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Modernization of the electrical centre of a grain dryer

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Thesis abstract

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The purpose of this thesis was to design a logic controlled electrical centre for a grain dryer and to sketch electrical drawings that can be used when producing the electrical centre. The work was implemented via JPT-Industria Oy. The design work was started by clarifying the grain dryer’s functionalities by examining the old centre’s electrical drawings and interviewing the customer.

In addition to the grain dryer’s devices, the customer also wanted the same electrical centre to control the oat dehuller’s devices and the screw conveyors that are located in the same building, but not related to grain drying. The customer also wanted some auxiliary motor controlling circuits to the centre in case that new devices will be added to the same electrical centre in the future.

Some of the direct on-line electric motor circuits were changed to be controlled by Vacon 100 frequency converters. The frequency converters were connected to the logic controller by Profibus. Beckhoff CX5020 embedded PC was selected for the programmable logic controller and Beckhoff 19” touch screen for the human-machine interface.

The frequency converters also needed cooling and the logic controller and the touch screen needed heating which were controlled by a thermostat, because the electrical centre will be used a little also in wintertime. Kymdata Oy:s CADS Planner Electric Pro –software was used for sketching the electrical drawings.

Keywords: grain dryer, electrical centre, electrical drawings, programmable logic controller, profibus

SEINÄJOEN AMMATTIKORKEAKOULU

Opinnäytetyön tiivistelmä

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Tämän opinnäytetyön tarkoituksena oli suunnitella logiikkaohjattu sähkökeskus viljankuivaamolle ja piirtää kuvat, joiden perusteella sähkökeskus voidaan rakentaa. Työ toteutettiin JPT-Industria Oy:n kautta. Suunnittelu aloitettiin tutustumalla kuivaamon ja vanhan sähkökeskuksen toimintaan ja tutkimalla sen sähköpiirustuksia sekä haastattelemalla asiakasta.

Viljankuivaamon laitteiden lisäksi asiakas halusi saman keskuksen ohjaavan myös mm. kaurankuorijan laitteita, samassa rakennuksessa sijaitsevia muita kuin kuivaukseen liittyviä ruuvikuljettimia sekä ylimääräisiä varamoottorilähtöjä, mikäli tulevaisuudessa tulee tarve lisätä laitteita.

Osa moottorilähdöistä muutettiin suorista moottorilähdöistä Vacon 100-taajuusmuuttajilla ohjattaviksi lähdöiksi. Taajuusmuuttajat yhdistettiin logiikkaan Profibus-väylän kautta. Logiikkaohjaimeksi valittiin Beckhoff CX5020 sulautettu PC ja käyttöliittymäksi Beckhoffin 19”:n kosketusnäyttö.

Taajuusmuuttajille tarvittiin myös jäähdytys ja logiikkaohjaimelle sekä kosketusnäytölle lämmitys termostaattien kautta, sillä laitteita tullaan käyttämään jonkin verran myös talvella. Sähköpiirustuksien tekoon käytettiin Kymdata Oy:n CADS Planner Electric Pro –suunnitteluohjelmaa.

Avainsanat: viljankuivaamo, sähkökeskus, sähköpiirustukset, ohjelmoitava logiikka, profibus

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1 INTRODUCTION

This project was implemented for a customer of JPT-Industria Oy. JPT-Industria Oy produces feed mills for the fodder production of broilers, pigs and bovines. They also make devices for grain handling like conveyors, grain dehullers, bucket elevators and silos, and automatize heating plants. JPT-Industria Oy is located in the industrial area of Kestopuu, Ilmajoki. It was founded in Seinäjoki in 2008. (JPT-Industria Oy [Ref. 19.4.2014].) The revenue of JPT-Industria Oy in the year 2012 was approximately 4 million euros (Kauppalehti [Ref. 19.4.2014]).

One of the main reasons for the need to change the electrical centre was that the old electrical centre had a high fire risk caused by the dust in the grain drier building and insufficient dust protection, and there had already been a fire inside the logic controller cabinet. The customer also wanted the electrical centre to be renewed because there had been many changes and additions in the grain drier system after its commissioning, and therefore there were many small electrical centres installed afterwards next to the original. The customer wanted those equipment to be installed more clearly to one or two different electrical centres.

The target of this project was to design an electrical centre for the grain dryer and for the other electric motors in the grain dryer building. The starting point was that all the needed motors should be controlled by one or two electrical centres and by one logic controller. The HMI (Human-Machine Interface) was decided to be implemented with a touch screen. The customer also wanted some of the motor outputs with a direct on-line starter (DOL) and a star-delta starter to be changed to frequency converter drives.

This project started by a visit to the grain drier building with the aim to research the grain dryer’s functionalities with the help of the old electrical centre’s drawings. The customer was also interviewed about the functionalities and changes he wanted to the new electrical centre. After that, the electrical design and drawing of the electrical circuits was started. The electrical drawings were done using the CADS Planner Electric Pro software by Kymdata Oy.

2 THEORY OF GRAIN DRYING

After harvesting the moisture in grains needs to be reduced to an acceptable level before storaging in order to avoid grain spoilage. The acceptable moisture level for storage depends on the variety of grain, the length of storage time, storage structure and geographical location. A percentage value of moisture in grain (M_w) can be calculated with the following formula if the wet weight and the dry weight are known:

$$M_w = 100 \times \frac{(Wet\ weight - Dry\ weight)}{(Wet\ weight)} \qquad (1)$$

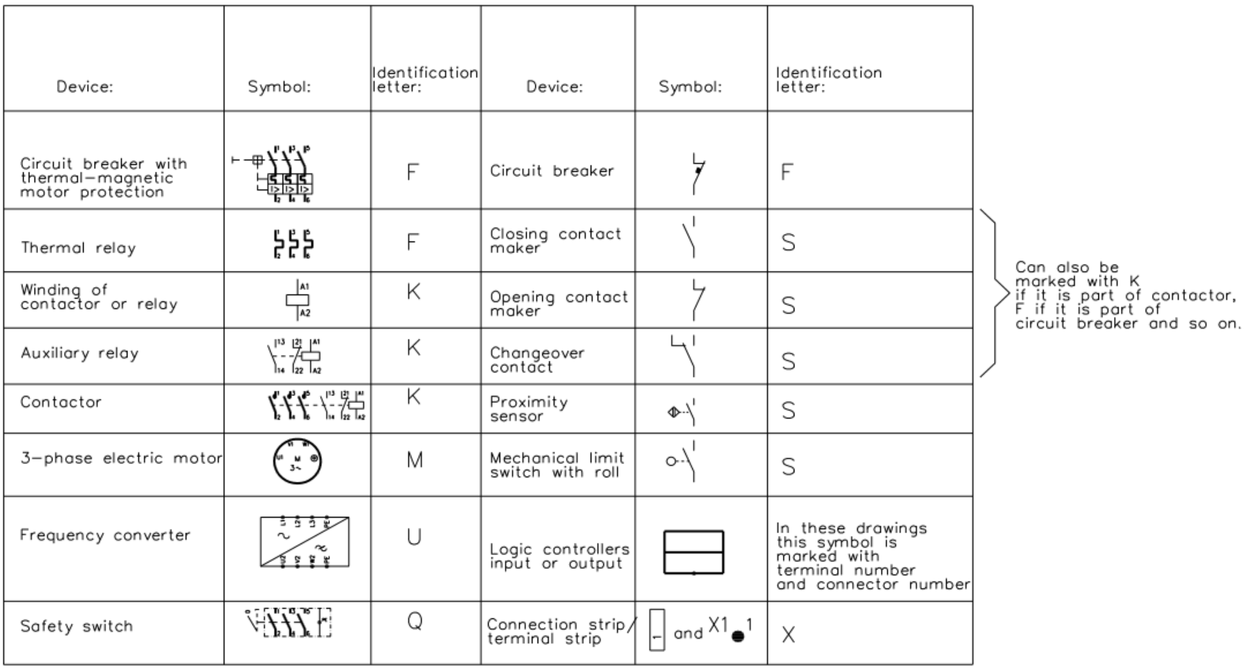
(Maier & Bakker-Arkema 2002.)

The moisture content of the grain is usually under 20 % when it is harvested and the suitable moisture percentage for storage is under 14 %. The drying of the harvested grain should be started within 12 hours from harvesting. If the grain is very humid, drying should be started even earlier. If the size of kernel is bigger than on average, the drying process with an automated drying system needs precise observation, because if the drying air is too warm it may only dry the surface layer of a kernel and leave the core wet. If that happens, the moisture stabilizes in the storage silo and the moisture content may be over 14 %. The grain should be cooled carefully after drying. Even when the moisture content is only under 15 % after harvesting, the grain should be circulated in the dryer system at least for one hour so that the precleaner removes all the impurities off the grain. (Farmit [Ref 20.4.2014].)

Grain should always be stored in to storage silos with a closed top. The grain silo's structure has to prevent rodents and birds from messing with the grain. (Farmit [Ref. 20.4.2014].) The storage silo has to be cleaned and checked before storing. Different kinds of grain are stored in separate silos. The appearance of all kind of harmful substances is minimized and the storable grain is not treated with any chemicals that could extend the length of storage time. During the storage time, the moisture level and temperature of grain are monitored to avoid the origin and spreading of spoilage. (Vilja-alan yhteistyöryhmä 2006.)

3 ELECTRICAL DRAWINGS

The most common symbols that are used in the electrical drawings of this thesis are shown in the figure 1. The figure 1 also shows the identification letters of different devices. The closing, the opening and the changeover contact makers are marked with the identification letter and number of the contactor, circuit breaker or a relay when they are part of them.



Device:	Symbol:	Identification letter:	Device:	Symbol:	Identification letter:
Circuit breaker with thermal–magnetic motor protection		F	Circuit breaker		F
Thermal relay		F	Closing contact maker		S
Winding of contactor or relay		K	Opening contact maker		S
Auxiliary relay		K	Changeover contact		S
Contactor		K	Proximity sensor		S
3–phase electric motor		M	Mechanical limit switch with roll		S
Frequency converter		U	Logic controllers input or output		In these drawings this symbol is marked with terminal number and connector number
Safety switch		Q	Connection strip/ terminal strip	and X1 1	X

Can also be marked with K if it is part of contactor, F if it is part of circuit breaker and so on.

Figure 1: Most common symbols of circuit and wiring schemas in this thesis.

3.1 Centre- and circuit schemas

Centre schema shows the components and configurations that are necessary for the distribution of the electrical energy in the electrical centre. Also the main line, and all the other devices in the centre structure, like control switches, auxiliary relays, controlling units etc. are notified in the centre diagram. (Ensto [Ref. 12.4.2014].)

Circuit schema presents components in the electrical circuits and the connections between them in detail. Marking letters of components are placed next to the graphical symbols. Nevertheless, a circuit schema does not consider the devices' shape, size or position in the electrical centre. Circuit schema is used for understanding the electrical functionalities of devices. To make the circuit schema more comprehensible, supplementary information like diagrams, tables and text is usually added in the drawings. Circuit schemas can form a hierarchic system which means that there are circuit schemas of different levels for the same electrical system. In that kind of hierarchical system, the circuit schemas of the lower level are presented as block symbols in the higher level circuit schemas. The block symbol refers then to its own circuit schema document where the structure of the circuit is clarified in detail. (Ruppa & Perkiö 1996, 53.) In the drawings of an electrical centre that controls motor outputs, circuit schemas include all the drawings of the motor output circuits and their control circuits, including 230V circuits and 24VDC circuits.

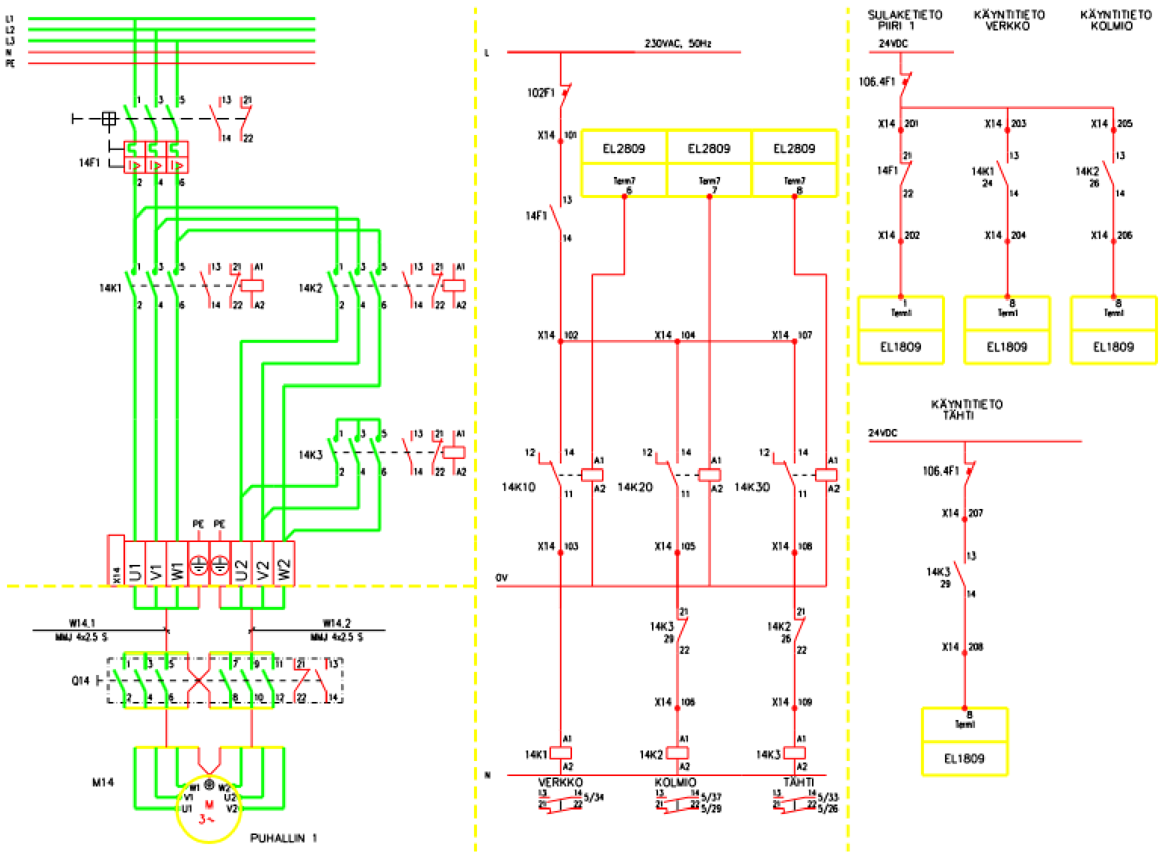


Figure 2: Circuit schema

In the circuit schema of figure 2, on the left side there is the actual motor output circuit where 14F1 is a circuit breaker, which includes a thermal-magnetic motor protection device, 14K1, 14K2 and 14K3 are contactors, X14 is a connection strip row, Q14 is a safety switch and M14 is an electric motor. In the middle part there is a 230V control circuit. 100F1 is a circuit breaker and 14K10, 14K20 and 14K30 are auxiliary relays that switch contactors on and off. EL2809 blocks are logic controller’s digital outputs. X14:101-X14:109 are connection strips. Between the winding of 14K2 and the auxiliary relay 14K20 there is an opening auxiliary contact of contactor 14K3. This is how the possibility to switch on the contactor 14K2 when the contactor 14K3 is switched on is ruled out. On the right side there is the 24VDC circuit. EL1809 blocks are the logic controller’s digital inputs.

