Project Assignment 2

by Liesel Williams

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Assignment 2 - Project design, Implementation and Evaluation.

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1. Executive Summary

An AC/DC motor generator set (Fig. 1) for teaching Electrical and Electronic Engineering modules up to Level 6 has been deisgned and built. This motor test rig can be used to investigate characteristics and performance of electrical motors and generators. Such technologies are rapidly gaining recognition in electric vehicles where efficiency is of utmost importance.

Regenerative braking systems (RBSs) are a way of harnessing the kinetic energy of a moving object into stored energy and increasing fuel efficiency, as opposed to friction brakes which simply waste the energy in the form of heat. RBSs are currently employed in all electric and hybrid electric vehicles.

This rig has modern industrial Siemens Drives which include regenerative modules and as such recover energy when the machine is forced to slow down and feed it back to the supply. The design is bespoke to CSG and uses the latest industrial technology and software providing extensive learning opportunities.

A Human Machine Interface (HMI) allows control, operation and monitoring of both machines, which can be run in manual or automatic mode and are coupled together thus providing the ability to apply complex load profiles to each machine.

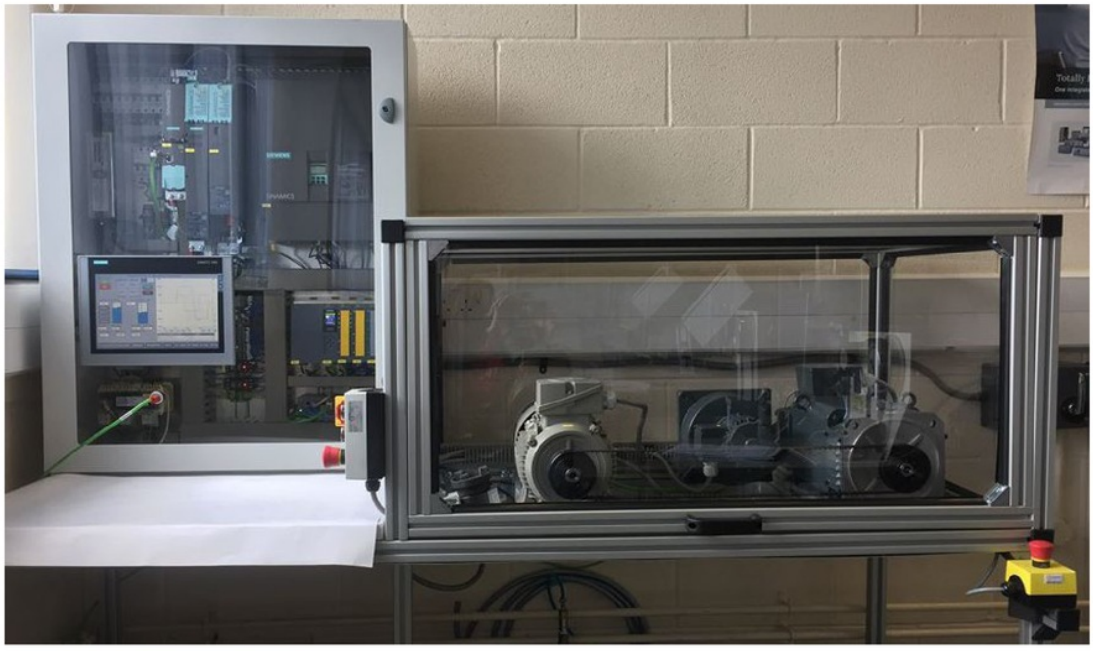


Figure 1 - ACDC motor generator set

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2. Introduction

The overall project aim was to provide an AC/DC motor generator set (referred to as the rig throughout the rest of the report) for teaching Electrical and Electronic Engineering modules at Levels 3 through to 6. The motor test rig would allow investigation into motor and generator characteristics and performance including 4 quadrant operation of both the AC induction motor and the DC motor.

The design is bespoke to CSG and uses the latest Siemens Drives, PLC, HMI and Software to industry standard providing the scope to extend the learning to cover such things as load testing, control strategies and loop tuning, integration methods and modelling using Matlab.

For this project the FDS scope taken from assignment 1 was:

- Demonstrate AC 4 quadrant operation
- Demonstrate DC 4 quadrant operation
- DC speed control using field weakening
- AC speed control using inverter drive

To achieve the above 4 HMI screens were designed allowing for both manual and automatic modes with a tracer graph in real time. Data would be uploaded to a webserver allowing student's access to analyse graphically the performance of both machines.

An alteration to the FDS was required due to a Drive configuration issue involving communication telegrams. Thus DCM field weakening and AC inverter speed above base values were not achievable.

4 quadrant demonstration of both machines was achieved and meets the FDS for this mode of operation.

(Williams 2019)

3. Design

3.1 Hardware design

The chosen solution to be developed and implemented was the Siemens motor-generator set and a block diagram gives an overview of the design. Each motor will be mounted in an enclosure and coupled together via a toothed belt. A torque transducer will sit on the AC motor shaft and provide an analogue 5V signal to the PLC.

The STP81030 electrical panel will be fitted with a plexi-glass door and have a 415V three phase 20A supply. It will contain appropriate protection and filtering and all the electrical components necessary for full functionality.

The DC motor will provide feedback to the drive through a tacho generator. Each motor will have a Siemens drive, mounted in the panel, controlling its operation and they will communicate via ProfiNET to the Siemens S7 1500 PLC which consists of a 24V power supply module, CPU module with user interface, 16 digital input module, 16 digital output module and 8 analogue input module. All operation will be controlled from a Siemens 12" Comfort HMI panel mounted in the panel door. A block diagram shows the design concept.

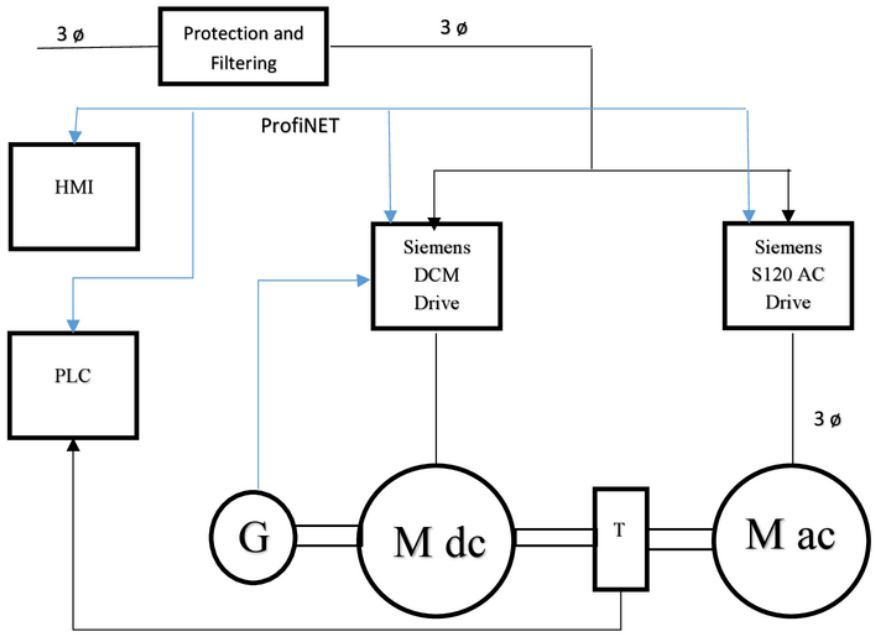


Figure 2 - Block diagram design

The motors and panel will sit on a bench approximately 2m in length by 0.8m depth and its overall height will be 1.75m. The bench will be mounted on castors and have a three phase 5

pin plug on a 3m length of 5 core 20A Silflex 6mm^2 cable. An Ethernet socket will be mounted on the panel door. Two emergency stops mounted on the panel and motor enclosure, a lockable isolator switch on the panel and a power to lock interlock guard on the motor enclosure will ensure the rig meets safety regulations.

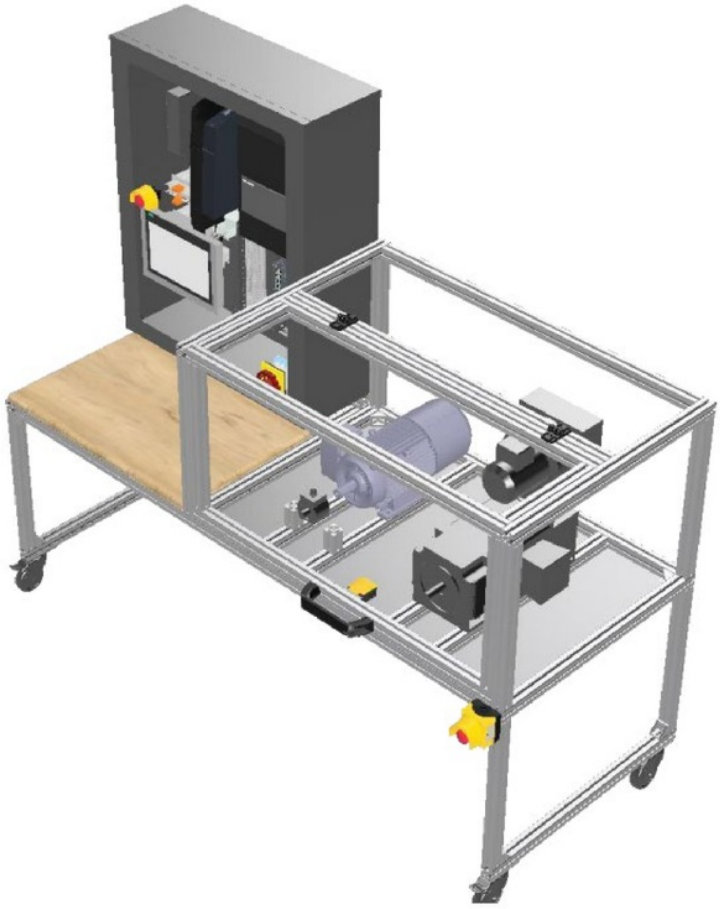


Figure 3 - CAD image of rig

A list of all components in the electrical panel is shown below and the position of each is identified by the key and shown on a labelled image in Fig 8, section 4.1.2. Reference is made to the electrical drawings and their identification tags are shown in brackets.

Key	Component
1	AC drive 3 pole protective device (MCB1)
2	DC drive 3 pole protective device (MCB2)
3	DC Field 2 pole protective device (MCB5)
4	230V PSU 2 pole protective device (MCB4)
5	SINAMICS S120 CPU (CU1)
6	SINAMICS S120 Smart Line Module 5kW Regenerative (1T1)
7	SINAMICS S120 Single MOMO Motor Module (1T2)
8	SINAMICS Stormrichter DCM (2T1)
9	SINAMICS S120 Line filter (R9)
10	DC Fan 3 pole protective device (MCB3)
11	3 pole DC Fan Relay (K1)
12	SINAMICS S120 Sensor Module for Incremental Encoder (SMC30)
13	SINAMICS S120 Line Reactor (R4)
14	Commutating reactor for converter (R7)
15	S120 Motor Inductor (R6)
16	24V Fuses
17	Connector Blocks
18	DC Enable Relay (K2)
19	Common ground connector block
20	Ethernet Switch (SW1)
21	Power Supply S7-1500 (PSU1)
22	PLC S7-1500 F series CPU (PLC1)
23	F-DI 16x24VDC Digital Input Module (A1)
24	F-DQ 8x24VDC/2A Digital Output Module (A2)
25	AI 8x U/I HS Analogue Input Module (A3)
26	Door mounted Isolator switch (Q1)
Door mounted	TP1200 Touch 12" (HMI1)

Table 1 - Panel components

The electrical schematic diagrams are an essential design tool upon which the build, test and fault finding were based and a full set is contained in Appendix A. Application of this technical literature is evident in modifications that were made to resolve a PLC error.

Drawings 1a to 6 detail the power supplies and protective devices for the SINAMICS S120, DCM, DC motor fan and PSU. The SINAMICS S120 also requires a line filter and reactor. Each 24V supply is fused from PSU1. The PLC CPU, digital I/O, analogue input modules, HMI, Ethernet switch and S120 control unit have 24VDC power supplies.

Drawing 7 and 8 detail the S120 smart line and motor module, the DC link between the two and the motor inductor and 3 phase induction motor, including encoder connections and sensor module for the encoder.

Drawing 9 shows how the DCM converter drive and reactor are linked, the 24V relay for the drive enable and motor and tacho connections.

