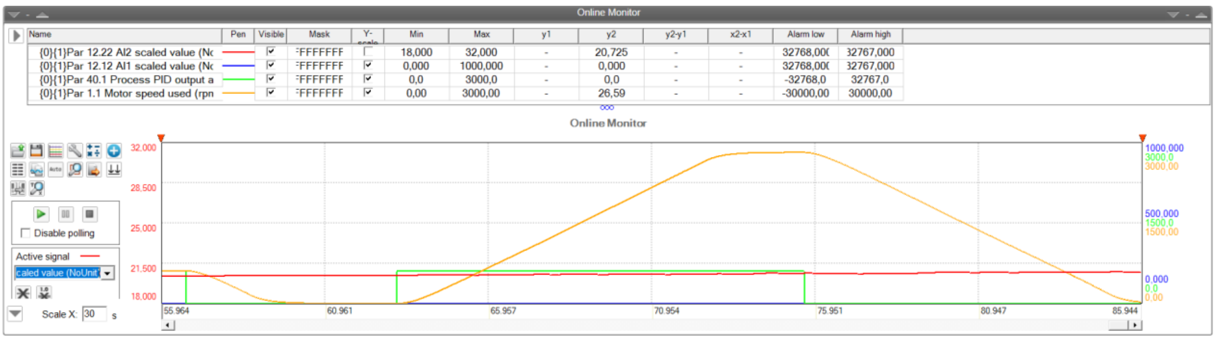


Figure 23 Emergency Ventilation Operation 2



Alarms and the operation of the GSM transmitter were tested one-by-one by manually creating fault conditions. High temperature alarm was achieved by manually heating up the PT100, gas alarm was generated by simulating its signal to be over the alarm limit, and the

VFD fault was achieved by disconnecting the auxiliary fan of the drive and setting it to trigger a fault.

6 Results and Conclusion

The results of this project were satisfactory as the system operated as demanded by the functional description. The motor speed was adjusted by the internal PID controller, and a room temperature setpoint could be set by using the drives control panel. Relevant values such as temperature, motor speed, gas level and the PID output speed were presented in the control panel for quick assessment of the VFD operation. Emergency ventilation was triggered by the gas level reaching 500ppm or by pressing the emergency ventilation button. Alarms were successfully sent through the Metis GSM transmitter.

This thesis allows a relatively easy implementation of this kind of a system in portable refrigeration solutions as the needed parameters, the application program and their functions are presented. The electrical and automation design aswell as the functional description will always be unique to each project, but the parameterization and programming of the VFDs PID control will not deviate by a large margin.

This project taught me about all aspects of electrical and automation design in the process industry where processes need accurate adjustment, control and monitoring. Variable frequency drives are a large part of the adjustment processes as pumps, compressors and other components utilizing electric motors are widely ran by VFDs. The use of variable frequency drives and PID adjustment does not only help meet the operational demands but also improves energy efficiency and lifetime of motors, as well as lowers the operational costs.

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Appendix 1: Changed Parameter List

28/11/2022

ABB

Device Info

FC01

Type ACS880-01-04A0-3+B056 (443)

Model ACS880

Serial AINF340x

Drive parameters

Index	Name	Value	Unit	Min	Max	Default
10.	Standard DI, RO					
24	RO1 source	Adaptive program	NoUnit			Ready run
27	RO2 source	Adaptive program	NoUnit			Running
12.	Standard AI					
15	AI1 unit selection	mA	NoUnit			V
17	AI1 min	4,000	mA	-22,000	22,000	0,000
18	AI1 max	20,000	mA	-22,000	22,000	10,000
20	AI1 scaled at AI1 max	1000,000	NoUnit	-32768,000	32767,000	1500,000
29	AI2 scaled at AI2 min	-50,000	NoUnit	-32768,000	32767,000	0,000
30	AI2 scaled at AI2 max	50,000	NoUnit	-32768,000	32767,000	100,000
19.	Operation mode					
11	Ext1/Ext2 selection	EXT2	NoUnit			DI3
20.	Start/stop/direction					
2	Ext1 start trigger type	Level	NoUnit			Edge
3	Ext1 in1 source	Not selected	NoUnit			DI1
7	Ext2 start trigger type	Level	NoUnit			Edge
8	Ext2 in1 source	Adaptive program	NoUnit			DI6
12	Run enable 1 source	Selected	NoUnit			DI5
22.	Speed reference selection					
22	Constant speed sel1	Adaptive program	NoUnit			DI4
26	Constant speed 1	2820,00	rpm	-30000,00	30000,00	300,00
23.	Speed reference ramp					