3.2 Centre layouts

Layout drawings show the location of the devices and the instrumentation inside and on the doors of the electrical centre, also including the wiring ducts, terminal strips etc. The layout drawing must also show the dimensions of the centre. The layout drawings are always drawn to scale. The centre layout presents the equipment identifications, types and all the information that has to be known when constructing the electrical centre. Only essential things are drawn to a centre layout and unnecessary details should be avoided. (Jumpponen 1991, 270.)

3.3 CADS Planner Electric

CADS Planner Electric is an electrical design software from Kymdata Oy. CADS Planner electric is designed for documenting and designing needs in the electric and automation field. Designers can use it to sketch electrical installations, industrial electricity and automation drawings. Also the layout and distribution network designing is possible with CADS. (Kymdata Oy 2014.)

CADS Planner Electric is available with the following applications:

- circuit schemas
- centre schemas

- installation drawings
- centre layouts
- logic design
- tables

The CADS Electric software also includes diverse database possibilities for specifying the components in electrical drawings. The electrical quantity calculating of CADS Planner makes it easier to generate electrical device lists, calculate metrical amount of wirings and trays, create different project-specific lists and take quantity lists to common offer calculation softwares. (Kymdata Oy 2014.)

There are three different CADS Planner Electric packages available:

- Lite: Includes circuit schemas-, tables-, centre schemas- and installation drawings –applications.
- Standard: In addition to the Lite –package, the Standard package includes also the centre layouts –application.
- Pro: Includes all the same applications as the Standard, but also a DB-database system and a possibility to sketch building system schemas. (Kymdata Oy 2014.)

4 ELECTRIC MOTOR CIRCUITS

4.1 Direct On Line (DOL) starter circuit

Direct on line starter is the simplest motor starter form for induction motors. It consists of a circuit breaker, a contactor and an overload relay for the protection of the motor. The circuit breaker can also include a thermal-magnetic motor protection device. In that case the separate overload relay is not necessary. The contactor can be controlled by separate start and stop buttons that switch the current of the contactor’s coil on and off. Typically the start and stop buttons are push buttons. When the start button is pushed it creates a holding circuit through the contactor’s contact makers and the stop button cuts the circuit. The contactor can also be controlled by a separate contactor relay which could be switched on, for example, by a logic controller. (Parmar 2012.)

4.2 Reversing starter circuit

The rotation direction in 3-phase electric motors depends on the order of the supply lines and how they are connected to the electric motor’s stator. In an induction motor, the stator consists of overlapping windings offset by an electrical angle of 120°. The 3-phase AC (alternating current) creates a rotating magnetic field when it is connected to the primary winding or stator of the motor. When two of the phases are interchanged among each other, the rotation direction reverses, because the phase sequence of supply lines determines the direction. (James 2012.) The rotation direction is normally clockwise, when looking from the front to the axle of the motor, when the phases are connected to the motor’s terminals in this order: L1-U1, L2-V1 and L3-W1 (Moves Oy [Ref. 19.4.2014]).

The reversing starter circuits of this thesis are implemented with two parallel contactors, which change the order of two phases. Both contactors can not be switched on at the same time, because it would create a short circuit between two phases. This is prevented by taking the contactor’s controlling current through the other contactor’s opening auxiliary contact.

4.3 Star-Delta starter circuit

Normally induction motors are connected with a direct on-line starter which runs the motor in either star or delta connection. For very powerful induction motors, however, a regular direct on-line starter is not enough, because with a star connection the maximum torque after the acceleration is too small and with a delta connection the starting torque is too small and the starting current gets very high causing overload in the circuit breaker. Too high starting current may also cause a disturbance to the voltage on the supply lines. Because of that, large motors need to be started at lower voltage (Star), and the full supply voltage (Delta) connected only after the rotation speed has run up to the maximum of the lower voltage. The change in the voltage is achieved by reconfiguring the coils of the motor. (Parmar 2012.) The figure 3 illustrates the delta connection (on the left side), and the star connection. N_1, N_2 and N_3 are the connection points of the supply voltage wires. R_1, R_2 and R_3 are the electrical motor's windings.

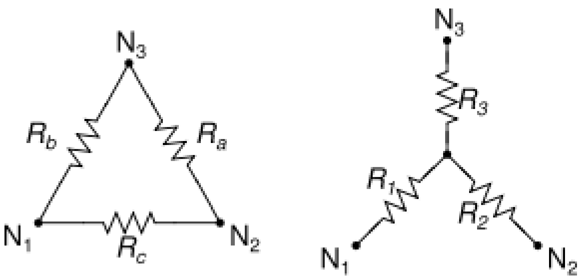


Figure 3: Delta connection and star connection (Wikimedia Commons 2014)

Usually the change from star-load to delta-load is achieved by using three contactors and a timer. The first contactor is the main contactor which connects the motor's primary terminal to the source voltage. The second contactor is the star contactor, which is closed immediately when the motor is started, connecting each of the three-phase current's phases to one point. The third contactor, the delta contactor, is open in the beginning but when the motor has reached the maximum rotation speed with a star-load, the delta contactor will be closed and the star contactor opened. The timer has been timed to change the state of star and delta contactors after the maximum rotation speed with a star-load has been reached. The timer can be a physical timer relay inside the electrical centre or, if the Star-Delta starter is controlled by a logic controller, it can also be a programmed timer in the program of the logic controller. (Parmar 2012.) The figure 4 shows one of the Star-Delta starter circuits of the electrical centre of this thesis. This circuit’s timer is programmed in to the program of the logic controller.

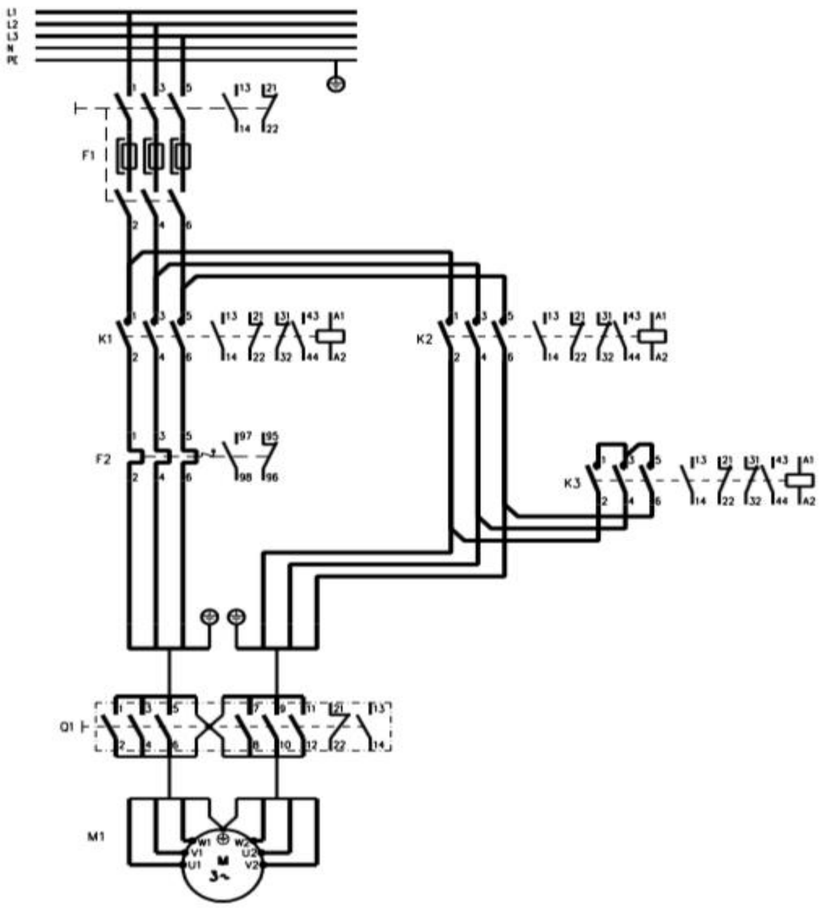


Figure 4: Star-Delta starter

4.4 Frequency converter drive

Frequency converter drives are commonly used when the speed and torque of the alternating current (AC) motor needs to be controllable. The frequency converter converts the desired frequency and voltage for the AC motor from the power supply network’s fixed AC frequency and amplitude. With the frequency converter the AC motor’s rotation speed and torque can be adjusted continuously.

Frequency is directly related to the rotation speed of the motor. The higher the frequency is, the higher is also the rotation speed. (VFDs.com 2013.)

Typical 3-phase frequency converter rectifies the supply frequency to direct voltage (DC) with a diode bridge that is respective to the requisite power. After that the AC ripples in the rectified electrical power is filtered by inductors and capacitors. At last the filtered DC is converted back to AC with transistors. Transistors in the frequency converter can make any phase to be positive, negative or zero. They work like switches connecting alternatively positive and negative voltage to each phase. This is how the frequency converter generates the desired frequency. (VFDs.com 2013) The internal electronic circuit of a frequency converter is shown in the figure 5.

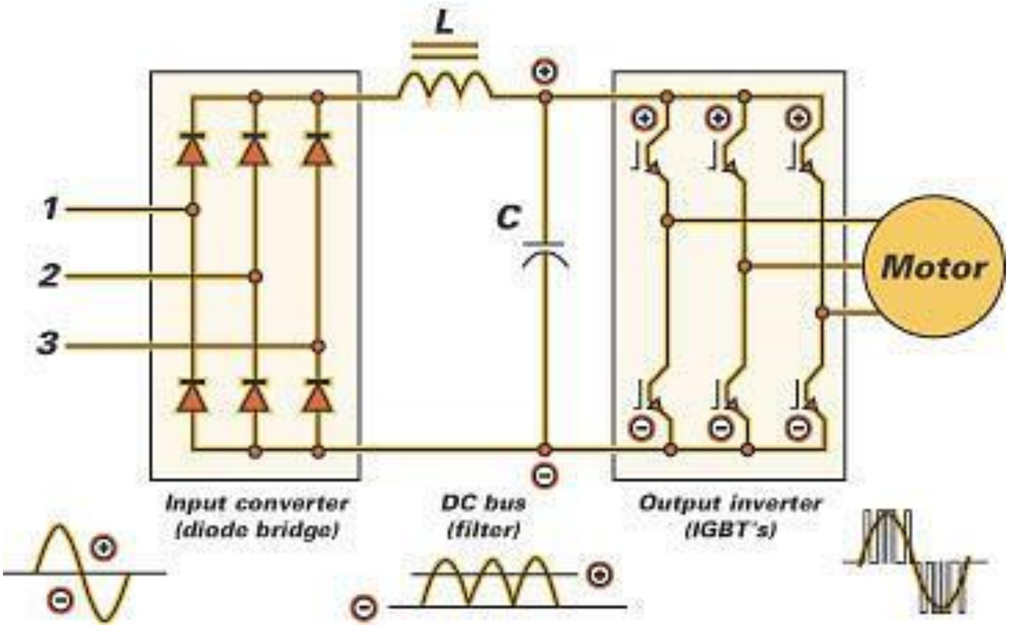


Figure 5: Operational principle of a frequency converter (Frequency inverter 2014)

5 GRAIN DRYER

The grain dryer of this thesis is shown in the figures 6 and 7. The figure 6 shows the entire building where the grain dryer is related to. Some of the devices that are part of the grain dryer system are inside the building, but as can be seen in the figure 7, the drying silos where the actual drying happens are on the outside. In the figure 7 also the drying fans can be seen on the left side of the drying silos.

Figure 6: Grain dryer building

Figure 7: Grain dryer

5.1 Motors of the grain dryers electrical centre

The grain dryer of this thesis has the following electric motors:

M11: Precleaner. Located above the upper conveyor. The grain that is going to the dryer goes through the precleaner, which filters out all the excessive matter, that is lighter than the grain. After that, it passes the grain to the upper conveyor, which moves it to the dryer.