Drawing 10 has the Ethernet switch connections to PLC and HMI.

Drawing 11 and 12 have the digital inputs from the pushbutton start, stop, safety Estops and door power to lock safety guard. Drawing 13 and 14 show the digital outputs to the door guard switch lock and relays for drives and fan motor.

Drawing 15 shows the torque transducer (mounted in the motor enclosure) analogue 0-5V signal to the analogue input module.

This rig uses intelligent, modular drives which are complex in nature and during the design, consideration was given to their operation by researching not only the configurable software but also the converters themselves.

For the DC drive, according to (Siemens, 2018) 4-quadrant unit armature supply is via two fully-controlled three-phase bridges connected in a circulating-current-free inverse-parallel configuration. This means circulating currents in the converters, which are traditionally avoided by isolation techniques, are in a parallel system, connected directly to ac and dc sides thus reducing size and cost.

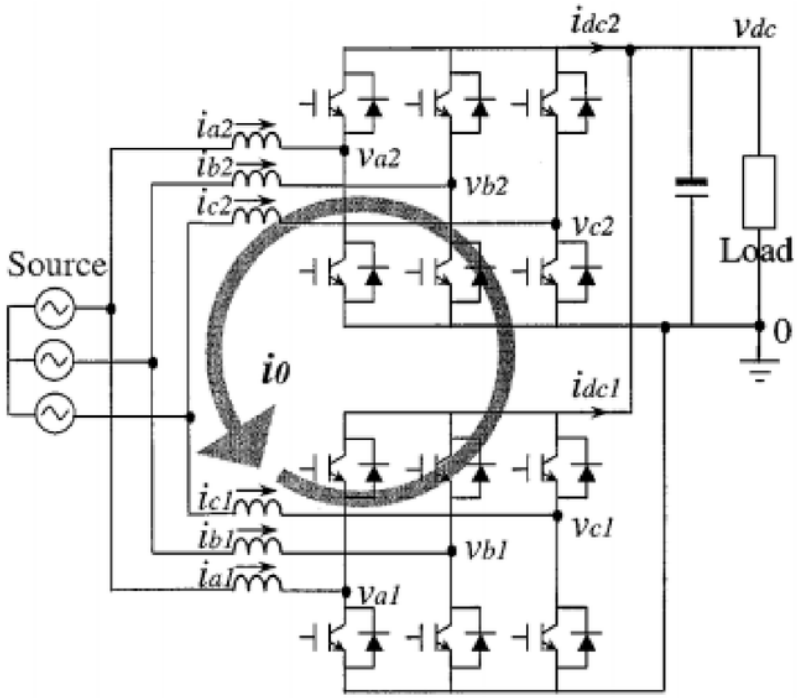


Figure 4 - Converter schematic diagram

(Zhihong Ye, 2002)

Drive commissioning via parameter assignment is achieved by plugging in via DRIVE-CLiQ, a communication interface which supports data communication at 100Mbits/s between the converter components along with IT integration of sensors, encoders and motors from any manufacturer. Advantages include high performance, integrated safety functions, automatic configuration and diagnostics tools.

(Siemens, 2017)

For the inverter drive according to (Siemens, 2017) “system architecture with a central Control Unit, on the SINAMICS S120, the drive intelligence is combined with closed-loop control functions into Control Units. These units are capable of controlling drives in the vector, servo and V/f modes. They also perform the speed and torque control functions plus other intelligent drive functions for all axes on the drive. Inter-axis connections can be established within a component and easily configured in the STARTER/Startdrive commissioning tool using a mouse”.

Costing the project was undertaken in the planning stage and a breakdown of main parts and labour was detailed in the planning report for comparison with other manufacturers and suppliers. (Williams, 2019). An excel spreadsheet in Appendix H gives a costing analysis including extra costs incurred during commissioning and installation.

3.2 Software design

Design of the software including Drive configuration included the ability to switch the drives from speed regulation to torque regulation at will via a push button on the HMI. This was required to allow the demonstration of 4 quadrant operation on both drives as when the S120 is motoring at 1000 rpm and 5Nm, then the DCM must be generating at the same speed and with an equal and opposing torque i.e. -5Nm. This holds true for both motors and all four quadrants and the design of the DC and AC 4 quadrant operation screens was based around this principle.

From the FDS a list of parameters for display on the HMI was drawn up.

Table 2 - DC data required for design

DC DATA	
Speed setpoint	rpm
Speed actual value	rpm
Torque stepoint	Nm
Actual torque	Nm
Active power	kW
Actual armature current	A
BackEMF	V
Armature firing angle	deg
Armature voltage	V
Field current	A
Supply voltage	V

Table 3 - AC data required for design

AC DATA	
Speed setpoint	rpm
Speed actual value	rpm
Torque setpoint	Nm
Actual torque	Nm
Output frequency	Hz
Output voltage	V
Actual current	A
Power factor	
Active power actual	kW

There was an awareness during the design stage that this undertaking was a new bespoke design unbeknown to have been trialled previously with no other similar test rig of this nature in existence. This fact influenced the amount of incomplete or uncertain information involved and that it was essential to research drive theory and mathematical models available on Matlab before programming the drives for this particular application. (Williams, 2019)

A flow chart was used as a design tool for the application of the test rig and a sequence will be programmed from it.

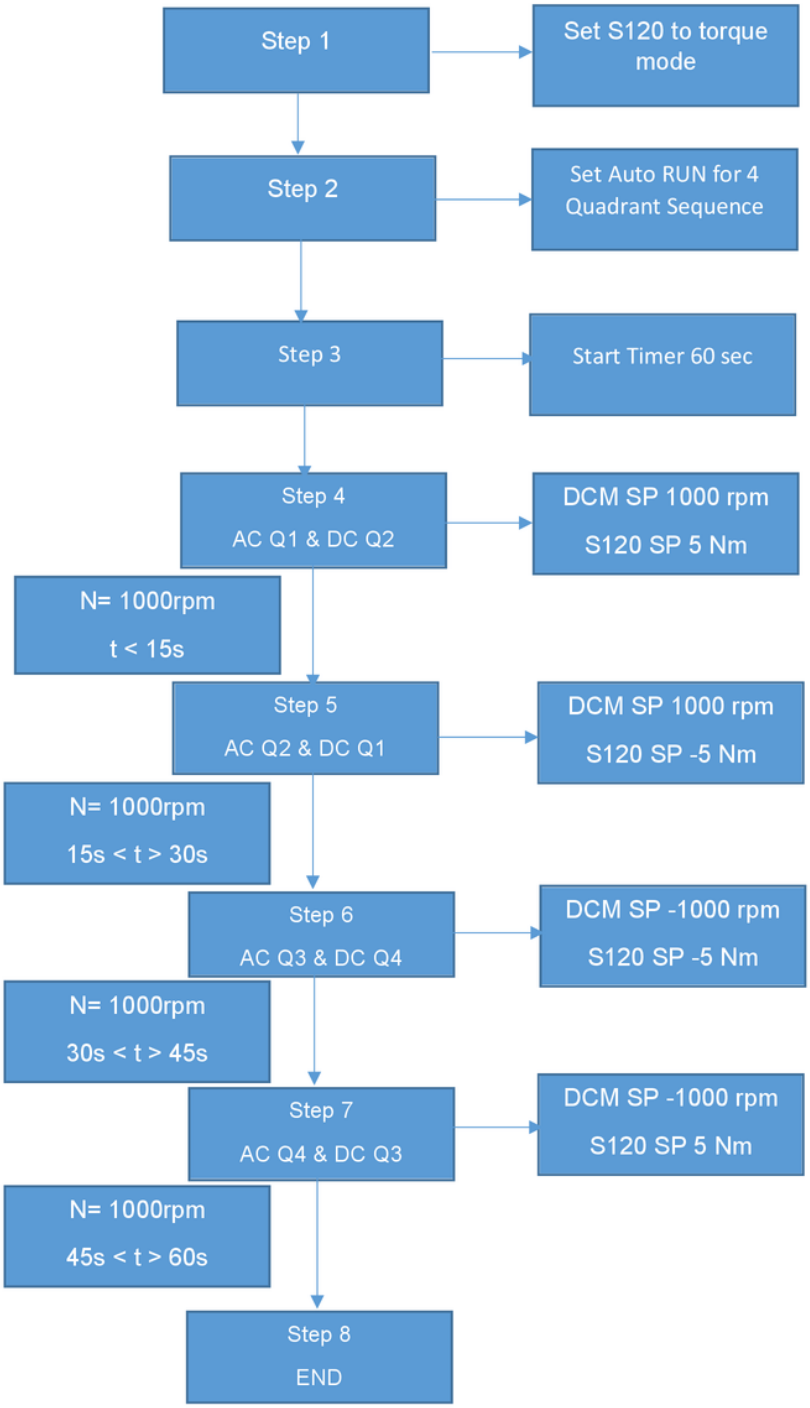


Figure 5 - Design flowchart for auto sequence

Investigation and research into motor control and 4 quadrant drive operation was an essential part of the design process and used to develop the correct HMI operation and when validating results.

3.3 Safety design

According to Siemens “The safety functions integrated in the device – known as "Functional Safety" – not only increase the safety level, but also make the device and the overall system more compact, cost effective, reliable and maintenance friendly. All this is achieved as one of the main contactors or circuit breakers required until now can be eliminated”.

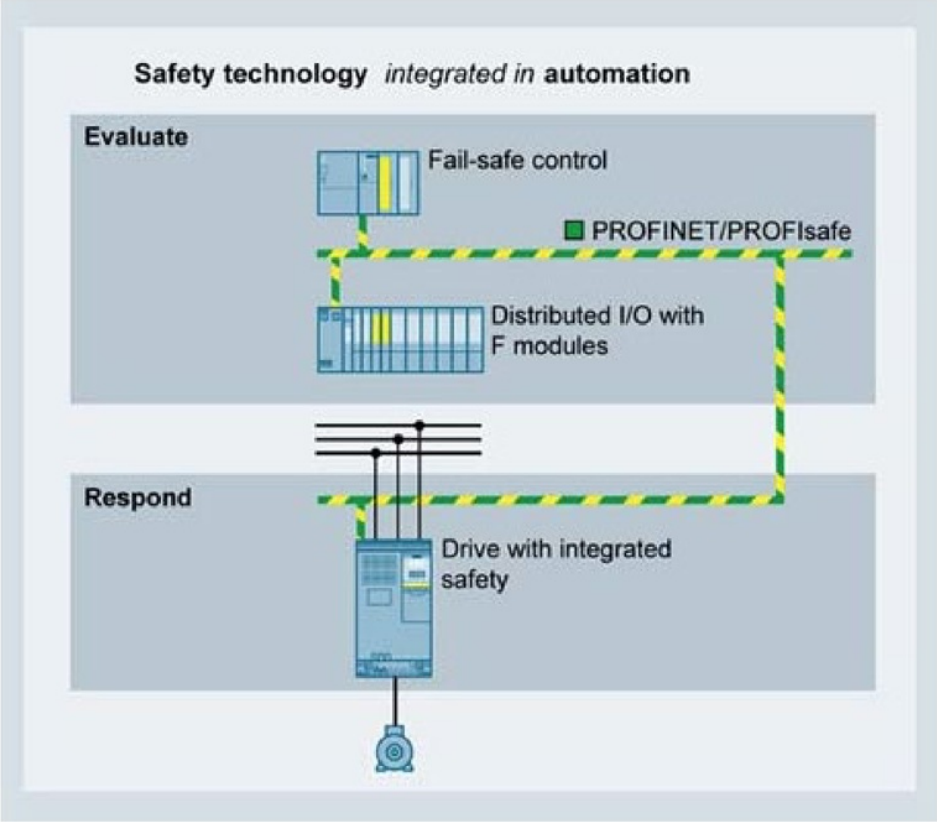


Figure 6 - Integrated safety technology

(Siemens, 2019)

The SIMATIC Safety F-system is used to control processes and to force the system into a safe state after shutdown, thus they can only be used where an immediate shutdown does not pose danger. The standards achieved via this software creation are SIL3 in accordance with IEC 61508:2010 and PL (e) category 4 in accordance with ISO 13849-1:2015.

Safety functions are contained in the fail-safe inputs and outputs (F-I/O) from field sensors such as emergency stops, light barriers, interlocks.

S7-1500 F series CPU safety is built in. Failsafe Organisation Block F-OB is inserted from global library and calls the main safety block which contains the Functional safety sensors I/O and activates the Main Safety OK contact.