Index	Name	Value	Unit	Min	Max	Default
12	Acceleration time 1	5,000	s	0,000	1800,000	20,000
13	Deceleration time 1	5,000	s	0,000	1800,000	20,000
30.	Limits					
11	Minimum speed	600,00	rpm	-30000,00	30000,00	-1500,00
12	Maximum speed	2820,00	rpm	-30000,00	30000,00	1500,00
31.	Fault functions					
36	Aux fan fault function	Warning	NoUnit			Fault
40.	Process PID set 1					
7	Set 1 PID operation mode	On	NoUnit			On when drive running
9	Set 1 feedback 2 source	AI2 scaled	NoUnit			Not selected
12	Set 1 unit selection	PID user unit 1	NoUnit			%
14	Set 1 setpoint scaling	28,00	NoUnit	-32768,00	32767,00	100,00
15	Set 1 output scaling	2820,00	NoUnit	-32768,00	32767,00	1500,00
16	Set 1 setpoint 1 source	Control panel	NoUnit			Internal setpoint
21	Set 1 internal setpoint 1	24,00	PID user unit 1	-32768,00	32767,00	0,00
26	Set 1 setpoint min	19,00	NoUnit	-32768,00	32767,00	0,00
27	Set 1 setpoint max	40,00	NoUnit	-32768,00	32767,00	32767,00
31	Set 1 deviation inversion	Inverted (Fbk - Ref)	NoUnit			Not inverted (Ref - Fbk)
33	Set 1 integration time	10,0	s	0,0	32767,0	60,0
36	Set 1 output min	600,0	NoUnit	-32768,0	32767,0	0,0
37	Set 1 output max	2820,0	NoUnit	-32768,0	32767,0	1500,0
41	Set 1 sleep mode	External	NoUnit			Not selected
42	Set 1 sleep enable	Adaptive program	NoUnit			Not selected
44	Set 1 sleep delay	0,0	s	0,0	3600,0	60,0
43.	Brake chopper					
11	Brake resistor fault limit	105	%	0	150	105

ABB

Index	Name	Value	Unit	Min	Max	Default
95.	HW configuration					
1	Supply voltage	380...415 V	NoUnit			Not given
96.	System					
1	Language	English	NoUnit			Not selected
97.	Motor control					
19	Hexagonal field weakening point	120,0	%	0,0	500,0	120,0
98.	User motor parameters					
2	Rs user	0,14311	p.u.	0,00000	0,50000	0,00000
3	Rr user	0,05732	p.u.	0,00000	0,50000	0,00000
4	Lm user	1,05938	p.u.	0,00000	10,00000	0,00000
5	SigmaL user	0,09038	p.u.	0,00000	1,00000	0,00000
9	Rs user SI	41,31230	Ohm	0,00000	100,00000	0,00000
10	Rr user SI	16,54686	Ohm	0,00000	100,00000	0,00000
11	Lm user SI	973,44	mH	0,00	100000,01	0,00
12	SigmaL user SI	83,05	mH	0,00	100000,01	0,00
99.	Motor data					
6	Motor nominal current	0,8	A	0,0	6400,0	0,0
7	Motor nominal voltage	400,0	V	0,0	800,0	0,0
8	Motor nominal frequency	50,00	Hz	0,00	1000,00	0,00
9	Motor nominal speed	2820	rpm	0	30000	0
10	Motor nominal power	0,25	kW	0,00	10000,00	0,00
11	Motor nominal cos φ	0,70	NoUnit	0,00	1,00	0,00
200.	Safety					
254	CRC of the configuration	100	NoUnit	0	65535	0