M12 and M13: Dumping hopper’s shutters. These motors are spindle motors. Dumping hopper’s shutters are opened when the grain has to be passed from the dumping hopper to the elevator.

M14 – M17: Dryer fans for grain drying. There is one fan for each grain drying silo. A fan blows the warm air mass through the drying battery and the grain, and vaporizes the moisture.

M21 – M27: Screw conveyors of the silos. These screw conveyors are used for moving the grain to the storage silos.

M28 and M29: 8-way distributors. The 8-way distributor distributes the grain to seven separate storage silos and to the grain dryer. The second 8-way distributor circuit in the electrical centre is auxiliary in case that the customer wants to add another distributor in future.

M31 – M35: Motor operated shutters above the drying silos. There are five shutters on the drying silos. One for each drying silo, and one spare shutter. Shutters are opened one at a time until the silos upper limit sensor becomes active. After that the shutter of the filled silo closes and the next shutter will be opened.

M36 and M37: 3-way distributors. 3-way distributor takes the grain from the elevator to the 8-way-distributor, the grain drier or the feed mixer. When the grain goes from the 3-way distributor to the dryer, it is taken through the precleaner, which passes it again to the upper conveyor. The second 3-way distributor circuit in the electrical centre is auxiliary in case that the customer wants to add another distributor to the system in future.

M38 and M39: Motor operated shutters below the drying silos. There are four shutters below the drying silos. One for each silo. These shutters are closed and opened by two spindle motors. One spindle motor operates two shutters at the same time. These shutters are opened when the dried grain has to be moved from the drying silos to the lower conveyor.

M41: Lower conveyor. Brings the grain from the dryer to the elevator.

M42: Upper conveyor. When the elevator has brought the grain to the upper conveyor, the conveyor moves it to the drier. There are four drying silos in the dryer, and each of them has a motor operated shutter above them. Shutters are opened one at a time, as long as the grain has piled up to switch on the upper limit sensor.

M43: Circulation pump, which brings the warmth to the dryer from the separate heating plant.

M51 and M69: Elevators. Elevator lifts the grain from the dumping hopper to the 3-way distributor. Only one elevator was in use when this electrical centre was designed, but there is also all the equipment for the second elevator in the new centre, if the customer wants to add another one. Elevator has a speed monitor at the opposite end from the motor. It monitors that the elevator’s belt is not broken.

M52 – M55: Grain outlet devices. Grain outlet device unloads the grain from the lowest part of the dryer to the lower conveyor, which takes the grain back to the elevator, and eventually to the storage silos or back to the grain dryer.

M61 – M68: Screw conveyors above the dumping hopper. These screw conveyors brings the oat to the oat dehuller and from the dehuller to storage containers and to the further processing.

In addition, the customer wanted the new oat dehulling machine that was ordered from JPT-Industria Oy, to be controlled by the same electrical centre. The new oat dehulling machine has following motors:
M44: Main motor (5,5kW)

M45 and M46: Screw conveyors (3kW)

M47: Fan (15kW)

M48 and M49: Rotary feeders (7,5kW)

By the customer's request, there are also four auxiliary motor controlling circuits in the centre. Two circuits for 7,5 kW motors and two for 3kW motors.

The figure 8 points out the positions of the motors, silos, dumping hopper and the old electrical centre.

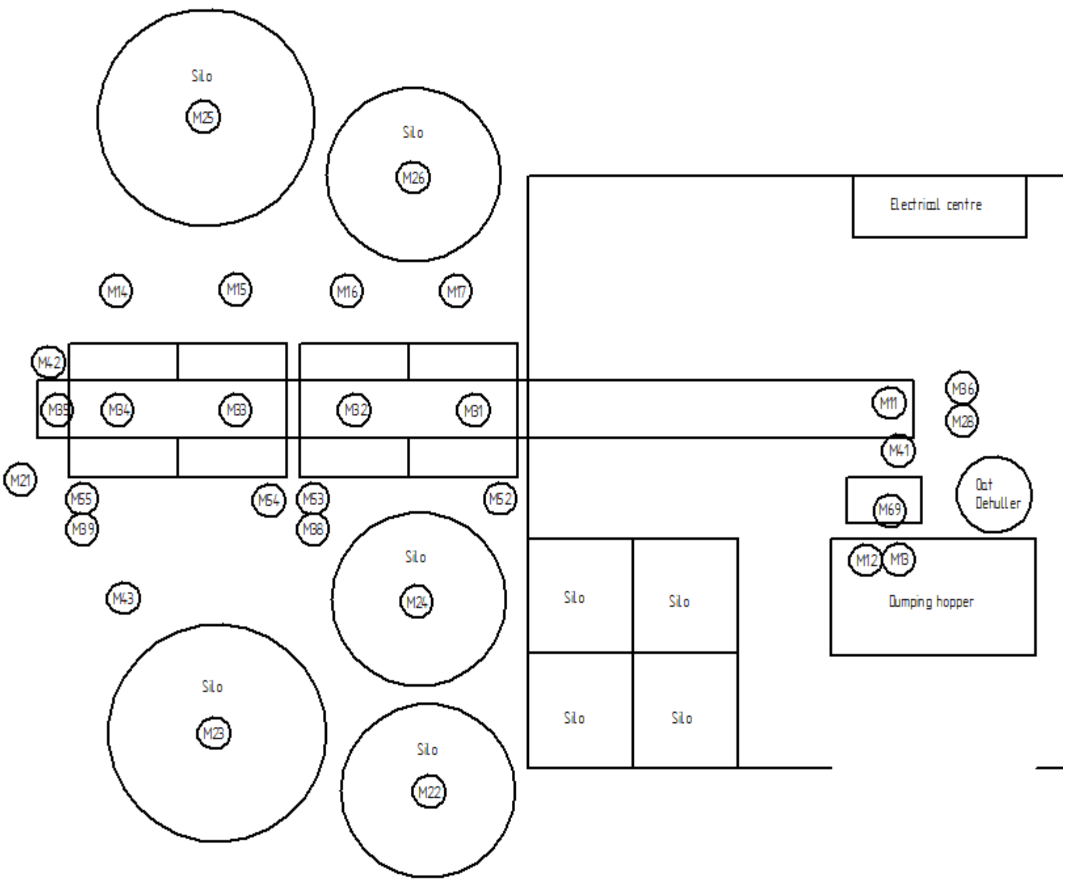


Figure 8: Positions of motors

5.2 Electrical centres

Direct on-line motor starter circuits, reversing motor starter circuits and star-delta circuits of this project are fulfilled with circuit breakers that include the thermal-magnetic motor protection devices, so that the separate overload relay is not required. Each of the contactors in these circuits are controlled by auxiliary relays. These auxiliary relays are switched on and off by the logic controller. Each contactor has also been wired to the logic controller's digital inputs so that the 24 VDC goes through contactors closing auxiliary contact to the input. This is how the contactor's state is indicated for the logic controller. The circuit breakers' states are also indicated for the logic controller the same way as with contactors, but they are grouped based on the six main circuits, so the logic controller gets the information if some of the circuit breakers' contacts in the main circuit are opened. Circuit breakers' fault condition informations were grouped to main circuits, because the required number of digital inputs would have increased too high compared to benefits if every circuit breaker would have had own input.

Frequency converter circuits are fulfilled without the overload relays or thermal-magnetic devices in the circuit breakers, because the frequency converter can recognize the fault conditions itself. However the frequency converter circuits' circuit breakers' fault conditions are implemented the same way as with direct on-line motor circuits. The state of the electric motor of the frequency converter circuit is transferred to the logic controller by the Profibus DP cable, as are also the rotation velocity and the torque information.

Motor circuits also include safety switches, which are located outside of the electrical centre, near the electric motors. Safety switch is a rotary switch, which has to be switched off when the electric motor needs maintenance or repair. Safety switch can be locked to off state with a padlock.

5.2.1 Dividing to main circuits

The original plan in the beginning was that there would be about 30 motor controlling circuits in the new centre, but during the project the customer wanted some changes and additions to the centre, and finally the number of motor controlling circuits increased to 52. Because of that, motor controlling circuits were divided to six main circuits. In addition to motor output main circuits, there were also two other main circuits for the circuit breakers of control circuits, logic controller, UPS, cooling, heating devices and some spare circuit breakers, if the customer wants to add lighting or wall sockets to the centre in future.

5.2.2 Splitting the centre to two separate cabinets

The place of the old electrical centre is shown in the figure 9. As can be seen, the space for the electrical centre is very small. There was not enough space for one big centre in the position of the old electrical centre and because of that, the circuits had to be split to two different centres. The maximum width for the centre that was placed to the old centre’s position was 1300 mm, and the maximum height that the manufacturer of the electrical centre had in their selection was 1960 mm. The other centre was decided to be placed on the left side of the smaller centre, behind the pipes that can be seen in the figure 9. The maximum height for the other centre was also the same 1960 mm, but the maximum width was 2250 mm. The motor controlling circuits were decided to be split in such way that the main circuits 3, 4, 5 and 6 were placed to the bigger centre, because those main circuits had motor controlling circuits with more equipment, like contactors and frequency converters. Also the main circuit 20 was placed to the big centre, because it includes the 230 V control circuits of the motor circuits of that centre. The figure 9 shows the old electrical centre.

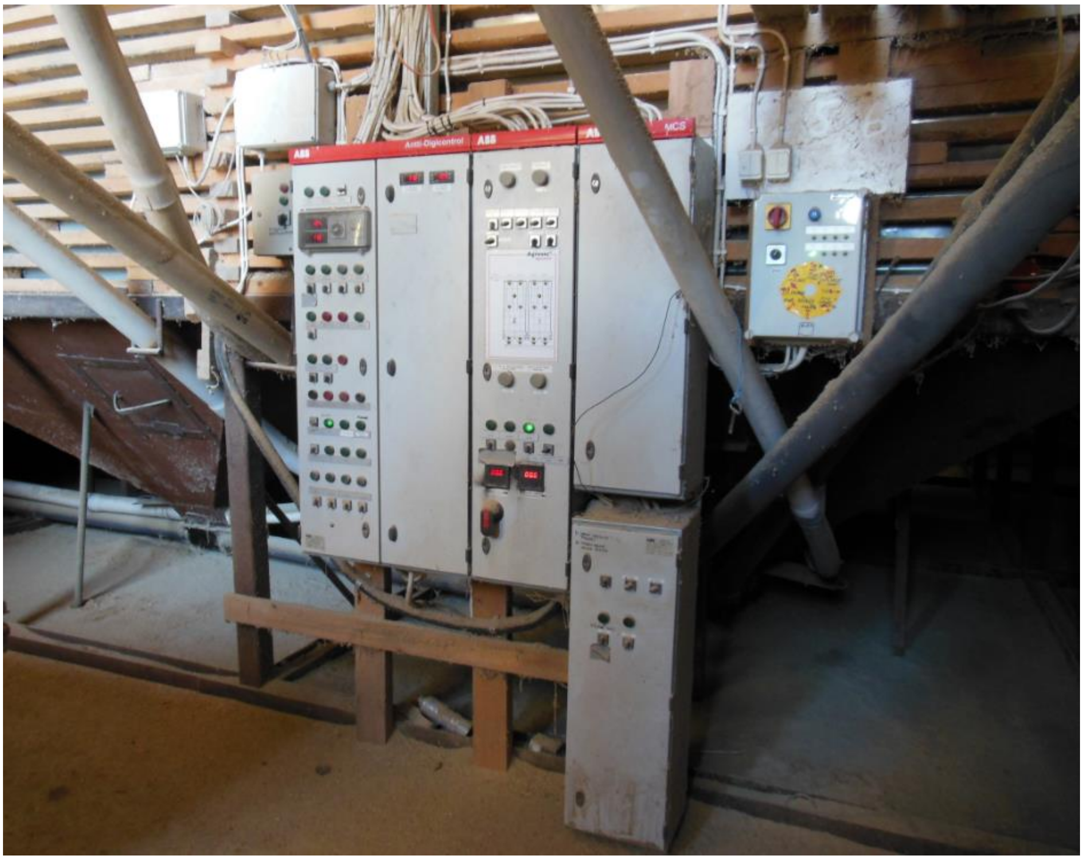


Figure 9: The old electrical centre

The logic controller and the HMI (Human-Machine Interface) was decided to be placed to the smaller centre, because the smaller centre would be placed to the position of the old centre and its controlling switches, and that has been noticed to be good place to control the grain dryer. However some of the logic controllers terminals were placed to the bigger centre, because there were also contactors that had to be controlled by the logic controller. The logic controllers terminals were split to two centres with an Ethercat fieldbus module and 24 VDC was transferred there from the smaller centres AC/DC –converter. There is still own 24V circuit breakers in the bigger cabinet. Both centres are protected with overvoltage protectors.

5.3 Frequency converter centre

There were four frequency converters in the old centre for the grain outlet devices, but the customer wanted also some of the other motors to be controlled by frequency converters, so that the rotation speed and the torque could be controlled. Following motors are controlled by Vacon 100 frequency converters in the renewed solution:

Motor	Frequency converter
Upper conveyor (7,5kW)	Vacon 0100-3L-0016
Lower conveyor (5,5kW)	Vacon 0100-3L-0012
Circulation pump (7,5kW)	Vacon 0100-3L-0016
Oat dehuller’s main motor (5,5kW)	Vacon 0100-3L-0012
Oat dehuller’s screw conveyor 1 (3kW)	Vacon 0100-3L-0008
Oat dehuller’s screw conveyor 2 (3kW)	Vacon 0100-3L-0008
Oat dehuller’s fan (15kW)	Vacon 0100-3L-0038
Additional elevator (15kW)	Vacon 0100-3L-0038
Grain outlet device 1.1 (1,5kW)	Vacon 0100-3L-0005
Grain outlet device 1.2 (1,5kW)	Vacon 0100-3L-0005
Grain outlet device 2.1 (1,5kW)	Vacon 0100-3L-0005
Grain outlet device 2.2 (1,5kW)	Vacon 0100-3L-0005

5.3.1 Cooling of the frequency converter centre

The frame sizes of the frequency converters can be seen in the table 1. It shows that there are 8 frequency converters with a frame size of MR4, 2 frequency converters with a frame size of MR5 and 2 frequency converters with a frame size of MR6 in the centre. When the frame sizes are known, the necessary quantity of cooling air in the frequency converter centre can be calculated using the table 2.