Functional safety satisfies requirements of Part5-2 of IEC 61800 for variable-speed drive systems, one example being safe stopping functions. E.g. Safe Torque Off (STO) ensures no wearing of parts from electronic shutdown and converter online diagnosis. Safe Stop (STO) is used when a high moment of inertia needs to be quickly and safely braked. Safe Brake Control (SBC) ensures a safe position is kept under no current conditions.

Relevant standards are :

EN ISO 13849-1:2016 Safety of Machinery; Safety-Related Parts of Control Systems – Part 1: General principles for design. Part 2: Validation

EN 61800-5-2:2017 Adjustable-speed electrical power drive systems – Part 5-2: Safety requirements – Func- tional safety

EN 62061:2015 Safety of machinery – Functional safety of safety-related electrical, electronic and pro- grammable electronic control systems

EN 61508-2:2016 Functional safety of electrical/electronic/programmable electronic safety-related systems–
Part 2: Requirements placed on safety-related electrical/electronic/programmable electronic systems

Functional safety as validated in the risk assessment Appendix I

Table 4 - Functional safety levels

Safety integrity level (SIL) according to IEC 61508	SIL 3 Depending on the application and diagnostic test interval
Performance Level (PL) according to EN ISO 13849-1	PL e Depending on the application and diagnostic test interval

During CE mark testing it was noted that compliance with ISO 13849 required that a push button start and stop were required as well as the HMI push button start and stop. Refer to Appendix I.

4. Implementation

4.1 Hardware implementation

4.1.1 Rig construction

The frame was made from TSLOTS Structural Extrusion 40mm x 40mm and mounted on castors for mobility. The panel was mounted on the left hand side with a plexi-glass door hinged on the right side and the adjacent motor enclosure opening upwards.

The motors were mounted side by side in a plexi-glass enclosure with shaft mounted 85mm pulleys driving a toothed belt. The torque transduced was coupled to the AC motor shaft. Appropriate wiring was routed via rear mounted trunking to the panel.

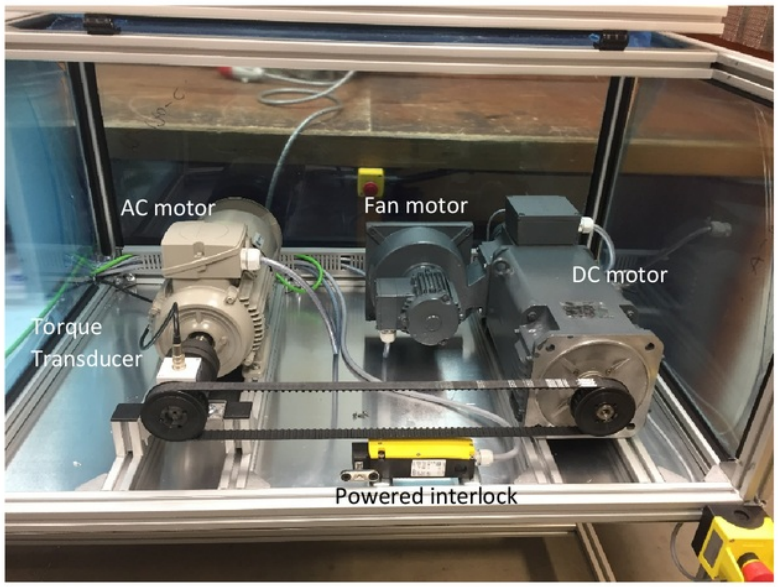


Figure 7 - Motor enclosure

4.1.2 Panel construction

The components chosen during the design stage were positioned and fixed in the panel as seen below. Each component in the image is listed in the table 1 section 3.1.

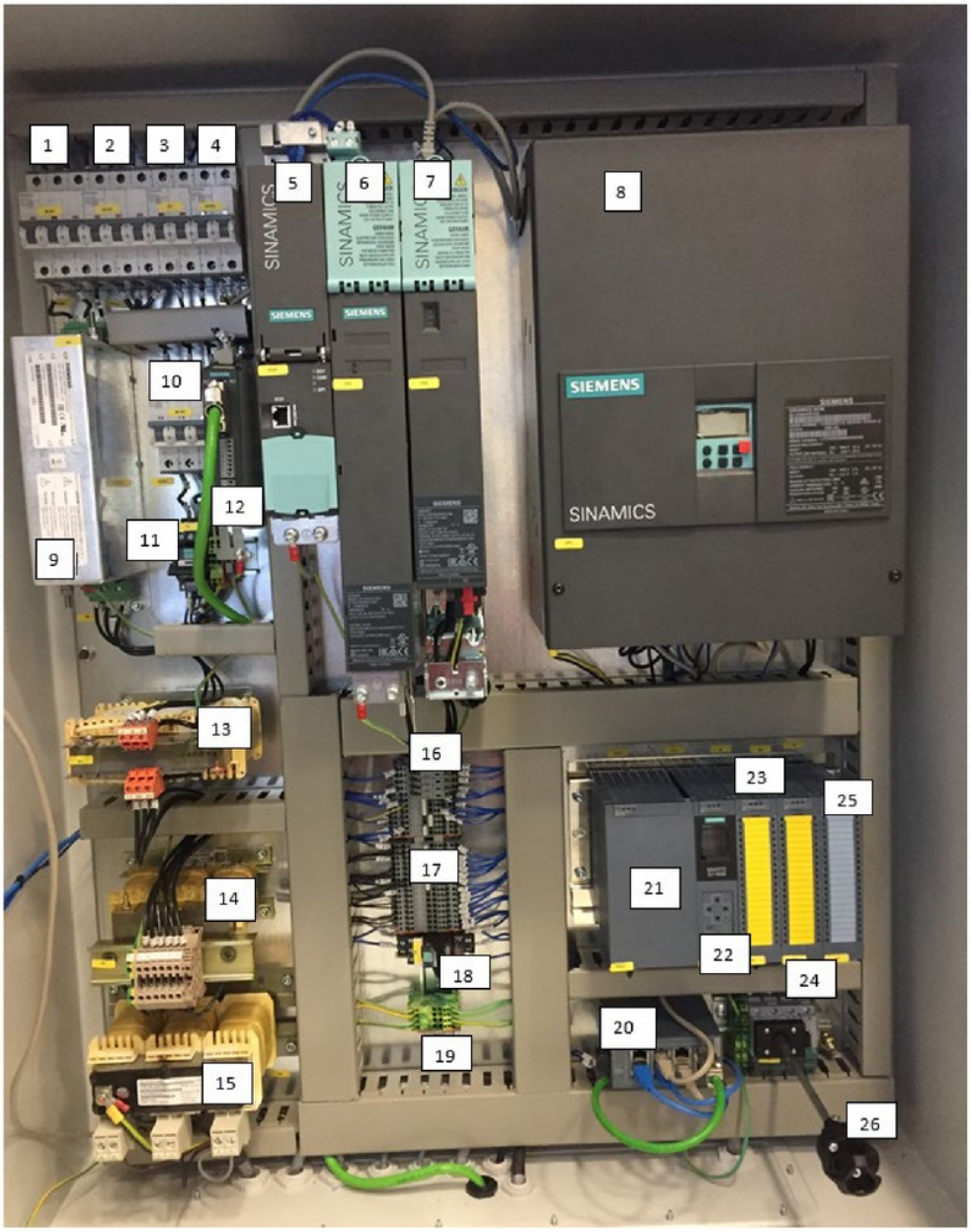


Figure 8 - Panel components

Appropriate installation techniques were followed from the design electrical drawings with cable identification markers fitted and cable routing via trunking to allow for the most efficient utilisation of space in the panel.

Project management using accurate and meaningful project planning was essential for smooth running and successful completion. Delays are an inevitable part of the process and tracking and monitoring key project deliverables during the design and implementation stages enabled managerial decisions to be taken. Cost drivers were evident throughout this process and in particular depended on key dates such as financial year end when delivery and invoicing became a major factor. Outcomes at key stages of the process were evaluated and close monitoring of component delivery, construction and safety certification meant the project was kept on track. Microsoft project was used as the main planning tool and is shown in Appendix G.

4.2 Commissioning

4.2.1 Technique Services Ltd, Manchester

The implementation phase contained several stages. A visit to the supplier of the rig in Manchester was scheduled for 20-21/02/2019 and to provide training on the S120 and DCM drives.

The main construction of the rig was carried out in Oxford it then had to be dismantled to fit into the van for transportation to Manchester. The re-wire and testing at Manchester was carried out, unfortunately the Siemens drive specialist John Inskip was off sick, so training had to be delayed.

Due to the complexity and vast variety of modules and options that Siemens provide a large amount of rework was required during commissioning and led to problems such as missing or incorrect components or plugs for power supplies, software and/or firmware updates and various configuration problems. Upon examining the DCM drive main card the communication socket was seen to be missing, a replacement was fitted and a 230V supply and circuit breaker added.

The S120 firmware was updated to 4.8 and configured and a 24V supply run from the common supply on the CPU. This was later seen to produce a short circuit error on the PLC which was discovered via TIA portal diagnostics.

TIA and Starter software updates had to be carried out before configuring the drives. All part numbers had to be correctly entered into the Starter software and measuring of motor parameters then began. The belt drive was removed for open loop configuration, the AC motor encoder proved difficult to identify so EMF feedback for speed testing was employed as a temporary measure. The belt drive system was then re-assembled.

The PLC initially showed multiple errors including configuration, program loading and network communications. There was an unknown drive communication issue which needed further investigation and was linked to the telegrams protocol. The drive expert John Inskip would resolve this upon his return.

IP addresses were set up as 10.13.90.150-PLC, 151-AC motor, 152-DC motor and 153-HMI all were reconfigured and download successful.

Program testing revealed some signals were being received but the output was not reaching the drive, re- download of hardware and software loaded the HMI screens but remaining communication problems needed to be resolved.

4.2.2 Coleg Sir Gar

Following rectification of most of the above issues the rig was delivered to CSG on 07/03/2019. A cracked panel door occurred during transit meaning a further visit was scheduled for 15/03/12019 to replace the door and reconfigure the drives for torque regulation mode.

Installation took place and initial tests on basic functionality were completed. Remaining problems included a fault on the PLC meaning Digital output Q3 shows a red light, and the diagnostics state a short circuit to ground on the S120 enable 24V.

Despite this error functionality tests were successful and the drives were controlling the motors.

The telegrams were not operating correctly due to an unknown drive configuration issue, meaning not all of the parameters required were accessible. The AC Drive was configured to allow the operator to toggle between speed regulation mode and torque regulation mode from a push button on the HMI.

As seen in log entry 23 the Siemens function block SINA_PARA was used to access drive parameters on an acyclic basis and allows reading or writing to these variables via the parameters screen Appendix C.3. This process was automated to provide the data necessary for implementing the final HMI design screens.

Further testing and drive interrogation revealed a number of invalid parameters were being read and the correct ones had to be selected from the vast array of thousands available. Using technical knowledge gained from drive theory and problem solving skills, the design solution was adapted and solutions found either in the drive itself or in the program code to maintain safe and accurate operation and reliability.

4.3 Hardware modifications

To address the PLC short circuit fault on the S120 24V enable a relay, K3, was added to the panel and wired accordingly. Here we see the relevant drawing extracts showing the addition of a supply fuse F5 from the PSU (DWG 4), K3 24V relay to S120 enable (DWG 9) and the relay coil from digital output Q3 (DWG 15)

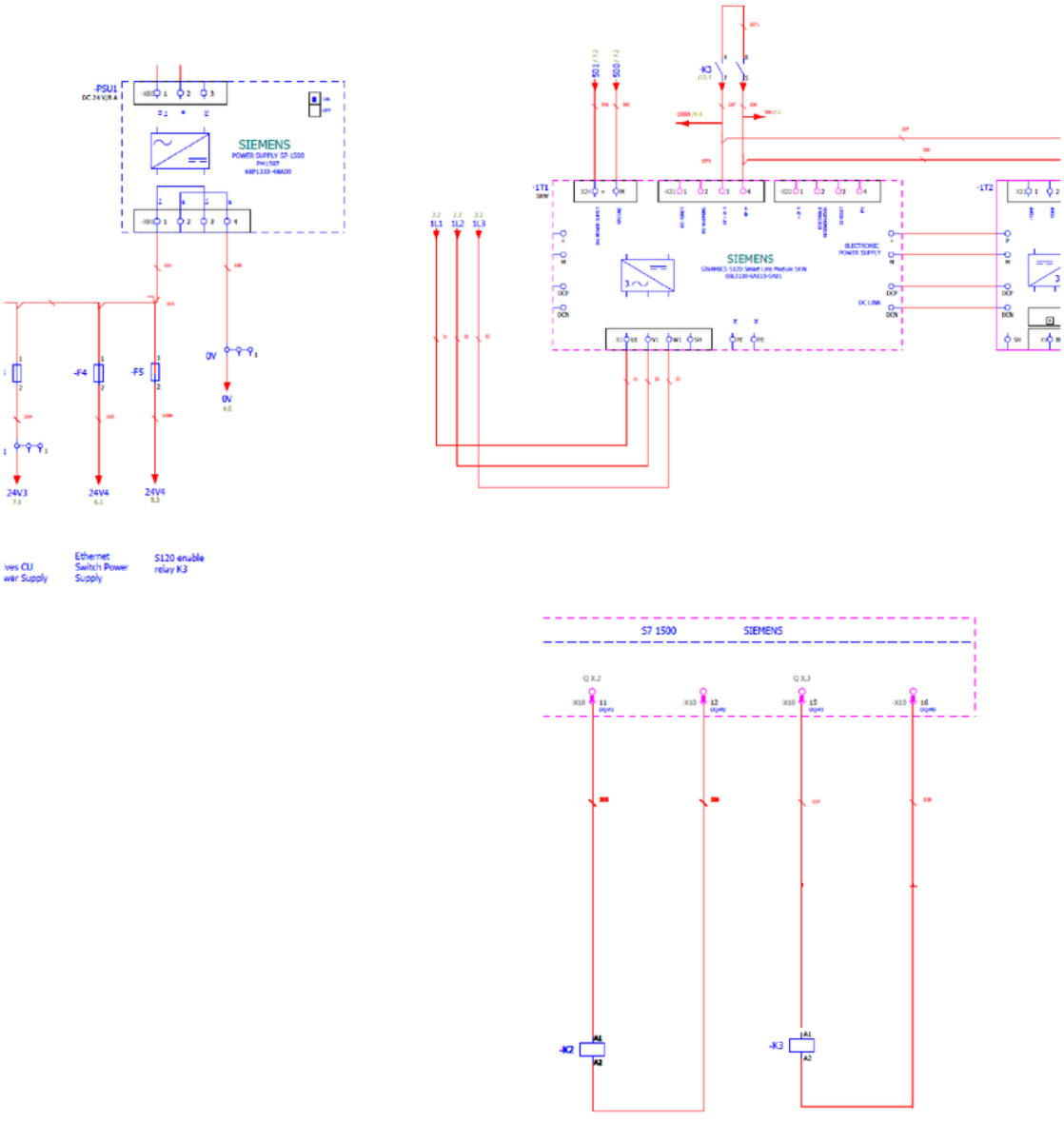


Figure 9 - Drawing modification extracts

4.4 Software implementation

The rig was delivered with a basic functional project and basic HMI screens, to enable control of both drives, a sequence for speed set points for both motors, an acyclic routine to read or write multiple and single parameters from and to the drives and a basic safety monitoring screen. A full explanation of this is contained in Appendix E. The devices and network configuration were functioning and all accessible via TIA portal.

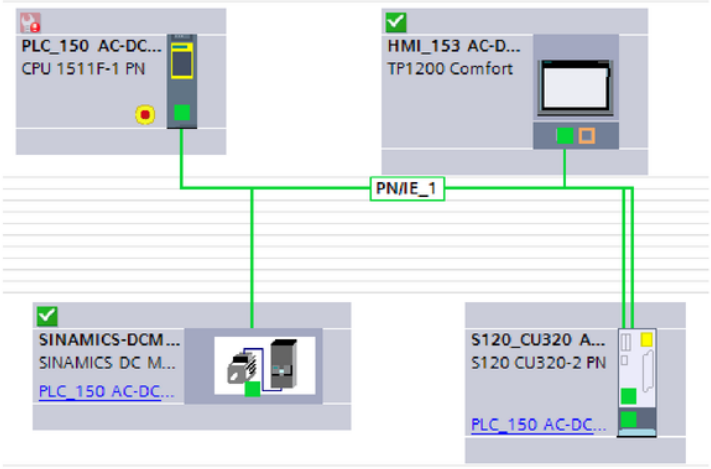


Figure 10 - Device network configuration

Drive commissioning was carried out using the STARTER commissioning tool. This wizard guides you through the commissioning process and sets up the operation of the drive.

Two types of drive parameter are available i.e. p type adjustable (read/write) and r type display (read only) they can all be accessed via PROFIBUS or changed using the p parameters in the drive.

Within the drive are a high number of variables which are interconnectable I/O or internally used control variables and they are made interconnectable via Binector and Connector (BICO) technology.

Both analogue and digital signals are made connectable by the use of BICO parameters and as such they contain a prefix BI, BO, CI or CO, where BI and BO are Binector I/O i.e. a binary signal either 0 or 1; CI and CO are Connector I/O i.e. a digital signal of say a 32 bit format used to mimic words, double words or analogue signals.

Parameters are further subdivided into data sets containing command, drive and encoder types for pre-configured signals and automatic control configurations and if modified must be saved to non-volatile memory before switching off. (Industry.siemens.com, 2019)

From the original FDS a list of parameters required from both drives was drawn up and in modified form used in the testing and analysis of results.

Table 5 - DC Drive data

DC DATA	
Speed setpoint smoothed (rpm)	r20
Speed actual value (rpm)	r63
Actual torque smoothed (Nm)	r31
Active power actual value smoothed (kW)	r32
Absolute actual current smoothed (A)	r27
Armature current actual value (%) - not used	r50019
EMF actual value (V)	r50037
CO: Cl-loop field current ctrl current actual value (%) – not used	r52265
Armature firing angle (deg)	r50018
Field firing angle (deg) – not used	r50034
CO: Armature voltage signed actual value (%)	r52292
Armature voltage actual value (V)	r50038

Table 6 - AC Drive data

AC DATA	
Speed setpoint smoothed (rpm)	r20
Speed actual value smoothed (rpm)	r22
Torque setpoint (Nm)	r79
Actual torque smoothed (Nm)	r31
Torque Utilization Smoothed – not used	r33
Output frequency smoothed (Hz)	r24
Output voltage smoothed (Vrms)	r25
Absolute actual current smoothed (A)	r27
Current actual value torque-generating smoothed (Arms) – not used	r30
Power factor smoothed	r38
CO: Active power actual value smoothed (kW)	r32
CO: DC Link voltage smoothed (V)	r26
Phase current actual value (A) – not used as unstable	r69

Currently user operation is limited to the HMI. From the root screen seen in Appendix B, nine other screens are accessible. Only the screens detailed in Appendix C i.e. the application screens will be explained in the scope of this project.

4.5 Software modifications

The design of the software required to achieve 4 quadrant operation and above base speed operation consists of a modified program, the structure of these additional blocks is seen in the table below.

Table 7 - Program blocks

Ref	Name	Description
OB1	Main	Main program cycle
FC3	LW Controls	Program for manual and automatic 4 quadrant operation
FC1	Parameters	Program block with SINA_PARA function
FB4	LW Get AC Drive Parameters	Program which automates the reading of multiple AC Drive parameters
FB5	LW Get DC Drive Parameters	Program which automates the reading of multiple DC Drive parameters
DB16	LW 4 QUAD	Data block for 4 quadrant operation
DB19	LW Get AC Drive Parameters_DB	Data block which automates the reading of multiple AC Drive parameters
DB22	LW Get DC Drive Parameters_DB	Data block which automates the reading of multiple DC Drive parameters
DB15	LW DCM Drive Data	Data block containing the required DC Drive parameters
DB14	LW S120 AC Drive Data	Data block containing the required AC Drive parameters

These modifications enabled the FDS to be partly realized and tested to confirm validity and accuracy of results.

Two fully functioning screens and their associated programs, in the table above, are explained in detail in Appendix E.

Assignment 1 contains a Matlab model using a mechanical coupling of two drives, namely an AC DTC Induction Motor Drive and a Four-Quadrant Single-Phase Rectifier DC Drive. The model proved a useful tool when predicting performance of the drives in each quadrant and is revisited with a view to replicating the rigs operation in Appendix J. The speed and torque set points have been changed to 5Nm and 1000rpm. The model provides block parameters which allow the user to enter specific values, nominal values have been used until the actual motor parameters can be accurately isolated.

5 Testing

Initial tests revealed that the validity of all parameters had to be verified and access to correct or modified parameters was essential to ensure accuracy, e.g. DC Actual Torque was significantly lower than the AC Actual Torque. The scaling factor used in Network 13 for Actual Torque DC was evaluated and altered to 11.65 i.e. the rated torque calculated from rated power and speed (3.05 kW divide by 261.8 rads/sec). By inspecting live values from Starter DCM drive software the value before and after the modification were verified. Following further investigation other invalid results were corrected thus showing how engineering problems were overcome.

The four quadrant operation was graphed on a time base and the results are seen below. The tests were repeated at a lower torque value to show further relationships for analysis, according to workshop and laboratory practice the tests were repeated for validity and several seconds given for the parameter value to steady. As the values recorded are instantaneous and as such changing rapidly, the tester took a mid-range value once settled.

It was also noted that the SINA_PARA program loop had to be slowed down to slug the receiving rate and thus prevent spurious results occurring.

Four quadrant operation was demonstrated in both automatic and manual modes.

For both drives in automatic control mode a tracer graph clearly shows the result.

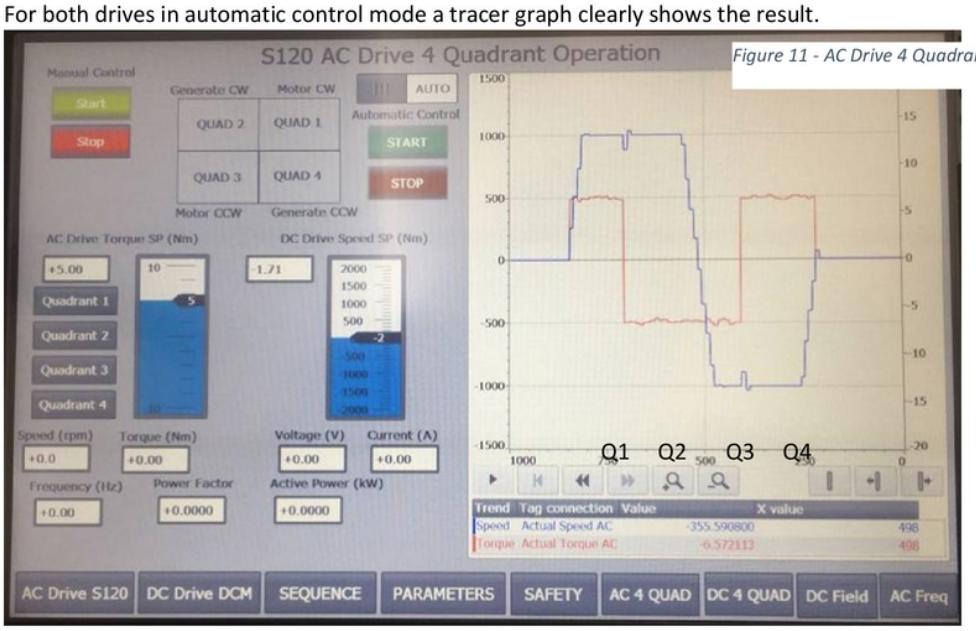


Figure 11 - AC Drive 4 Quadrant Operation

The blue trace is speed and the red trace is torque. Each quadrant can be easily identified. Also seen is the transient spike which occurs when the torque is reversed and the speed ramp function generator which speeds up and slows down the DC motor. The torque on the AC motor is applied as a step function.