Table 1: Data about Vacon 100 frequency converters (Vacon 2014)

Mains voltage 380—500 V, 50/60 Hz, 3~												
AC drive type	Loadability				Max current I_S	Motor shaft power				Frame size	Dimensions WxHxD [mm] WxHxD [inch]	Weight [kg] Weight [lbs]
	Low*		High*			400V supply		480V supply				
	Continuous current I_L [A]	10% overload current [A]	Continuous current I_H [A]	50% overload current [A]		10% overload 40°C [kW]	50% overload 50°C [kW]	10% overload 104°F [hp]	50% overload 122°F [hp]			
VACON 0100-3L-0003-5	3.4	3.7	2.6	3.9	5.2	1.1	0.75	1.5	1.0	MR4	128x328x190 5x12.9x7.5	6.0 13.0
VACON 0100-3L-0004-5	4.8	5.3	3.4	5.1	6.8	1.5	1.1	2.0	1.5			
VACON 0100-3L-0005-5	5.6	6.2	4.3	6.5	8.6	2.2	1.5	3.0	2.0			
VACON 0100-3L-0008-5	8.0	8.8	5.6	8.4	11.2	3.0	2.2	4.0	3.0			
VACON 0100-3L-0009-5	9.6	10.6	8.0	12.0	16.0	4.0	3.0	5.0	4.0			
VACON 0100-3L-0012-5	12.0	13.2	9.6	14.4	19.2	5.5	4.0	7.5	5.0			
VACON 0100-3L-0016-5	16.0	17.6	12.0	18.0	24.0	7.5	5.5	10.0	7.5	MR5	144x419x214 5.7x16.5x8.4	10.0 22.0
VACON 0100-3L-0023-5	23.0	25.3	16.0	24.0	32.0	11.0	7.5	15.0	10.0			
VACON 0100-3L-0031-5	31.0	34.1	23.0	34.5	46.0	15.0	11.0	20.0	15.0			
VACON 0100-3L-0038-5	38.0	41.8	31.0	46.5	62.0	18.5	15.0	25.0	20.0	MR6	195x557x229 7.7x21.9x9	20.0 44.0
VACON 0100-3L-0046-5	46.0	50.6	38.0	57.0	76.0	22.0	18.5	30.0	25.0			
VACON 0100-3L-0061-5	61.0	67.1	46.0	69.0	92.0	30.0	22.0	40.0	30.0			
VACON 0100-3L-0072-5	72.0	79.2	61.0	91.5	122.0	37.0	30.0	50.0	40.0	MR7	237x660x259 9.3x26x10.2	37.5 83.0
VACON 0100-3L-0087-5	87.0	95.7	72.0	108.0	144.0	45.0	37.0	60.0	50.0			
VACON 0100-3L-0105-5	105.0	115.5	87.0	130.5	174.0	55.0	45.0	75.0	60.0			
VACON 0100-3L-0140-5	140.0	154.0	105.0	157.5	210.0	75.0	55.0	100.0	75.0	MR8	290x966x343 11.4x38x13.5	66.0 145.5
VACON 0100-3L-0170-5	170.0	187.0	140.0	210.0	280.0	90.0	75.0	125.0	100.0			
VACON 0100-3L-0205-5	205.0	225.5	170.0	255.0	340.0	110.0	90.0	150.0	125.0			
VACON 0100-3L-0261-5	261.0	287.1	205.0	307.5	410.0	132.0	110.0	200.0	150.0	MR9	480x1150x365 18.9x45.3x14.4	108.0 238.0
VACON 0100-3L-0310-5	310.0	341.0	251.0	376.5	502.0	160.0	132.0	250.0	200.0			
VACON 0100-3L-0140-5	140.0	154.0	105.0	157.5	210.0	75.0	55.0	100.0	75.0	MR8 IP00	290x794x343 11.4x31.3x13.5	62.0 136.7
VACON 0100-3L-0170-5	170.0	187.0	140.0	210.0	280.0	90.0	75.0	125.0	100.0			
VACON 0100-3L-0205-5	205.0	225.5	170.0	255.0	340.0	110.0	90.0	150.0	125.0			
VACON 0100-3L-0261-5	261.0	287.1	205.0	307.5	410.0	132.0	110.0	200.0	150.0	MR9 IP00	480x970x365 18.9x38.2x14.4	97.0 213.8
VACON 0100-3L-0310-5	310.0	341.0	251.0	376.5	502.0	160.0	132.0	250.0	200.0			

* For all VACON 100 drives, overloadability is defined as follows: High: 1.5 x IH (1 min/10 min) @ 50°C; Low: 1.1 x IL (1 min/10 min) @ 40°C; IS for 2 sec.

Table 2: Cooling air requirements for Vacon 100 frequency converters (Vacon 2014)

Frame	The quantity of cooling air [m3/h]	The quantity of cooling air [CFM]
MR4	45	26.5
MR5	75	44.1
MR6	190	111.8
MR7	185	108.9
MR8	335	197.2
MR9	621	365.5

$$\text{The necessary quantity of cooling air} = 8 \times 45\,\frac{m^3}{h} + 2 \times 75\,\frac{m^3}{h} + 2 \times 190\,\frac{m^3}{h}$$

$$= 890\,\frac{m^3}{h}$$

The cooling air had to be brought from the outside of the building with two pipes, because the air in the grain dryer building is very dusty, and it was more reliable to bring the cooling air from outside, than to try to filter the air inside. Only the exhaust air vents with filters are placed on the doors.

5.3.2 Profibus DP

Profibus DP (Distributed Periphery) is used for connecting field devices like frequency converters and distributed I/O to automation system with very short response time. Profibus is an open fieldbus structure with a compatibility with IEC 61158 fieldbus standard. (Siemens AG [Ref. 1.4.2014].)

Profibus is the most common fieldbus in the industrial automation. Profibus DP is based on RS485-standard, which means that the data is transferred by two wires that are protected with a protective jacket. There is a termination resistor at the both ends of the cable, where the supply voltage of +5 volts is supplied. Profibus DP –cable goes from field device to another, and the termination resistor has to be activated at the first and at the last device in the fieldbus. (Aarrelampi 2009.) The figure 10 includes a model example of a profibus connection.

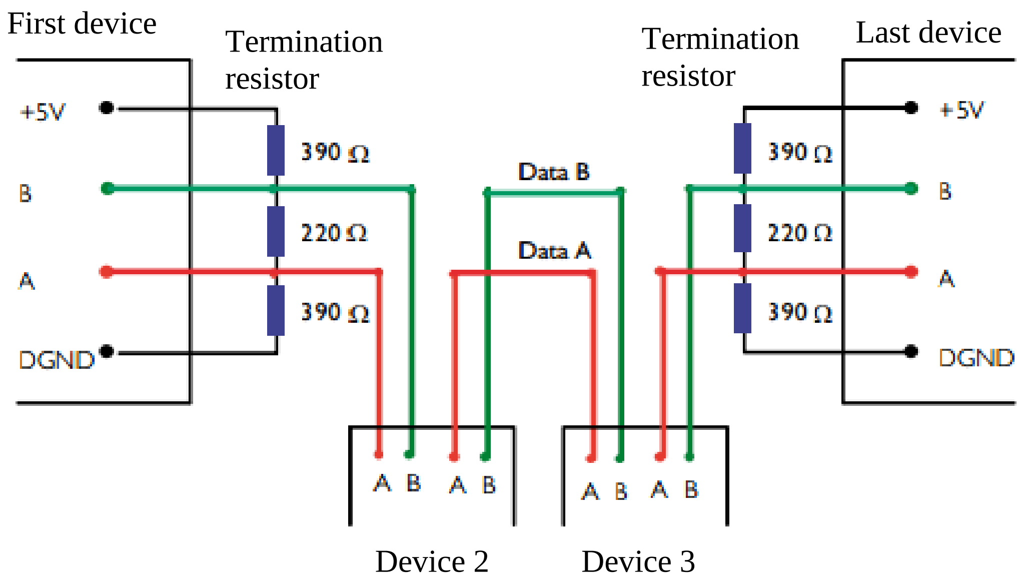


Figure 10: Example circuit diagram of Profibus DP –cable (Aarrelampi 2009)

Profibus DP –fieldbus has to be grounded well and the protective jacket should be still grounded even if the coupler falls off from the device (Aarrelampi 2009). Frequency converters of this thesis are connected to the logic controller by Profibus DP.

5.4 Logic controller centre

The logic controller centre, which is the smaller centre, includes main circuits 1, 2 and 10. Main circuits 1 and 2 have motor controlling circuits inside, and the main circuit 10 includes 230 V control circuits of the motor circuits, and also an AC/DC-converter which is powered by the UPS, electrical centre's heating devices, circuit breaker for a wall socket of a heater of an oil tank, and some auxiliary circuit breakers. The logic controller, the control panel and the sensors gets their supply voltage of 24 VDC from the AC/DC-converter through small fuses.

5.4.1 Programmable logic controller (PLC)

PLC is an industrial control system that consists of CPU (Central Processing Unit), input terminals and output terminals. CPU has a non-volatile memory where the programmed control instructions are stored. Input terminals receive electric signals from field devices and the internal program of the CPU controls outputs based on the input signals. One of the biggest benefits of PLC is its modular structure, which allows the user to put together a configuration of inputs and outputs that suits best personally. Another is the ability to change and replicate operations and processes at the same time as it is communicating with the controllable devices. Devices that are connected to the programmable logic controller's input terminals are usually switches, pushbuttons, sensors and encoders. Output terminals are connected to devices like control relays, lights, valves, motor starters etc.

Programmable logic controllers are often programmed with a Ladder Diagram language which is a graphical programming language. Ladder Diagram visualizes the opening and closing contact makers and outputs in controlling circuits. Ladder Diagrams include also counters, timers, shift registers and math operations. There is also some other ways for programming PLC like Structured Text, Instruction List and Sequential Function Chart. (AMCI [Ref. 26.4.2014].)

5.4.2 Beckhoff CX5000 series logic controller

Both of the electrical centres are controlled by Beckhoff CX5020 embedded PC. Embedded PC is a combination of an industrial PC and a PLC (Programmable Logic Controller). It has the computation capacity, connectivity and versatile programming language of the PC combined with compact size, DIN-rail mountability and modular I/O level of PLC. The CX5000 series devices have two independent Gigabit Ethernet ports, four USB 2.0 ports and a DVI-D interface for a monitor or a control panel. They also can be used as an EtherCAT slave and therefore a CX5000 series device can become a programmable local controller within an EtherCAT network.

There is two options for the operating system of the CX5000 series embedded PC: Windows CE and Windows Embedded Standard. The operating system and TwinCAT and user projects are stored on the Compact Flash card, which serves as a hard disk. The Compact Flash card can be quickly exchanged. That makes it easy to update the software and upkeep the hardware. (Beckhoff 2014.) Beckhoff CX5020 was decided to be chosen to serve as a logic controller because it has a good price-quality ratio, and because the logic programmer of JPT-Industria Oy already has extensive knowledge in Beckhoff -logic controllers.

5.4.3 Inputs and outputs

The I/O level was implemented with following Beckhoff EtherCAT terminals:

- Digital inputs:
    - EL1809 16-channel digital input HD EtherCAT terminal with the nominal voltage of 24 volts DC.

- Digital outputs:
    - EL2809 16-channel digital output HD EtherCAT terminal with rated load voltage of 24 volts DC and maximum output current of 0,5 amperes per channel. Channels are short-circuit-protected.

- Analog inputs:
    - EL3204 4-channel PT100 input terminal for PT100 temperature transducers. This terminal can operate four transducers using a 2-wire connection method. Measuring current is over 0,5 mA. EL3204 terminal can be used with PT100, PT200, PT500, PT1000, Ni100, Ni120 and Ni1000 resistance measurement sensors. Temperature range is -200 - +850°C with PT sensors and -60 - +250°C with Ni sensors.

  - EL3054 4-channel 4-20mA analog input terminals for the return temperature transducer of the heat exchanger and the force transducers of the drying silos.

  - EL4002 2-channel 0-10V analog output terminal for the shunt valve.

- Safety logic:

  - EL6900 TwinSAFE PLC to control safety functions.

  - EL2904 4-channel digital output TwinSAFE terminal for the oat dehullers’ safety lock.

5.4.4 Control panel

All the motors of both electrical centres can be controlled via Beckhoff CP2919-0000 –touch screen. The 19” touch screen is placed on the door of the logic controller centre. Control panel is connected to the logic controller via DVI- and USB-cables.

5.4.5 Heating for the logic controller centre

The logic controller and the control panel needs heating, because they are used a little bit also in the wintertime and the hall where the centre will be positioned is not heated. The functionality of the logic controller and the control panel would not be reliable without a heater. There are two 50 watt heaters placed in the lower part of the logic controller centre. The heaters are controlled by a thermostat.