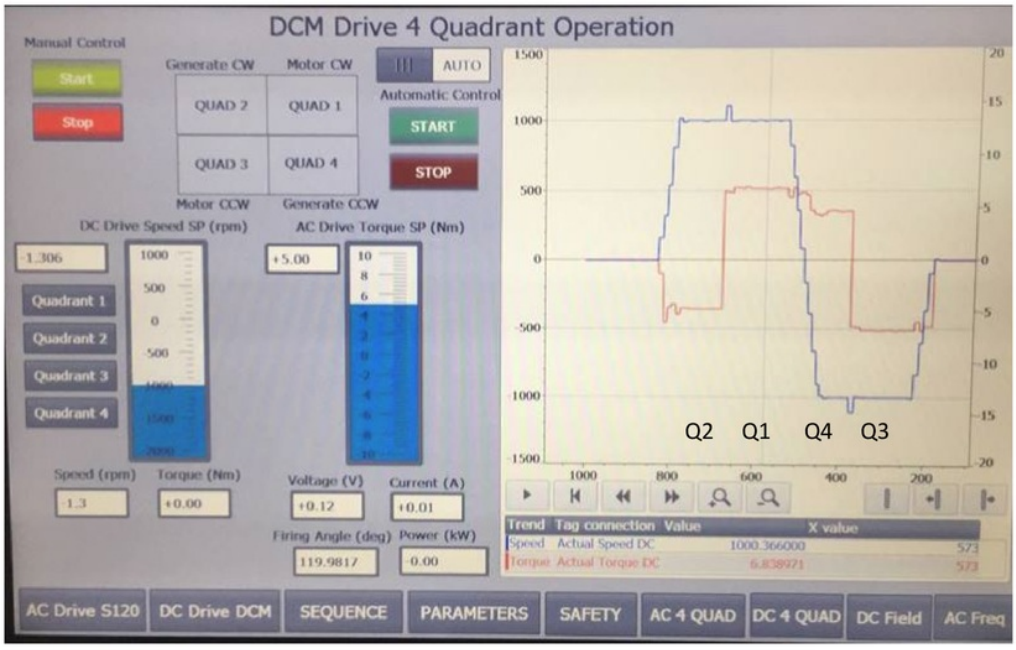


Figure 12 - DC Drive 4 Quadrant Operation

5.1 Analysis of test results

The results of the four main tests undertaken have been entered into excel spreadsheets and are found in Appendix F

5.1.1 DCM Four quadrant test – Appendix F.1

In manual mode each quadrant can be evoked at will by pressing the appropriate push button on the HMI screen. A set of two tests were undertaken for each drive as per the initial testing concept drawn up in the planning stage. (Williams, 2019). The results for 5Nm and 2.5Nm loads have been analysed using excel. From the raw data gathered some rudimentary calculations were completed.

Examining the results:

Speed and average voltage display correct sign for CW and CCW direction. Armature current, torque and mechanical power display correct sign for the appropriate quadrant i.e. negative power flow when generating. Electrical power is larger than mechanical power when motoring and show a positive power loss increased for higher torque. When generating mechanical power is greater in magnitude and the positive power loss is increased at higher torque. Back emf is the correct sign and remains constant for constant speed. Armature voltage is reduced with torque when motoring (V = Eb + IaRa) i.e. Eb and Ra constant and Ia reduces with torque. Armature voltage increases at reduced torque when generating (V = Eb – IaRa) these equations hold true for motoring Q1 and 3 as Va>Eb and for generating Q2 and 4 when Va<Eb. Alpha is seen to increase at lower torque this larger delay reduces the armature voltage. Alpha is greater than 90 deg when generating, i.e. inversion is taking place making cos alpha and average armature voltage change sign. Armature voltage calculations are correct for 5Nm tests (Vav = 3Vmax(line) cos alpha/pi).

According to Wildi “four quadrant drive analysis is simplified by subdividing the speed-torque curves and looking for moments when either speed or torque pass through zero indicating the transition from one quadrant to another. Knowing the quadrant, we know whether the machine functions as a motor or a generator and assuming that a positive (clockwise) speed corresponds to a positive armature voltage we can deduce the required current direction. This tells us which converter is in operation and whether it acts as a rectifier or inverter.”

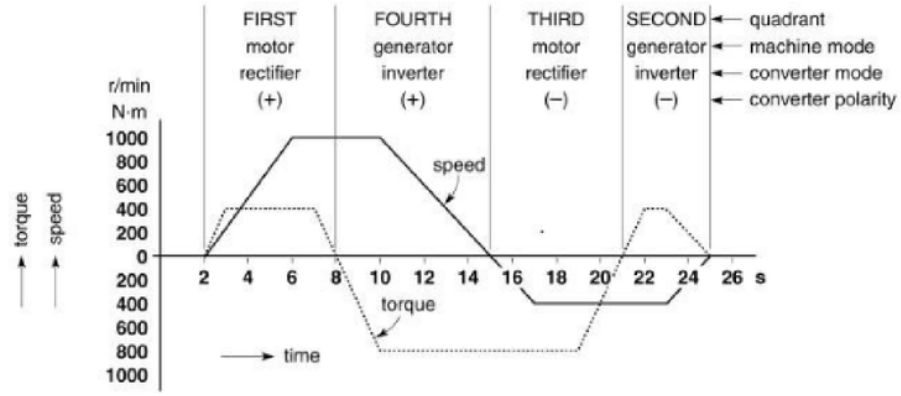


Figure 13 - 4 Quadrant graph

(Wildi, 2013)

5.1.2 S120 Four quadrant test – Appendix F.2

The S120 drive is automatically put into torque regulation mode when the start button is pressed. The same test procedure was adopted and two torque levels applied in each quadrant.

Examining the results:

Voltage and frequency have a slight reduction at lower torque when motoring and a slight increase when generating, the V/f ratio remains constant. The absolute current value reduces at reduced torque, thus maintaining the T/I ratio. Power and power factor increase at higher torque and display correct sign i.e. negative when generating. They are proportional to torque as the constant torque region is not exceeded. Electrical power is larger than mechanical power when motoring and conversely it is less when generating, both modes give a positive power loss which increases at higher torque. Speed and torque display correct sign for appropriate quadrant as per theory.

5.1.3 DCM No load speed demand 500 to 2500 rpm – Appendix F.3

Examination of the motor rating plate:

P = 3.05kW V = 420V I = 8.7A N = 2500 rpm

ω = 2*pi*2500/60 = 261.8 rad/s

T = 3050/261.8 = 11.65Nm

Km = Tr/Ia = 11.65/8.7 = 1.34

Examination of the excel results and calculations:

The torque is low and caused by friction and windage which increases linearly with speed. Back EMF increases linearly with speed and the gradient of the graph ke = 1.71. Power increases linearly with speed (P = Tw). The firing angle decreases linearly with speed thus demonstrating theory (V av = 3Vmax cos(α)/π). Armature current is proportional to torque and the gradient of the graph km = 1.36 which concurs with ratings. Field current is constant in this range as field weakening zone has not been reached. Average armature voltage increases with speed. Mechanical power increases with speed and power loss is positive and increasing with speed.

According to Lander "the speed of a motor can be controlled by the level of the mean output voltage of a rectifier…..determined by the angle of the firing delay set by the level of input voltage to the firing circuit". By creating a closed loop system using an amplified feedback signal, in the case of the DC motor a tacho-generator is employed, an error signal is created. It can be shown that change in motor speed instantly causes excessive thyristor and motor currents which must be automatically limited via a second current feedback loop. Limiting by a soft start controller reduces the voltage in the first period and stops this excessive current, the set limit accounts for the firing angle. In the event of a full first period (as shown below) excessive current creates a torque impulse and possibly mechanical damage. (Lander, 1993)

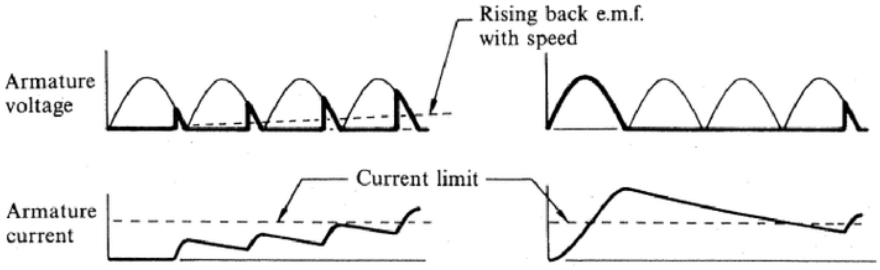


Figure 14 - Firing angle delay illustration

A ramp function generator (RFG) is used instead of a step change and guarantees a gradual alteration in firing angle. This RFG is enabled via the telegram configuration and can be seen in Network 9 Appendix E.

5.1.4 S120 No load speed demand 500 to 2500 rpm – Appendix F.4

Examination of the motor rating plate:

P = 3.0kW V = 415V I = 5.7A N = 1460 rpm

ω = 2*pi*1460/60 = 151.8 rad/s

T = 3000/151.8 = 19.76Nm

K = Tr/I = 19.76/5.7 = 3.46

Examination of the excel results and calculations:

The torque is low and caused by friction and windage which increases with speed. The V/f ratio is 7.26 up to base speed, above this, the ratio reduces as V is a maximum. DC link voltage remains constant. Power increses linearly with increasing speed. Power factor is low as expected due to the low load torque which also makes the current low and it is proportional to torque.

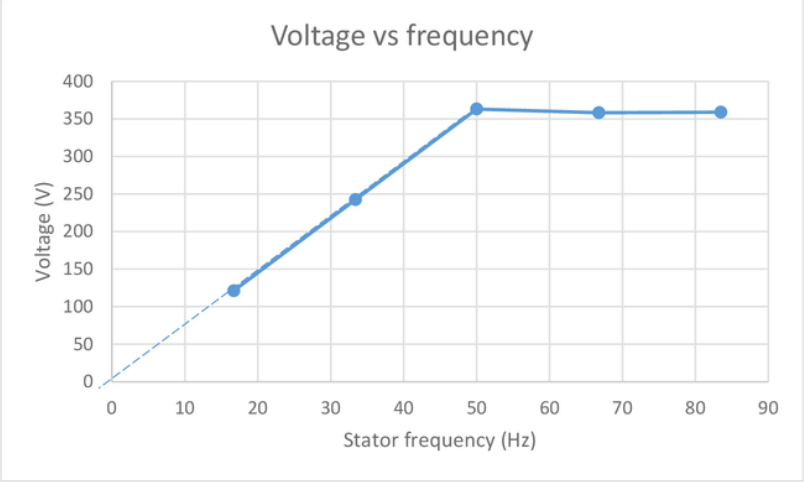


Figure 15 – S120 V/f ratio graph

Krishnan states that " the relationship between the applied voltage and the stator frequency appears linear, it does not go through the origin as a small voltage is need to overcome the stator resistance at zero frequency. Complex adjustments for air gap flux magnitude, stator impedance, stator current does not apply for low-performance applications and a pre-programmed V/f ratio is suffice in an inverter-fed induction motor drive. Voltage boost at low frequencies is employed to increase starting torque. (Krishnan, 2015)

Extrapolation of the V/f graph demonstrates this theory. Other graphs have been formed from the data along with all results in Appendix F which validate well established motor theory.

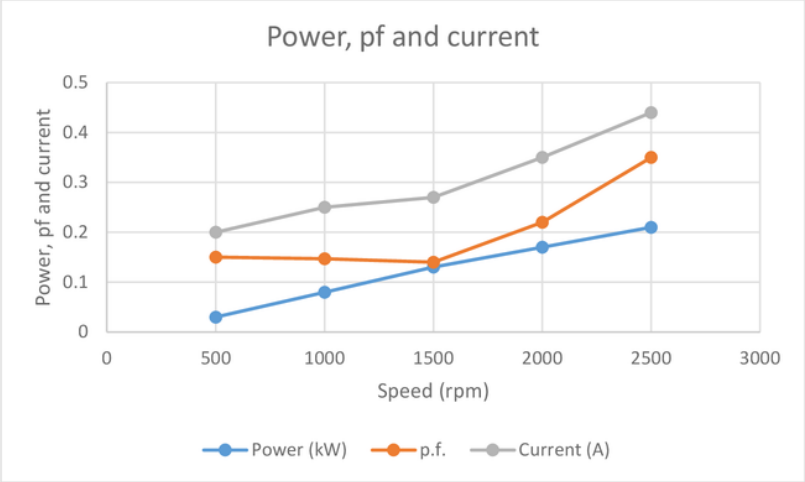


Figure 16 – S120 Speed vs Power, PF and Current

6. Evaluation

The original FDS stated four operable HMI screens and a working webserver. (Williams, 2019).

Two operable screens which demonstrate four quadrant operation of both drives in manual and automatic mode have been tested with success.

Configuration of the Webserver was accessed via the PLC properties. A www block was added to main along with a local temporary word called #web return value.

Upon correct creation when the IP address is searched on-line the page appears for the PLC and it can be controlled remotely from the web.

When used as a data logger and error occurred on the PLC unless the file was immediately closed upon completion, thus, further investigation and programming is required to run this data logger smoothly without causing the PLC to stall. This major improvement should be implemented as soon as possible to allow for ease of access to data and graphical analysis that the students will need for their studies.

In the software the ability to switch the DCM drive from speed to torque regulation is needed. When in torque control only the current controller is used feeding in a current reference signal and the load determines the speed. In this mode and without a load acceleration is rapid because V will be greater than E to maintain the set current (V=E-IaRa) speed will reach a level above full speed and the converter output will be a maximum making the set current unobtainable and thus, in theory, settle the speed.

Well-tuned PI speed controllers should achieve zero steady state error and a damped response, this is easier to achieve in a regenerative drive with negative current being supplied should the speed overshoot the demand. The drive has circuitry to detect a loss of tacho feedback and will revert to voltage feedback.

One of the desired HMI screens was to show how speed range can be extended using field weakening. When below rated speed field current is kept at maximum but above rated speed field current reduction and armature voltage are controlled so that at maximum armature voltage a safe minimum level of field current is reached.

Unfortunately, the drive configuration has limits preventing certain operations and as such the field weakening demonstration was unachievable in the allotted time, although during the design stage, research and theory led to understanding how to achieve this mode of operation the complexity of the drive programming was not unravelled and further training is

required. This was also the case for the inverter drive and its programmed maximum speed limit was not exceeded in the scope of this project.

Overall the project was delivered on time and in budget. There are aspects of the original FDS that were not met, and a plan is in place to complete the rest.

7. Conclusions and Recommendations

In conclusion approximately 50% of the original FDS has been achieved and satisfactory test results confirm this. The 4 quadrant sequence currently changes from +5Nm to -5Nm and this causes a transient spike, this would be reduced by an intermediate torque value of 0Nm for a brief period of say 2 seconds.

Recommendation for further work:

The two-non-functioning screens will require further development including some specialist drive training allowing for configuration changes to be controlled via the PLC, e.g. ability to toggle between speed and torque regulation for the DCM, ability to engage open loop control and re-configuration of the telegrams. This work will lead to a host of other experiments and allow for greater scope in demonstrating motor operation and drive characteristics.

Safety limits and safeguards preventing misuse will need to be added to the program e.g. ***CAUTION!*** **It is important that when in Torque mode the DC drive is on and will have a speed set point to hold the torque. If the DC drive is off the AC drive will try to reach torque set point under no load and the motor will run away!**

This is an important safety addition and one which should be priority before allowing students to use the rig.

As an extra safeguard a mechanical device called a torque limiting coupling could be installed, which uses pre-set adjustment of two friction plates via a centrally located threaded hub and will slip at a desired maximum torque level, say 10Nm. When the torque reduces below the threshold the coupling re-engages drive to the shaft without backlash. (JBJ Techniques Ltd, 2017)

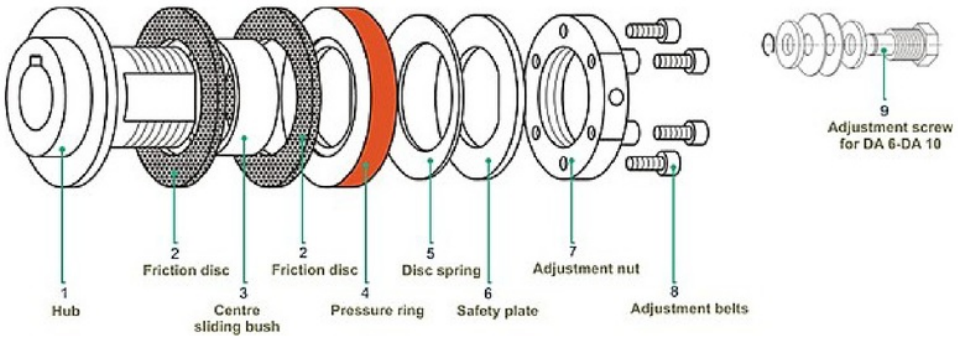


Figure 17 - Torque limiting coupling

A local supplier for this type of coupling has been sourced and a price estimate received of £230.00

Both drives have available a Basic Operator Panel 20 (BOP20) which allows powering the drive, display and modification of parameters and fault acknowledgement and diagnosis. The relevant materials and processes needed to systematically understand and apply the BOP are accessible via the drive operating instruction manual, section 9 of a 758 page document. The focus of the project however was to simply apply basic operating modes and read the resulting parameters for analysis. Re-configuration of both drives is a recommended future development and the BOP20 could be mounted in the door of the panel to allow students the access level to change parameters. Certain safety constraints and safeguards would be needed to prevent accidental misuse.

Further investigation into the motor parameters such as Ra, La, J and b would allow for accurate modelling using matlab where transient response and tuning could be developed for control systems theory. Parameters such as proportional and intergral gain constants are available to be read from and written to the drives thus allowing the matlab model to be trialled experimentally on the rig. Appendix J details the changes applied to the original matlab model from assignment 1 and how access to motor parameters are made available in the model and the graphical results that can be obtained.

The scope for this rig covers many more aspects, not only in motor and drive theory, but also in control systems, networking and communication, IT and mechanical engineering modules which UWTSD CSG students will benfit from in the near future.

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9. Appendix List

Appendix A – Final electrical drawings – modified

Appendix B – HMI root screen

Appendix C – HMI application screens

C.1 AC 4 quad

C.2 DC 4 quad

C.3 Parameters

C.4 DC Field Weakening

C.5 AC Inverter

Appendix D – Final code

D.1 Main [OB1]

D.2 LW Controls [FC3]

D.3 Parameters [FC1]

D.4 LW Get AC Drive Parameters [FB4]

D.5 LW Get DC Drive Parameters [FB5]

D.6 Drive Comms [DB5]

D.7 LW 4 QUAD [DB16]

D.8 LW DCM Drive Data [DB15]

D.9 LW S120 AC Drive Data [DB14]

D.10 Parameters_DB [DB4]

D.11 Main_Safety_RTG1 [FB1]

Appendix E – Final Code explanation

Appendix F – Excel Test Results

F.1 DCM 4 quadrant

F.2 S120 4 Quadrant

F.3 DCM No load

F.4 S120 No load

Appendix G – Microsoft Project Plan – Gannt chart

Appendix H – Costs spreadsheet

Appendix I – Risk Assessment

I.1 CE Risk Report

I.2 CSG Risk Assessment

Appendix J – Matlab Modelling

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Trafford Park
Manchester
M17 1GB

T +44(0) 800 084 2224
F +44(0) 161 873 7223
Email:
info@techniqueservices.com
www.techniqueservices.com

Company / customer	Coleg Sirgar
Project description	AC/DC Test Rig
Job number	507610
Commission	Technique Services
Manufacturer (company)	Technique Services
Path	GoogleDrive/Computers/My Laptop/Eplan
Project name	507610 Coleg Sirgar AC_DC Test Rig