5.5 Sensors

There are three kinds of sensors that send digital messages to the logic controller. Mechanical limit position switches, inductive sensors and capacitive sensors. The temperatures which have to be known to run the drying process properly are measured by two different kinds of transducers: Pt100-transducers and transducers that sends the temperature message in milliamperes.

5.5.1 Mechanical limit position switches

Positions of the machine’s components are converted to electrical signals with mechanical limit position switches. The moving component the position of which has to be known pushes the switching element of the mechanical limit position switch when it has reached the position. When the switching element is pushed, the states of contact makers are changed. Because of the change in the state of the contact makers, also the state of electrical signal from the limit position switch changes, and the position of the component can be processed in the control system. (Ahoranta 1999, 129.) In this project, mechanical limit position switches are used for getting the state of 8-way- and 3-way distributors and the state of dumping hopper’s shutters to the logic controller.

5.5.2 Inductive sensors

An inductive sensor makes it possible to sense metals without a physical contact. It creates an oscillating magnetic field with a high frequency around itself. When the metallic object gets closer to the magnetic field of the inductive sensor, the oscillation reduces. Finally, when the metallic object is close enough, the oscillation stops. When the oscillation stops, the electronic control circuit of the sensor reacts to it and switches the output on. (Omron 2014.) In the grain dryer inductive sensors are used to sense the states of motor operated shutters above and below the dryer. Also the speed monitors of the elevators and conveyors are inductive. The speed monitor gets pulses caused by the metallic parts in the sheave of an elevator or a conveyor. The speed monitors' output is active only when the pulse frequency is high enough.

5.5.3 Capacitive sensors

Capacitive sensors work like inductive sensors but instead of magnetic field they create an electric field. When the inductive sensor detects only metals, a capacitive sensor senses all materials in its electric field. The sensing distance of a capacitive sensor depends on the material of the recognizable object. Metallic objects and objects that include water are sensed easier than other objects with a capacitive sensor. (Ahoranta 1999, 131.) Capacitive sensors are used as grain filling limit sensors in the grain dryer.

5.5.4 Pt100 –sensors

Pt100 sensor is a temperature measurement sensor. The platinum resistors' resistance inside the Pt100 sensor changes with temperature. The name Pt100 comes from its resistance value of 100 ohms when the temperature is 0 ºC. Pt100 sensors are usually used for measuring temperatures between -200 ºC and +850 ºC. In some cases even over +1000 ºC temperatures are measured with them. (Inor [Ref. 28.4.2014].) Pt100 sensors are used for measuring incoming and outgoing temperatures of the heating water which heats the drying air.

5.5.5 4-20 mA –sensors

The temperature sensor of the heat exchanger sends the information about the temperature in current between 4 and 20 milliamperes. A milliampere message is used because it is not too sensitive to electromagnetic interferences and the resistance of wires does not have an influence on it.

6 SUMMARY

The aim of this thesis was to design a new logic controlled electrical centre for a grain dryer. In the new centre the customer wanted some of the antecedent direct on line and star-delta motor controlling circuits to be changed to frequency converter drives. Frequency converters in the new solution were connected to the logic controller via Profibus DP. The control panel was decided to be a 19” Beckhoff touch screen.

The original goal in the beginning was to design one centre for about 30 motor controlling circuits. However during the project the number of motor outputs increased to 52 in total due to the customer’s changes and additions to the plan. The maximum width of one electrical centre was 1300 mm and the maximum height 1960 mm. Because of that all the motor controlling circuits did not fit in one centre. Eventually the motor outputs were decided to be distributed to six main circuits and the main circuits to two different centres. The logic controller centre’s width was 1300 mm, and the frequency converter centres width was 2250 mm. Beckhoff CX5020 was selected for a logic controller. The terminals of the logic controller were also distributed to both centres. The distribution was implemented with an Ethercat fieldbus module.

The final circuit and wiring schemas and centre schemas were drawn with Kymdata CADS Planner Electric –software. Also the centre layout drawings were made with CADS Planner, but the final layout drawings were made by the electrical centre manufacturer. Because there were many changes and additions to the electrical centre during the project, finishing the drawings took a little bit longer than was planned in the beginning.

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APPENDICES

APPENDIX 1. Centre layout of the logic controller centre

APPENDIX 2. Centre layout of the frequency converter centre

APPENDIX 3. Centre schema 1/8

APPENDIX 4. Centre schema 4/8

APPENDIX 5. Centre schema 7/8

APPENDIX 6. Star-Delta starter circuit

APPENDIX 7. Direct on line starter circuit

APPENDIX 8. Reversing starter circuit

APPENDIX 9. 3-way distributor

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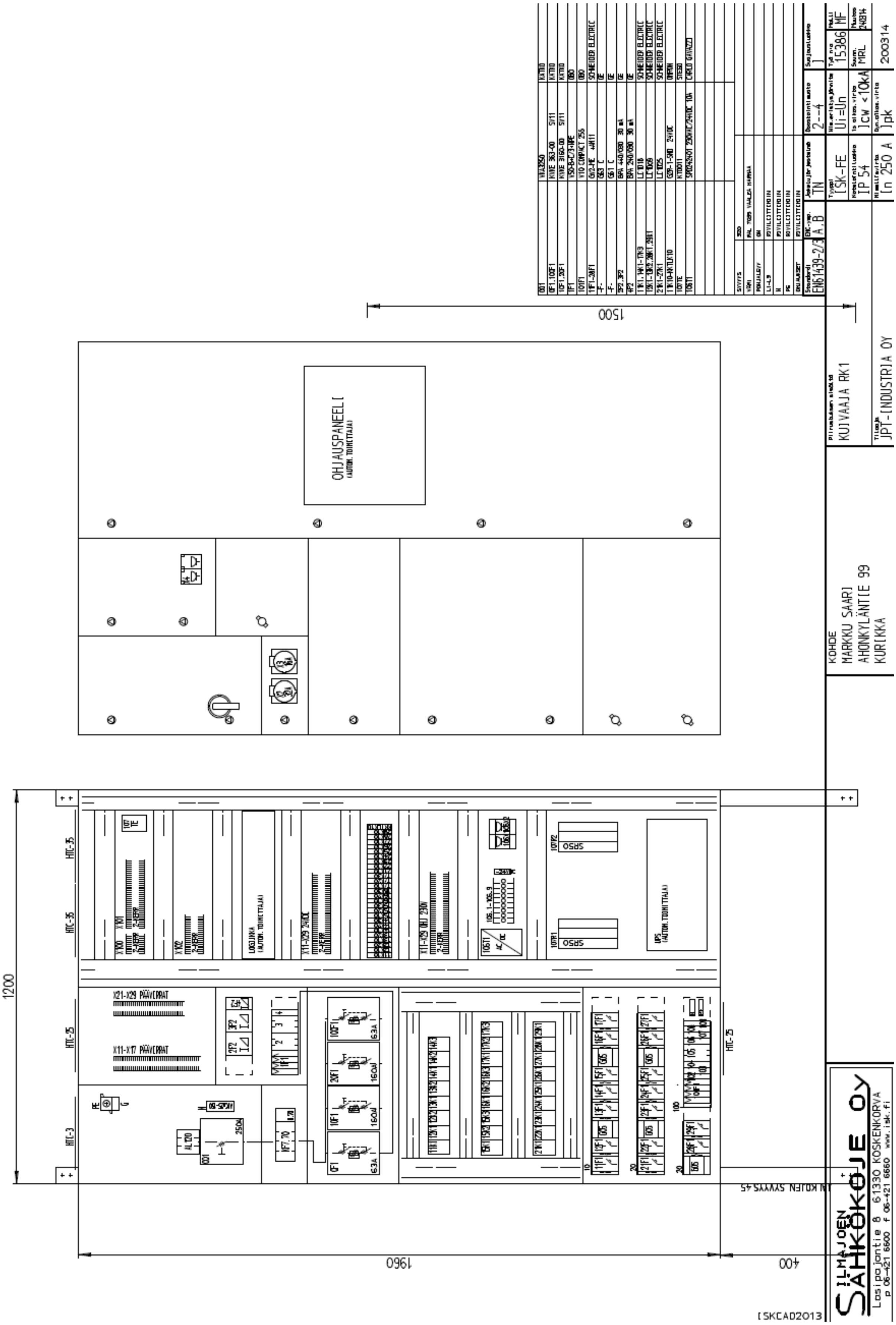
APPENDIX 11. Digital inputs