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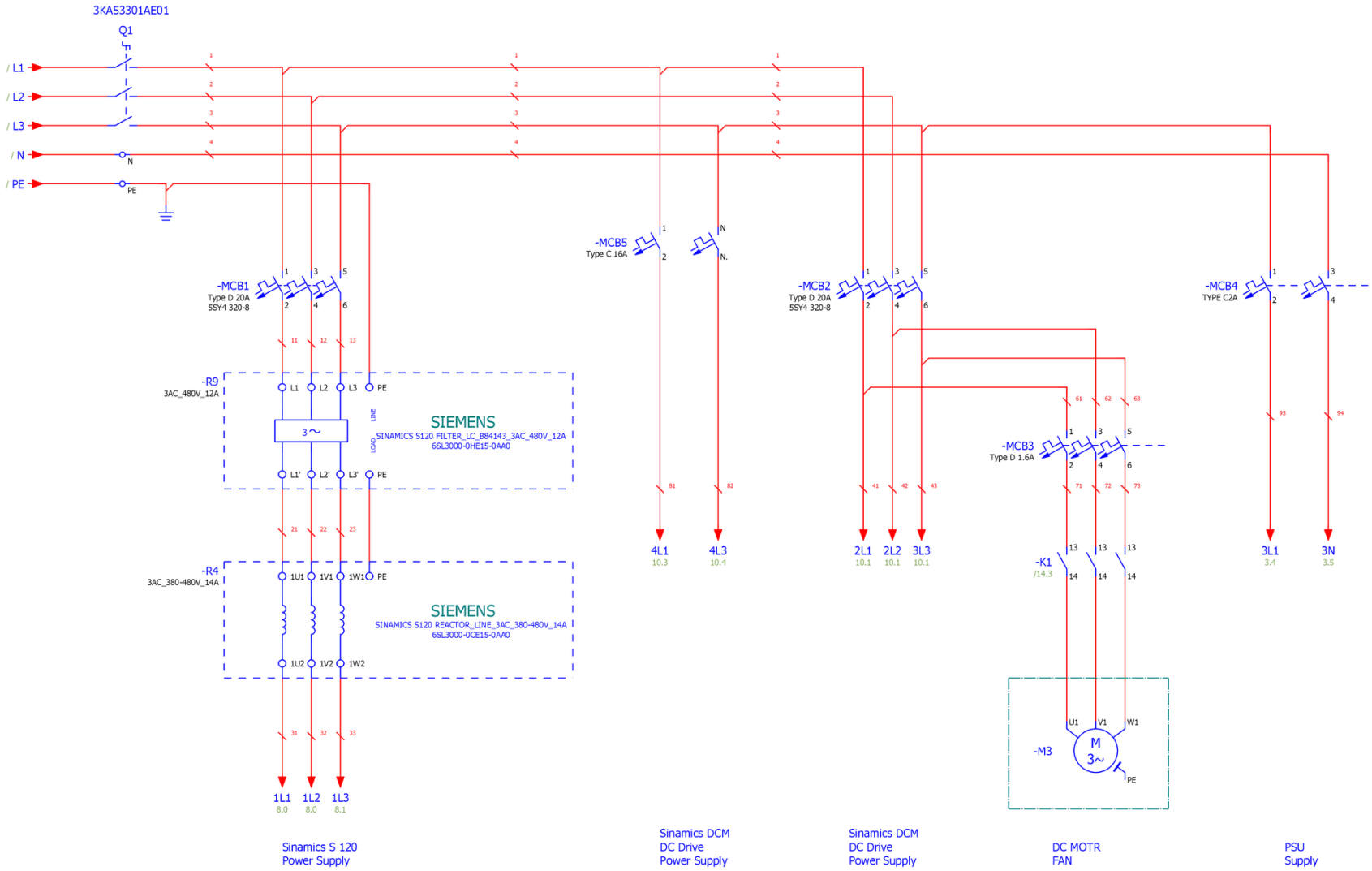
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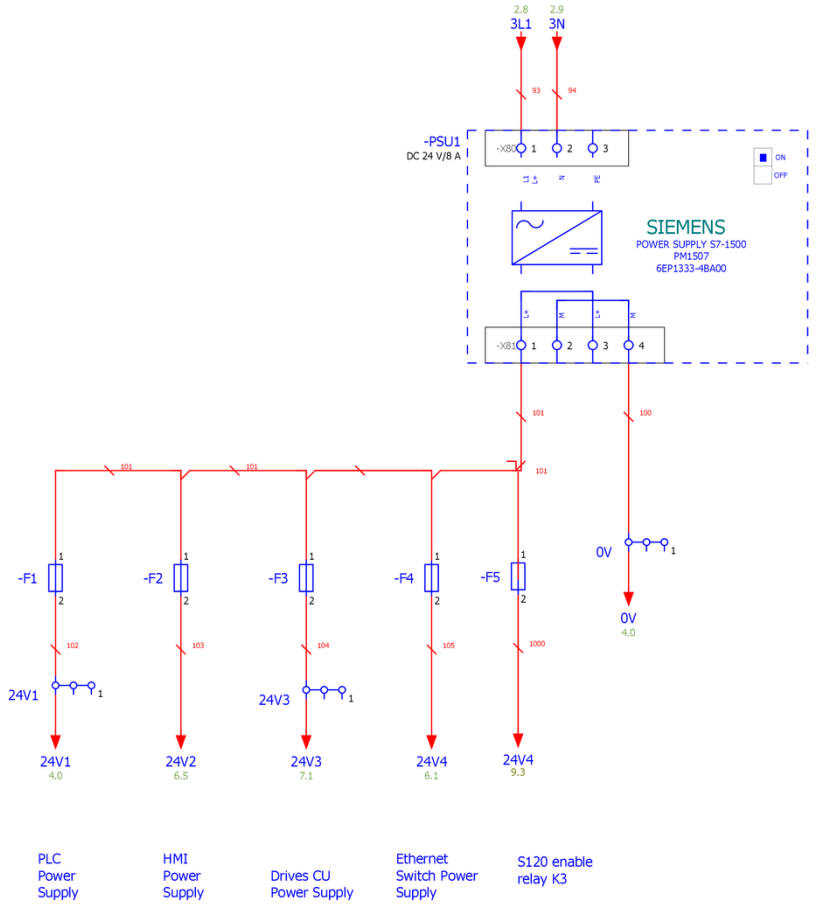
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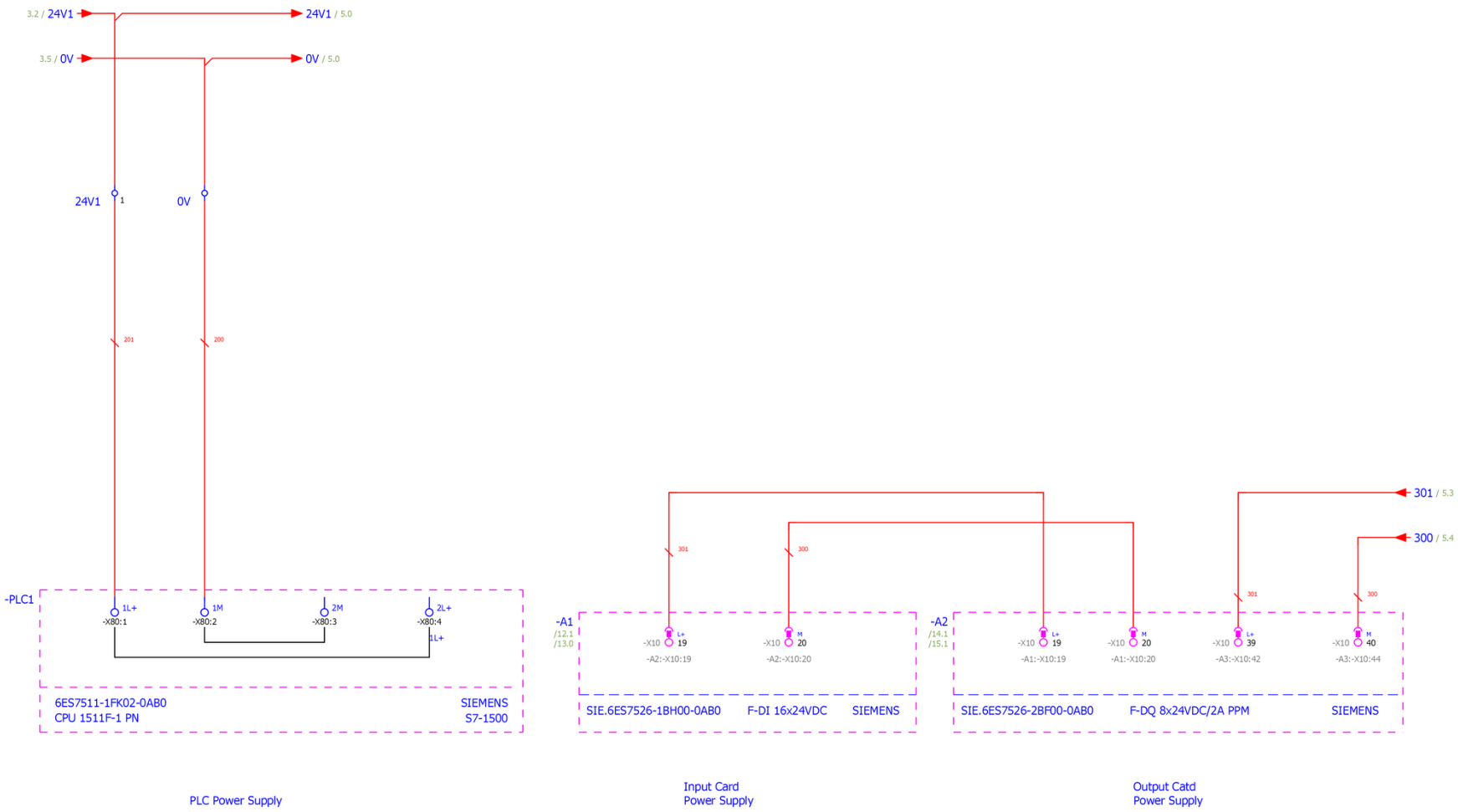
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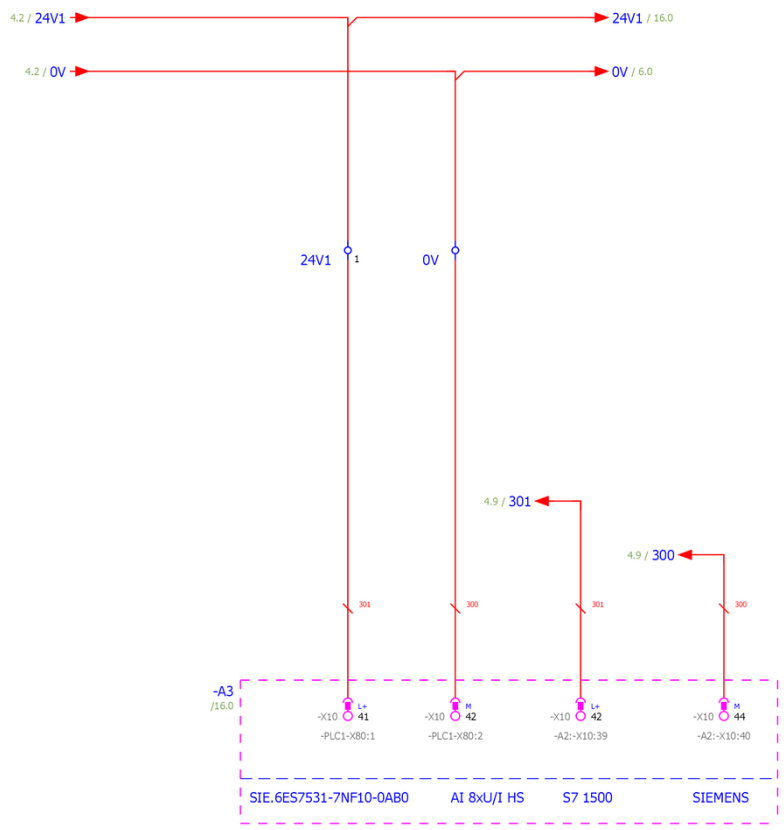
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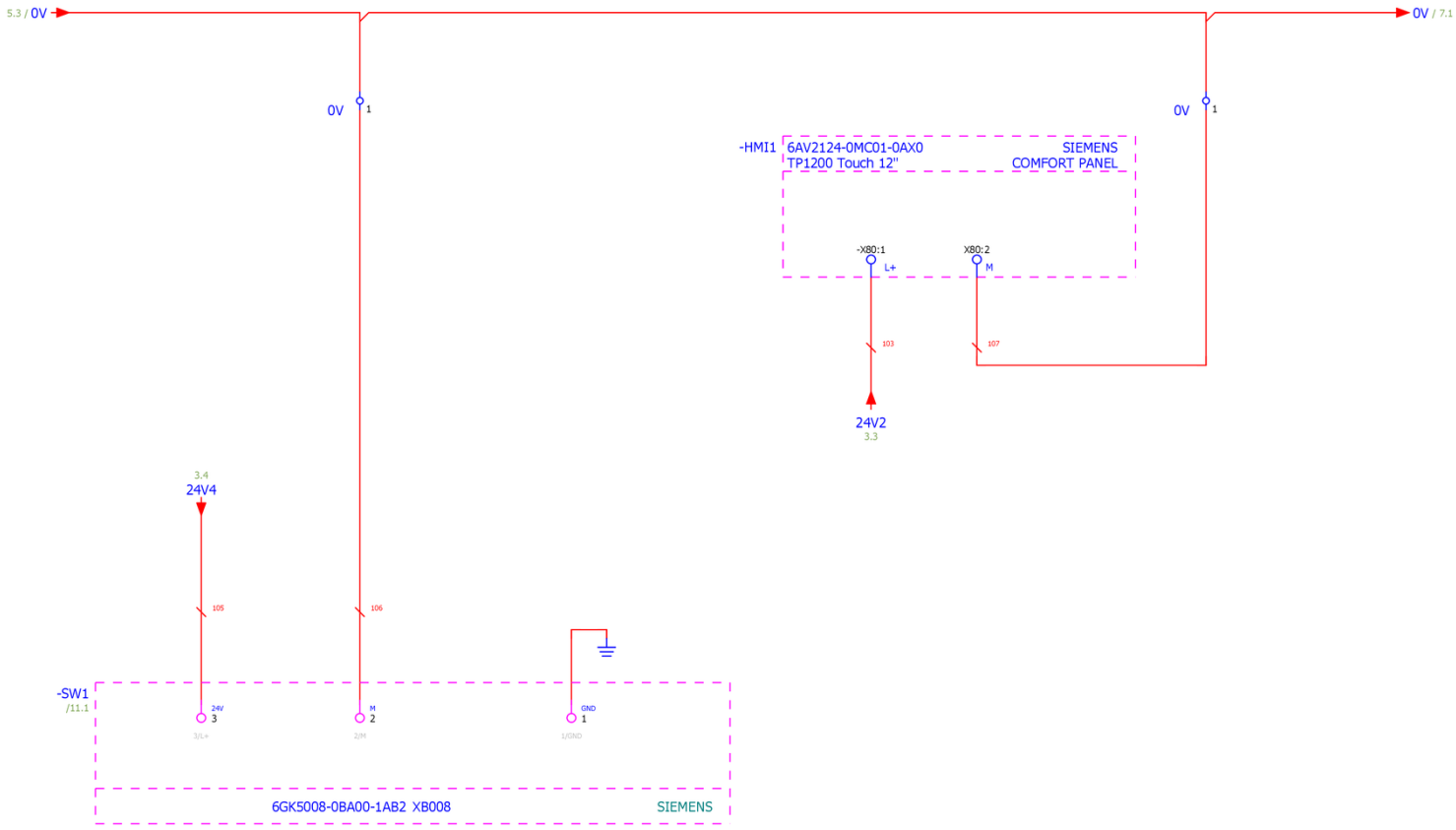
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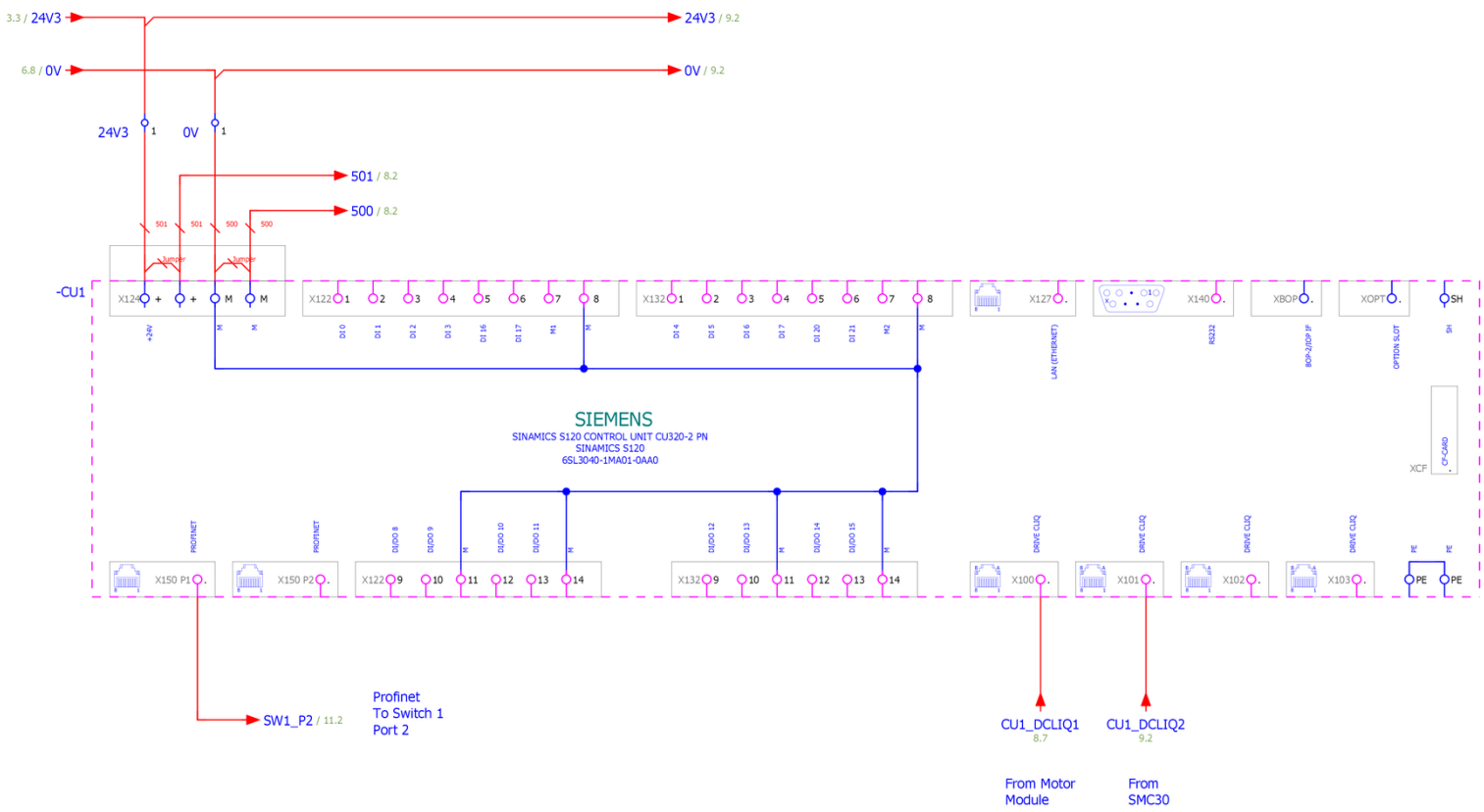
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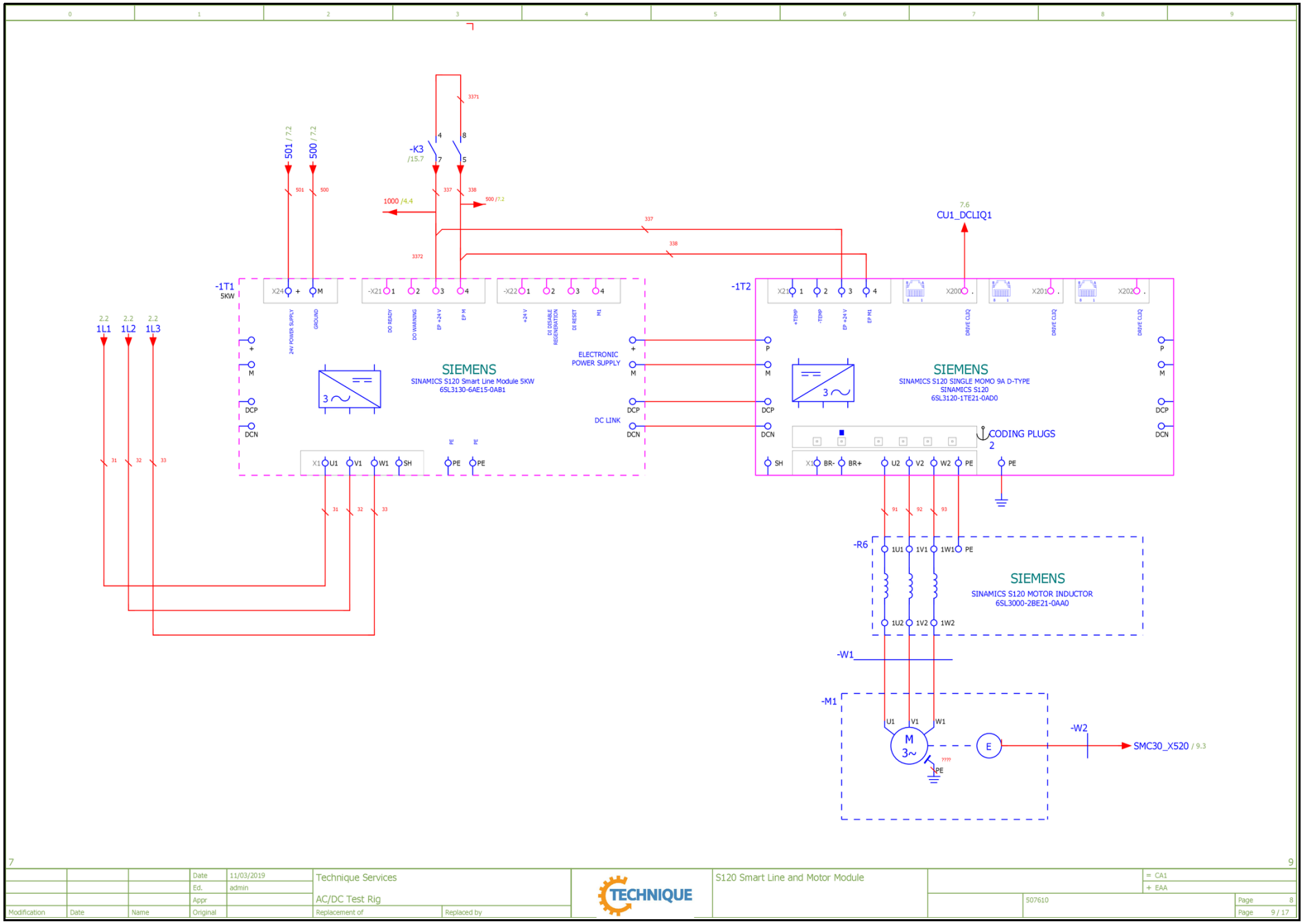
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Modification	Date	Name	Original		Replacement of	Replaced by			Page 6 / 17