APPENDIX 12. Digital outputs

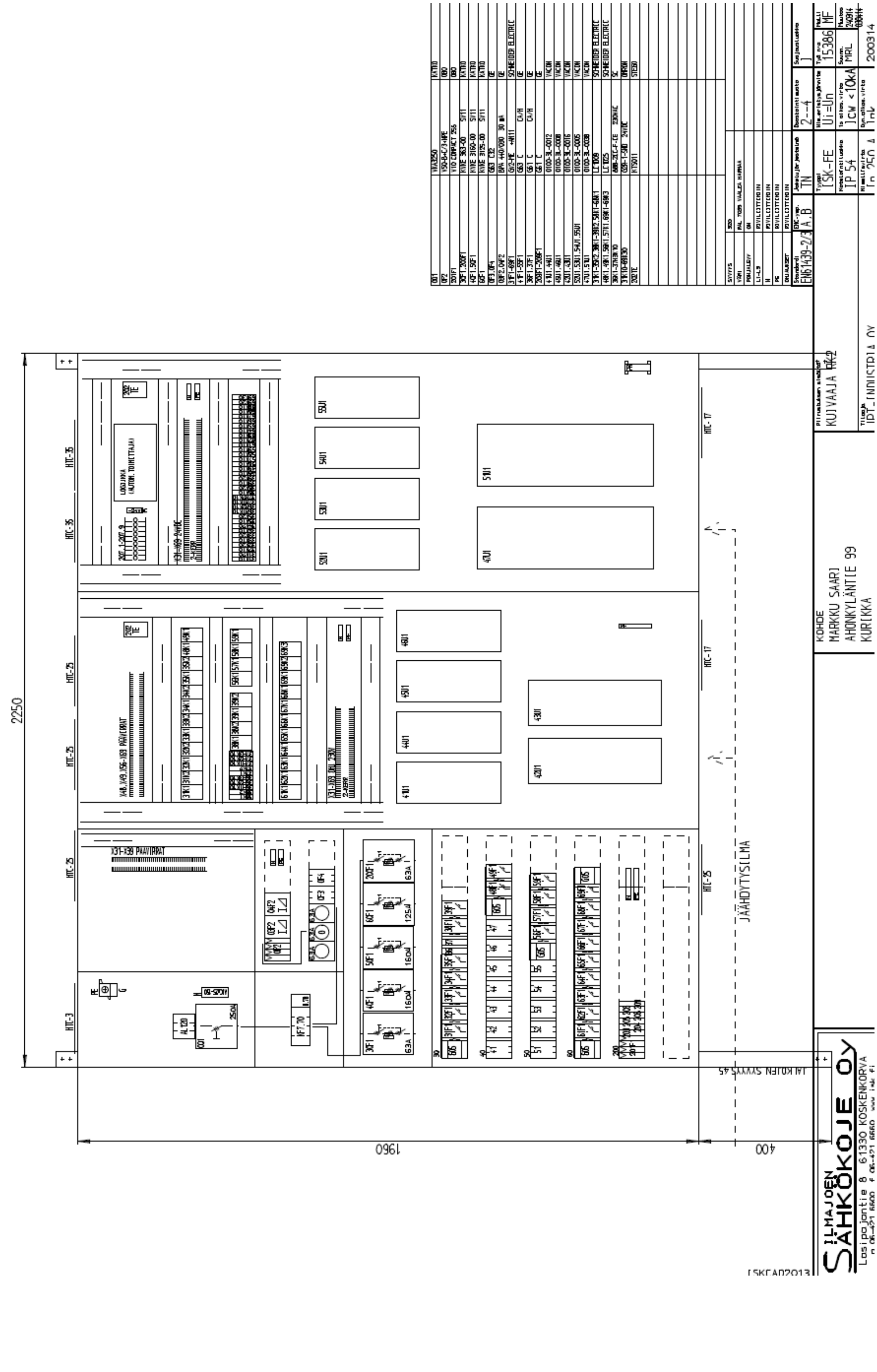
APPENDIX 13. Pt100 transducers

APPENDIX 14. 4-20 mA transducers

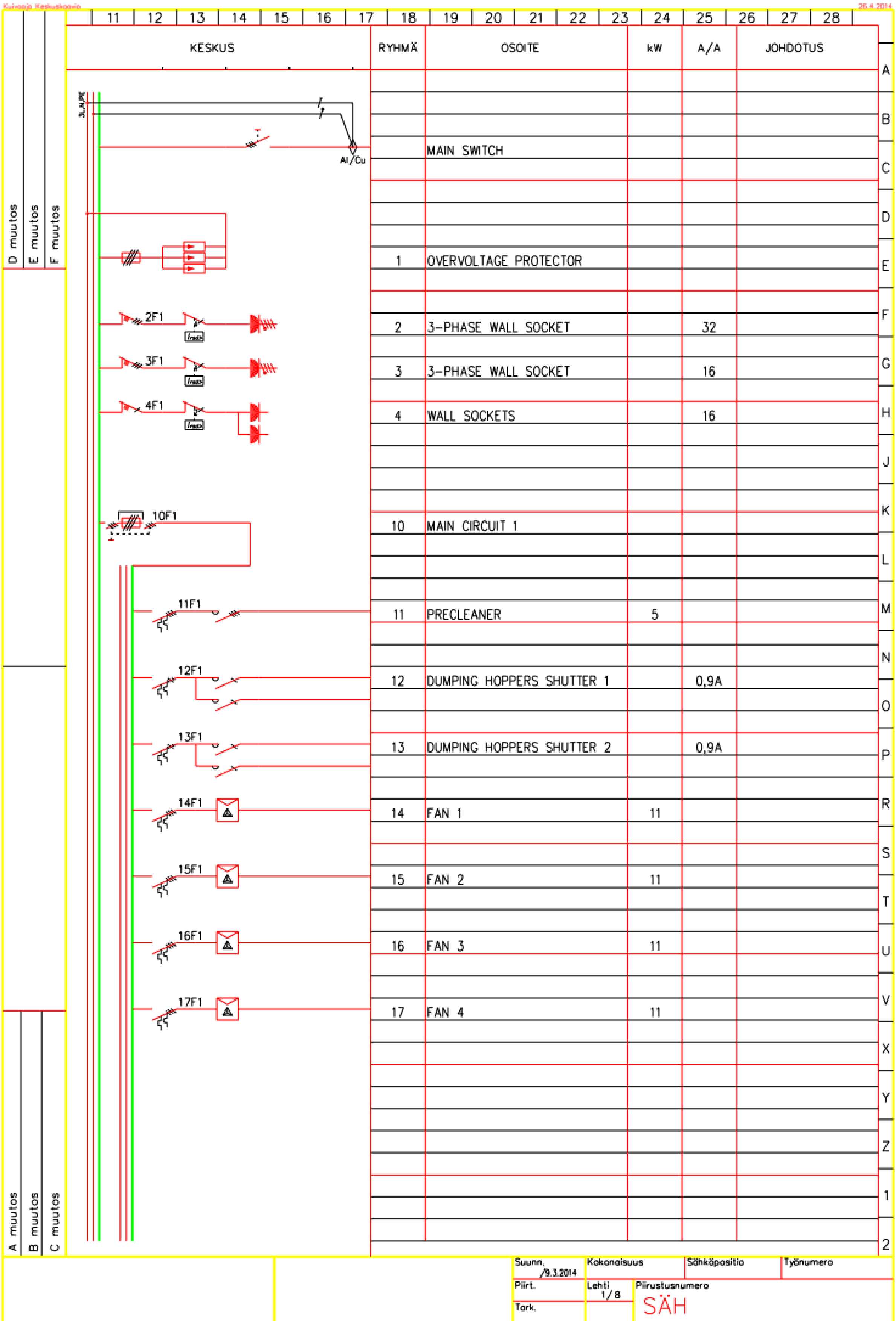
APPENDIX 1. Centre layout of the logic controller centre



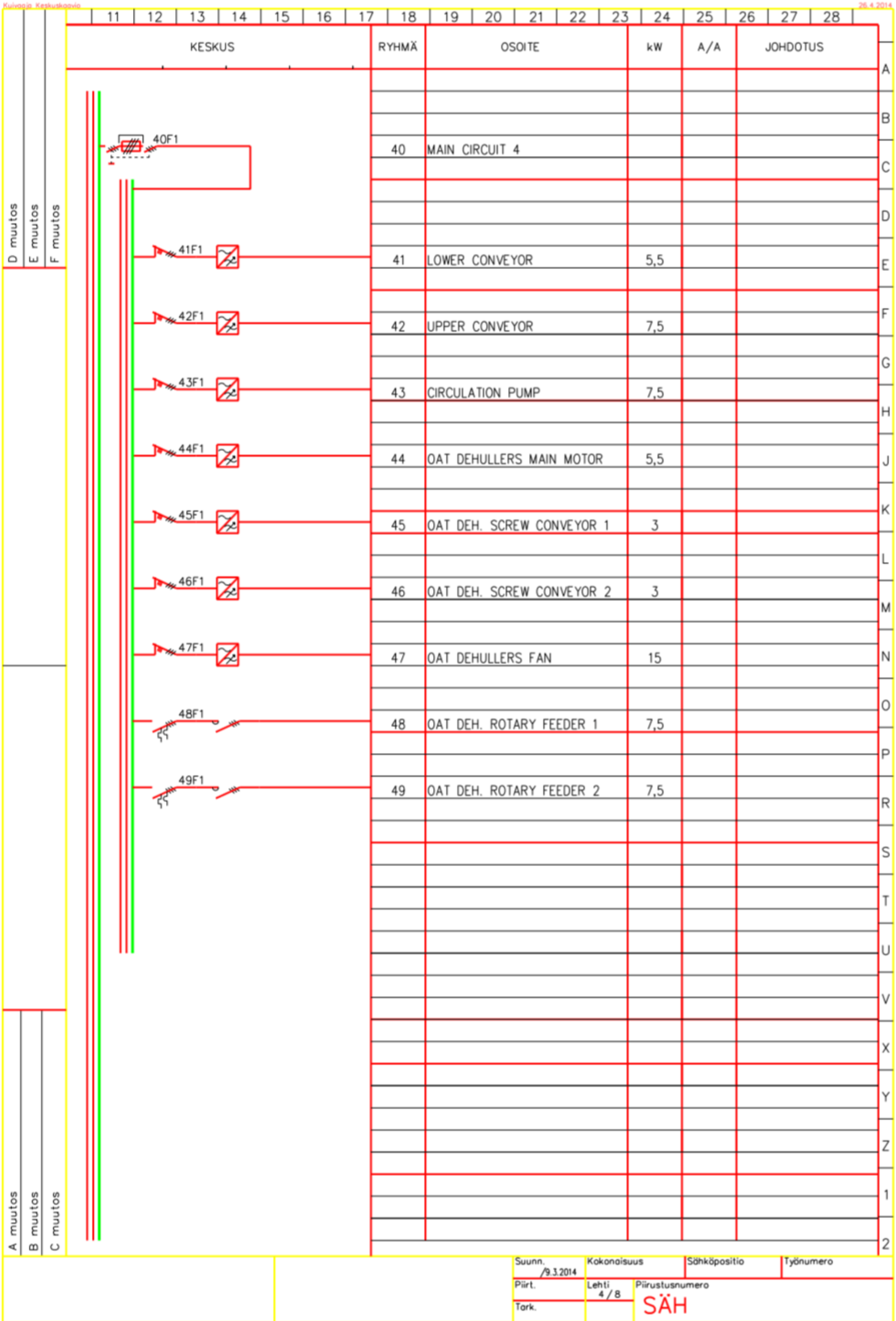
APPENDIX 2. Centre layout of the frequency converter centre



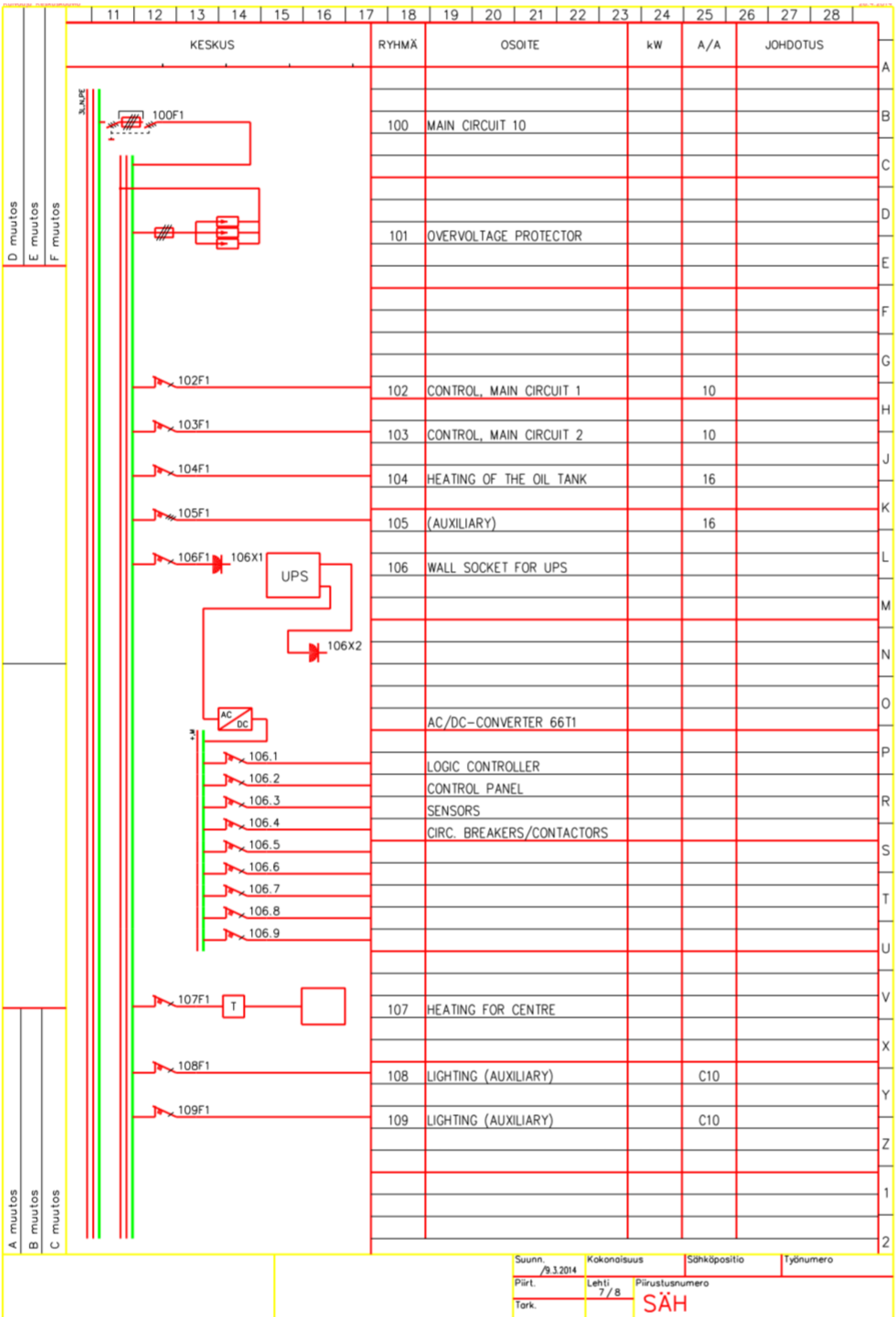
APPENDIX 3. Centre schema 1/8



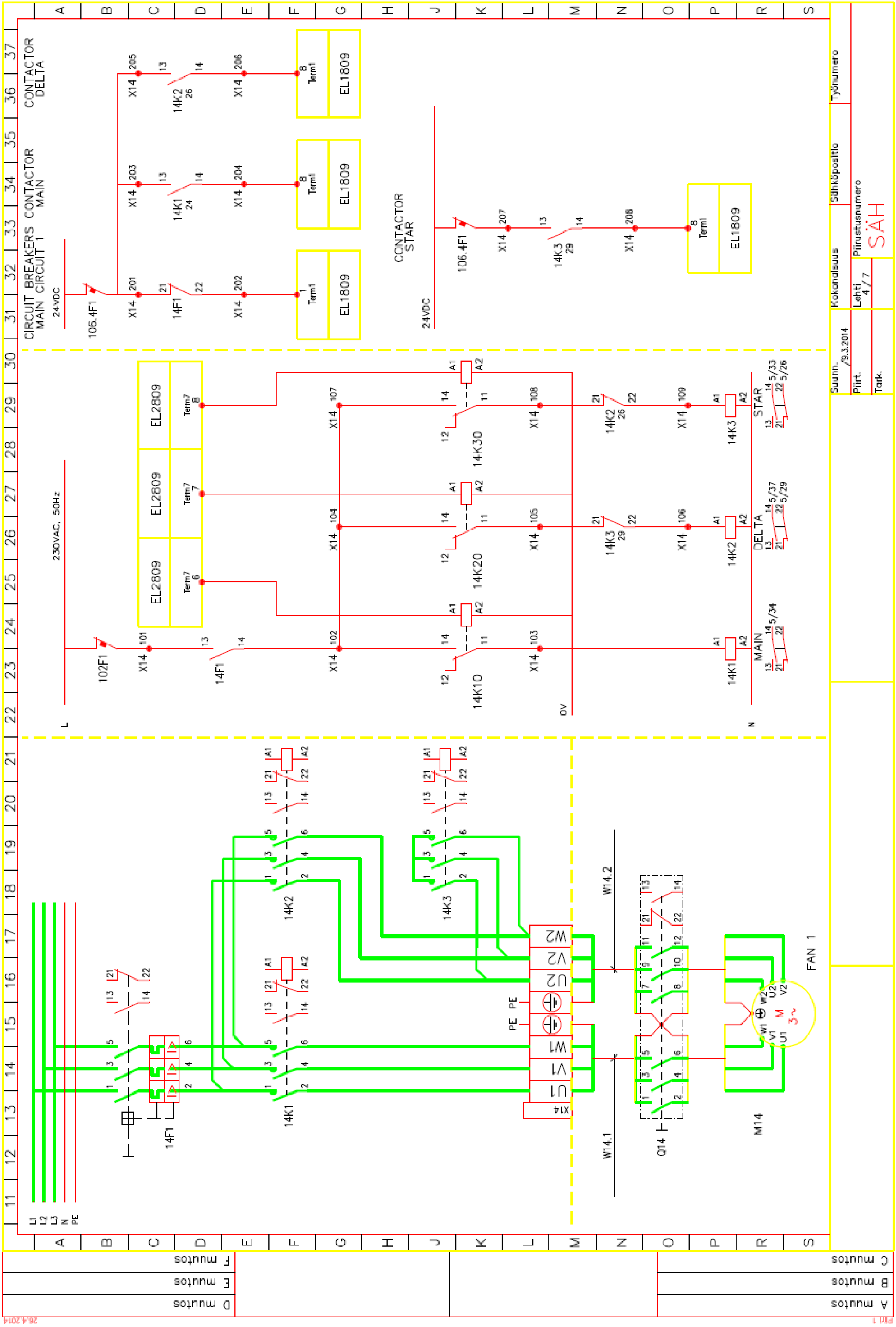
APPENDIX 4. Centre schema 4/8



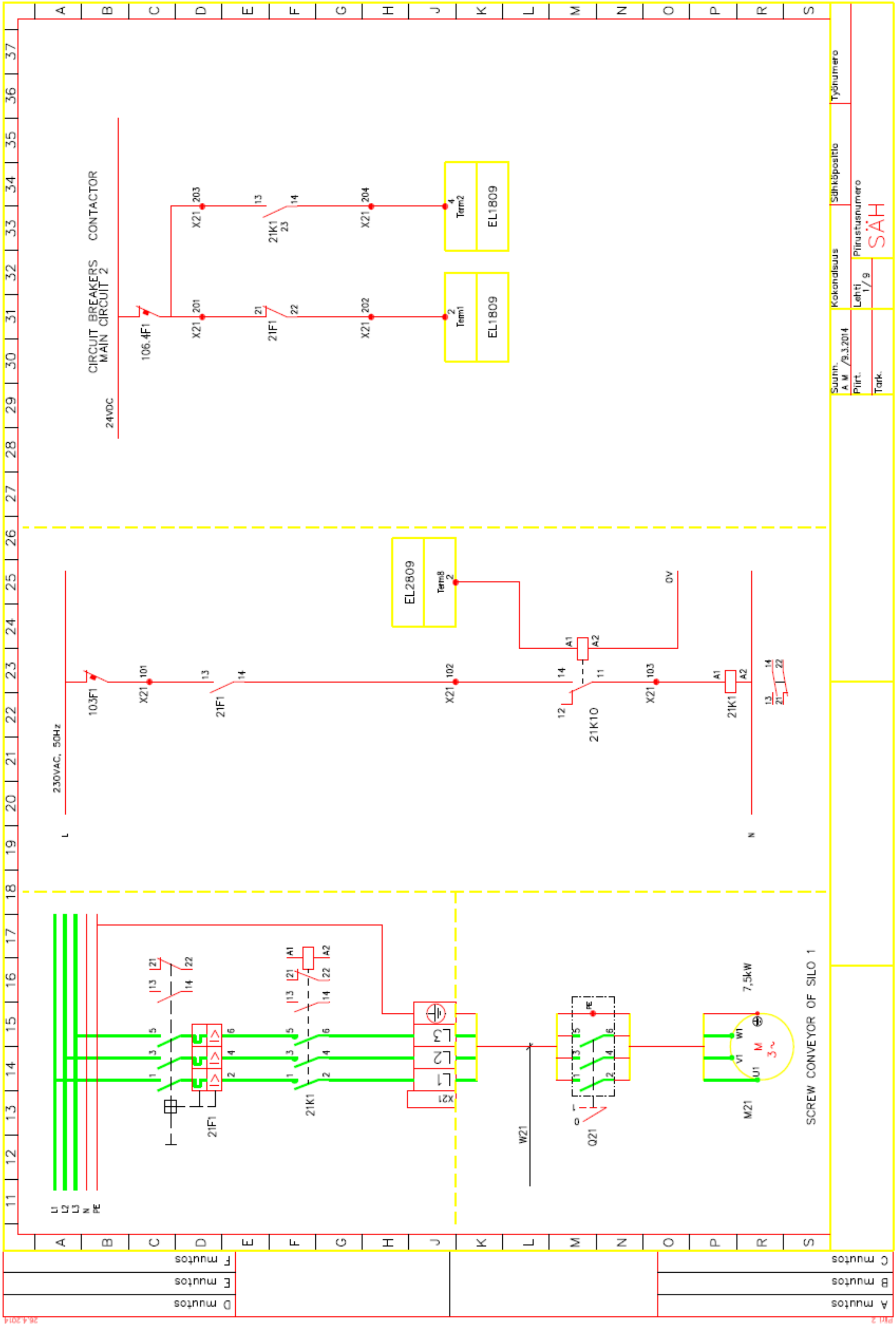
APPENDIX 5. Centre schema 7/8



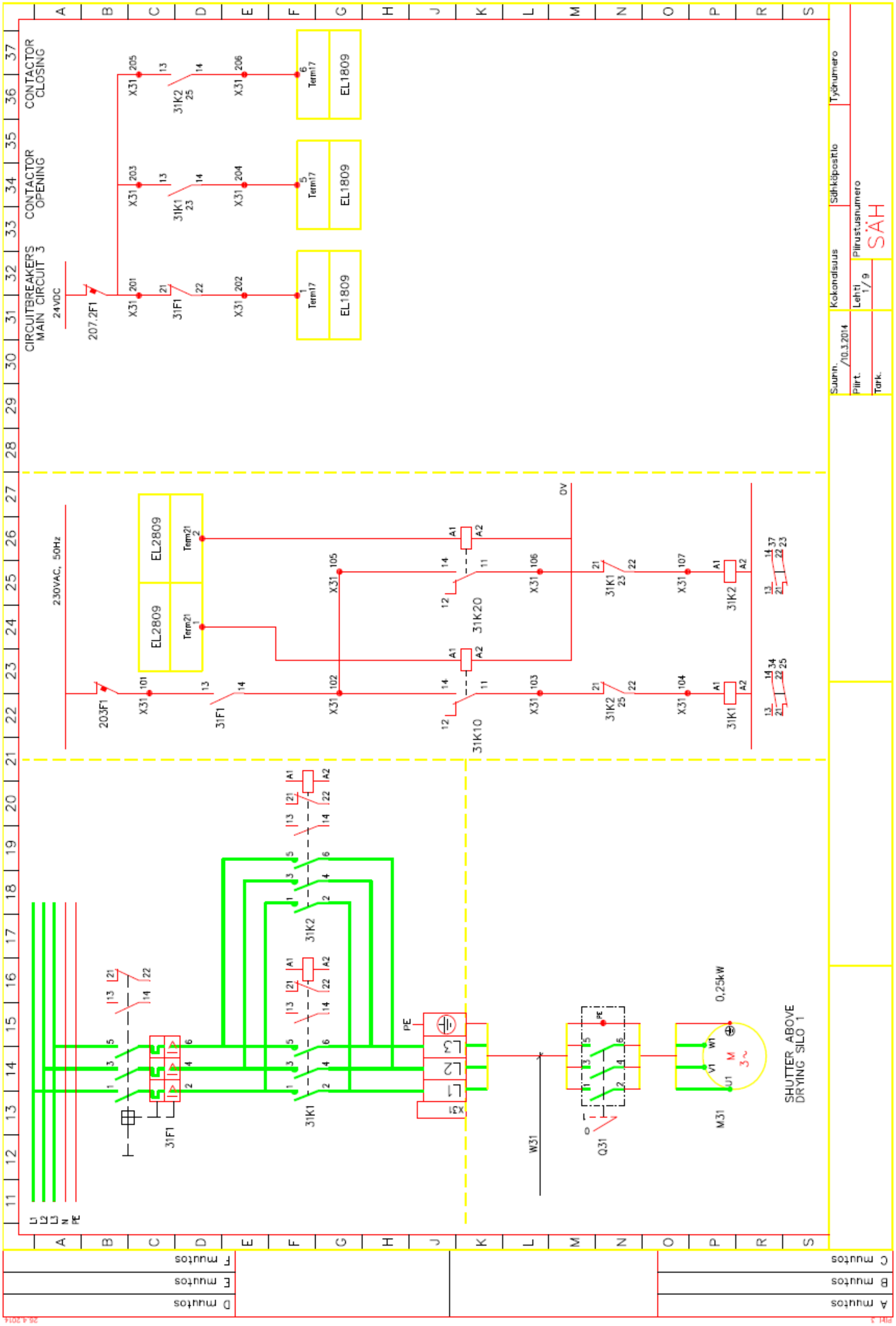
APPENDIX 6. Star-Delta starter circuit



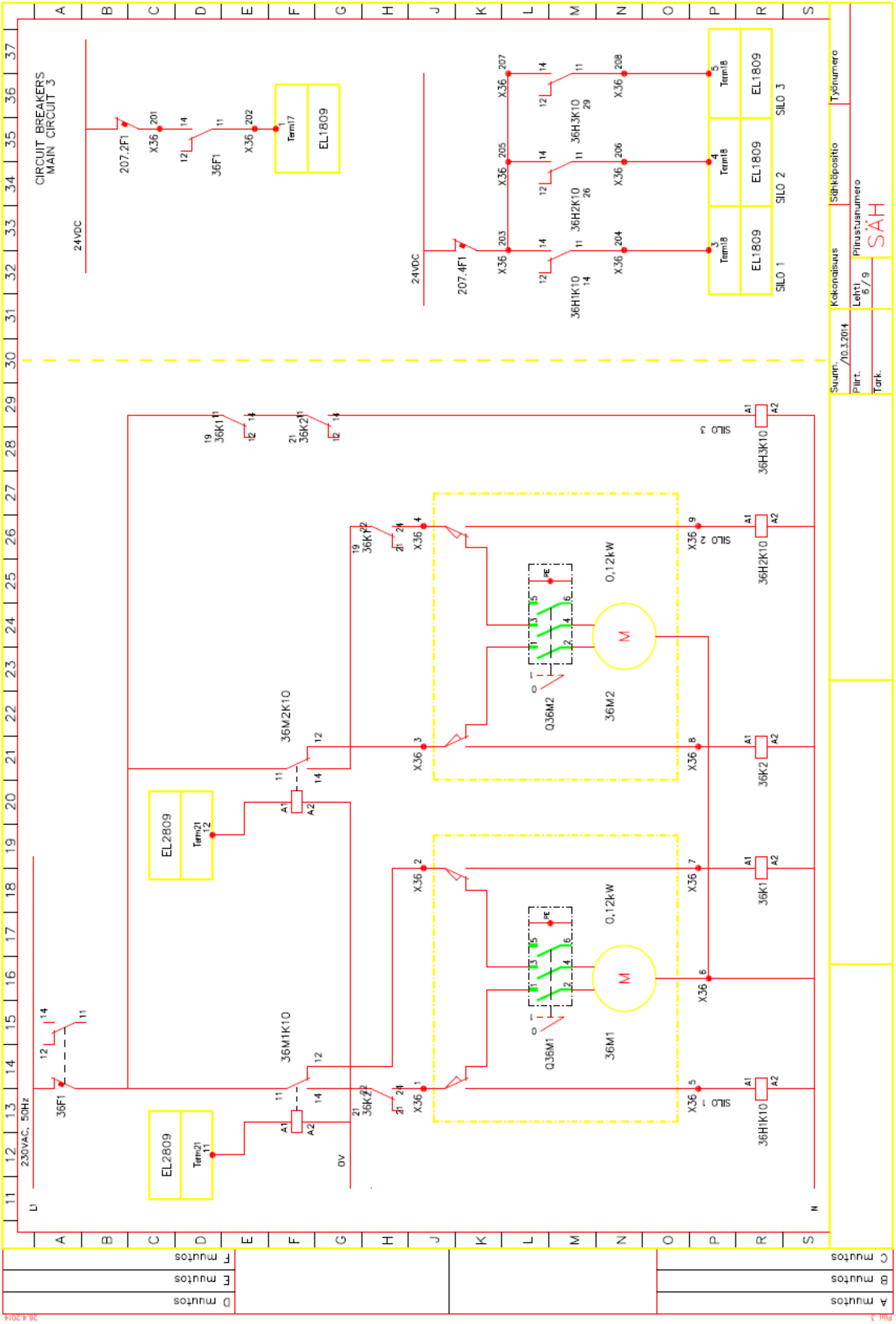
APPENDIX 7. Direct on line starter circuit



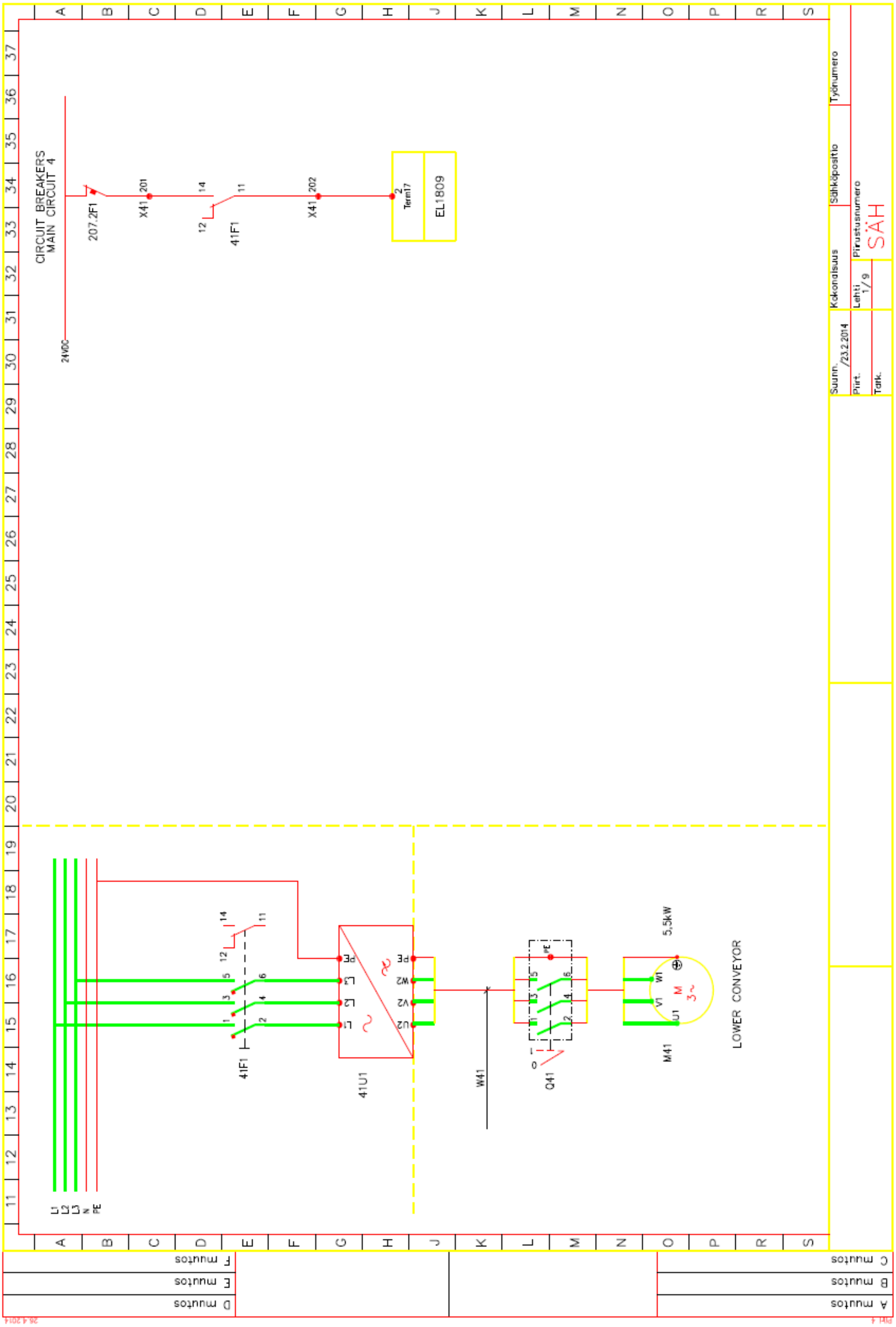
APPENDIX 8. Reversing starter circuit



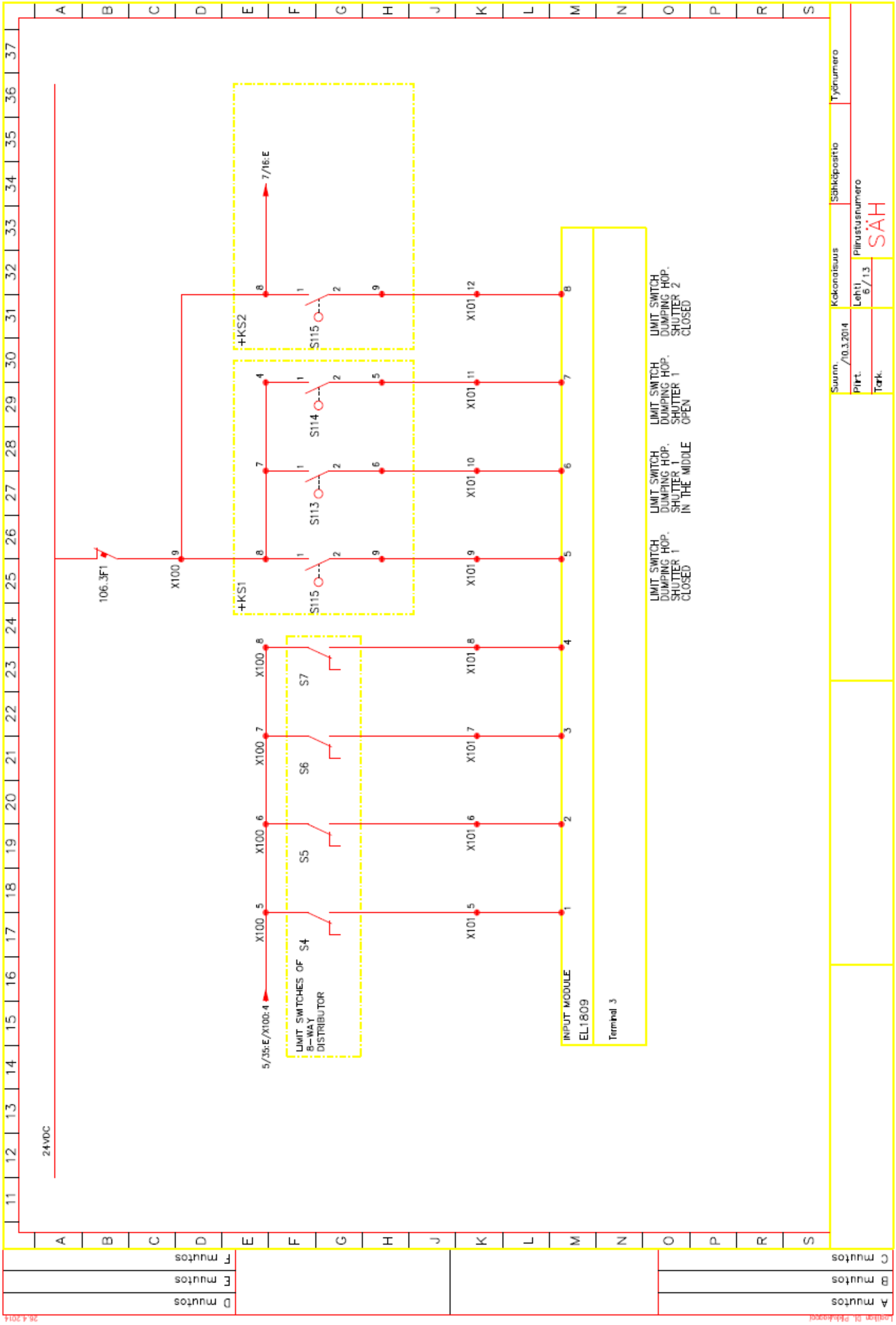
APPENDIX 9. 3-way distributor



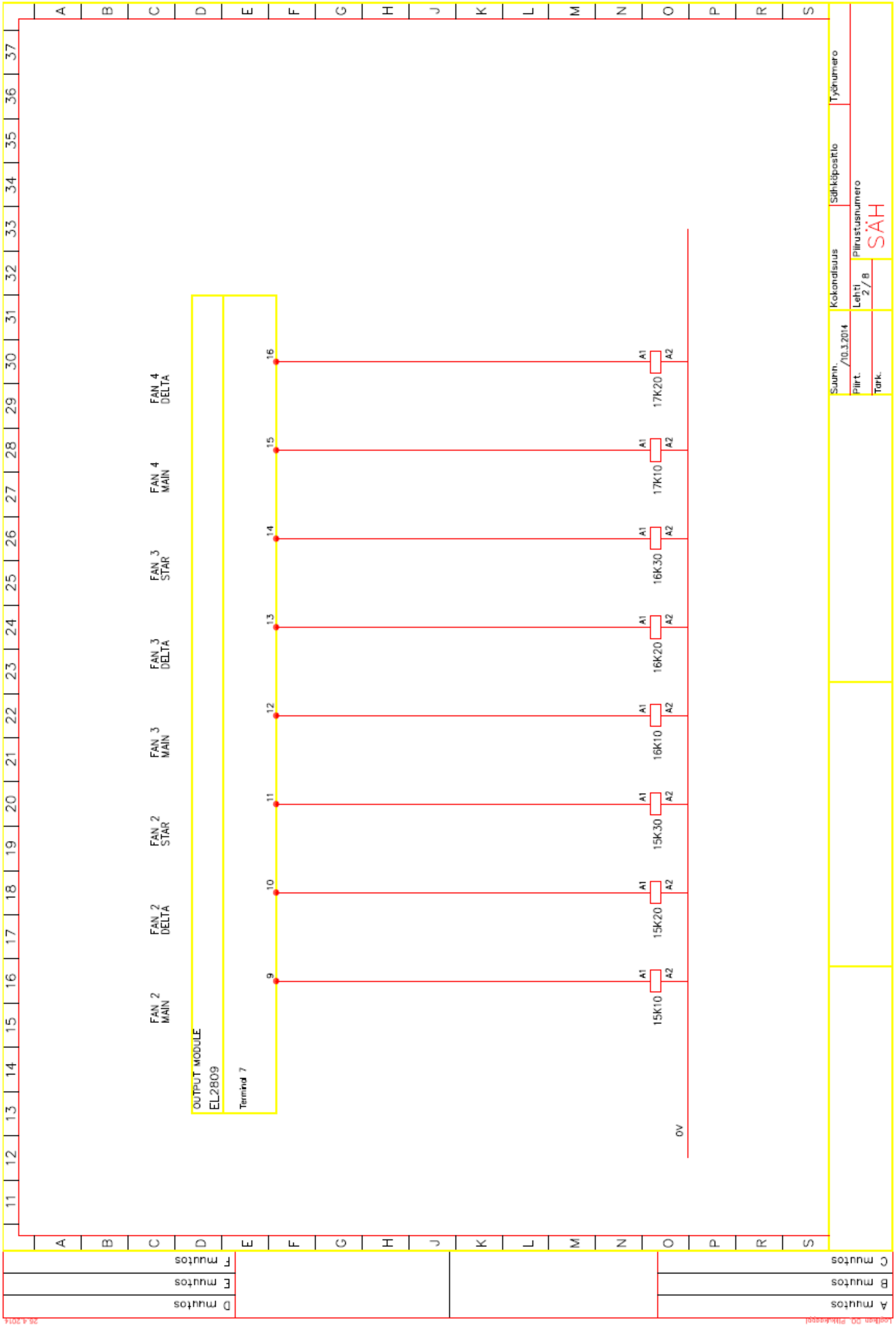
APPENDIX 10. Frequency converter drive



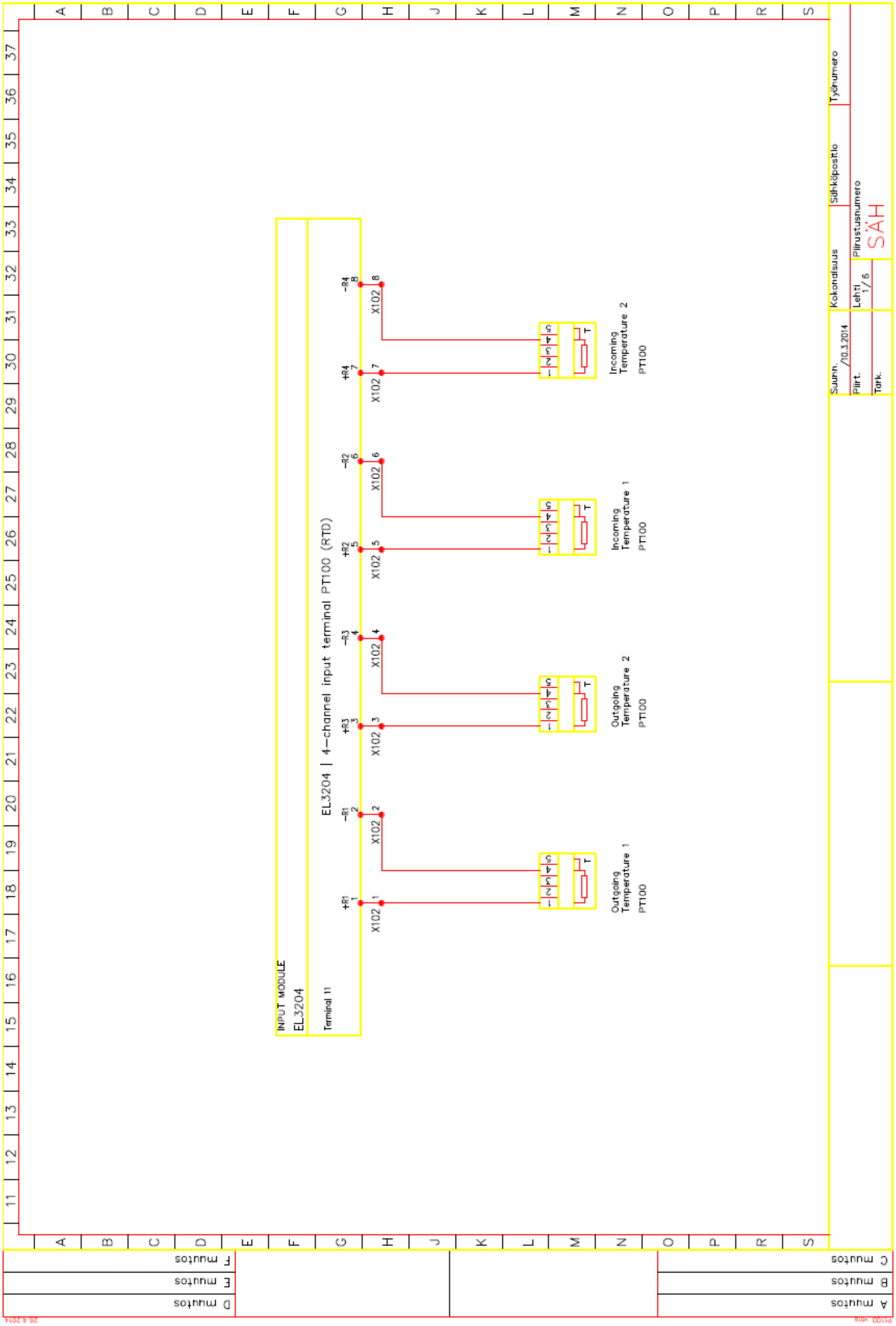
APPENDIX 11. Digital inputs



APPENDIX 12. Digital outputs



APPENDIX 13. Pt100 transducers



APPENDIX 14. 4-20 mA transducers