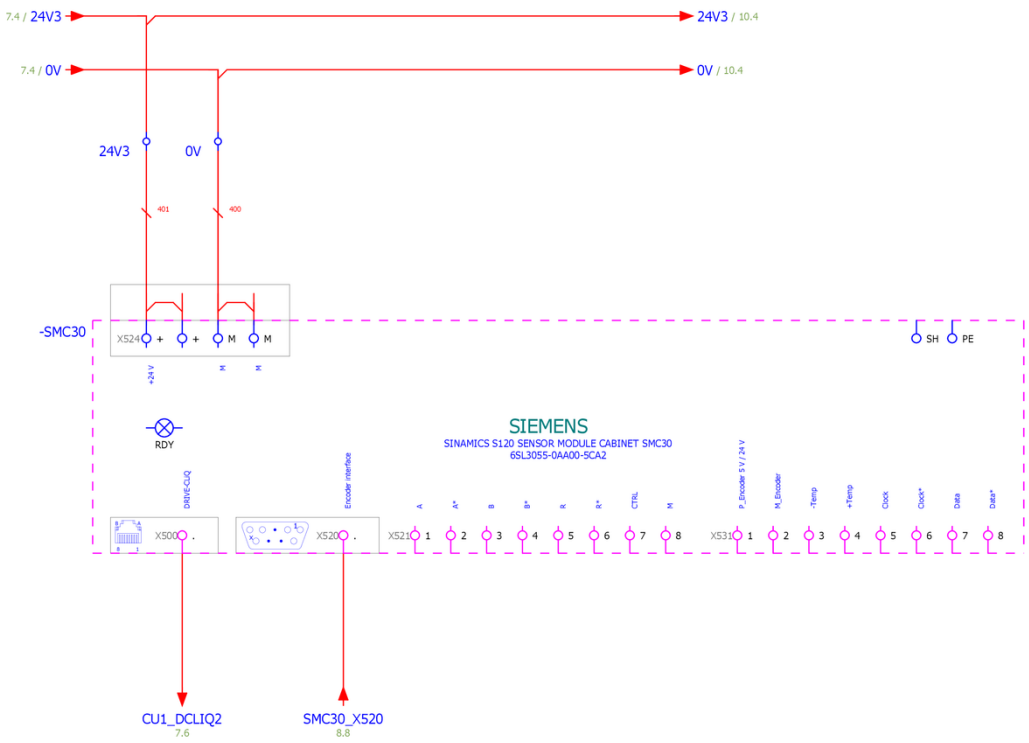
			Date	19/02/2019	Technique Services		Power Supply	= CA1	
			Ed.	admin				+ EAA	
			Appr		AC/DC Test Rig			507610	Page 6
Modification	Date	Name	Original		Replacement of	Replaced by			Page 7 / 17



			Date	11/03/2019	Technique Services		S120-Control Unit CU320-2PN	= CA1	
			Ed.	admin				+ EAA	
			Appr		AC/DC Test Rig			507610	Page 7
Modification	Date	Name	Original		Replacement of	Replaced by			Page 8 / 17

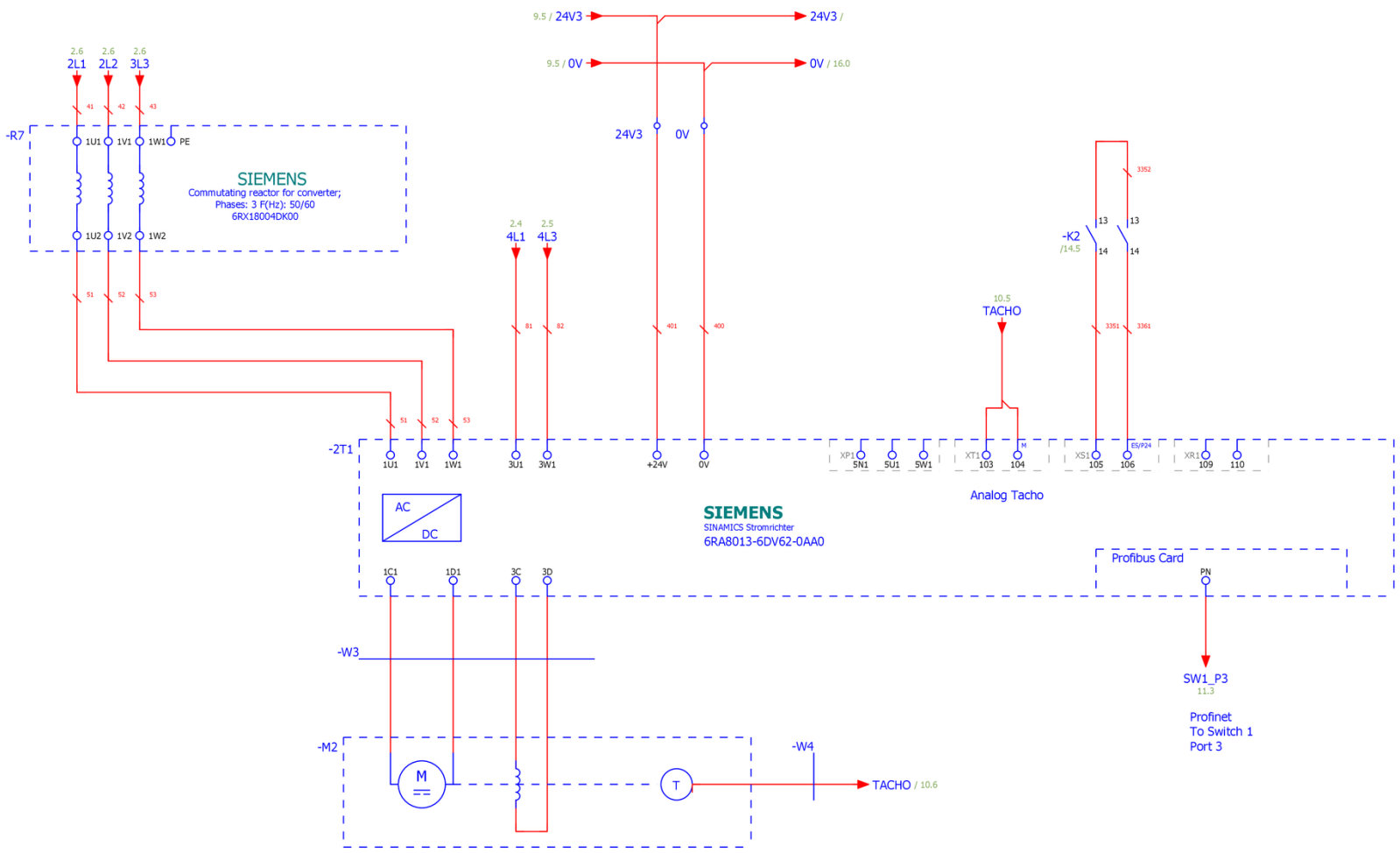


			Date	11/03/2019	Technique Services		S120 Smart Line and Motor Module	= CA1	
			Ed.	admin	AC/DC Test Rig			+ EAA	
			Appr					507610	Page 8
Modification	Date	Name	Original		Replacement of	Replaced by			Page 9 / 17



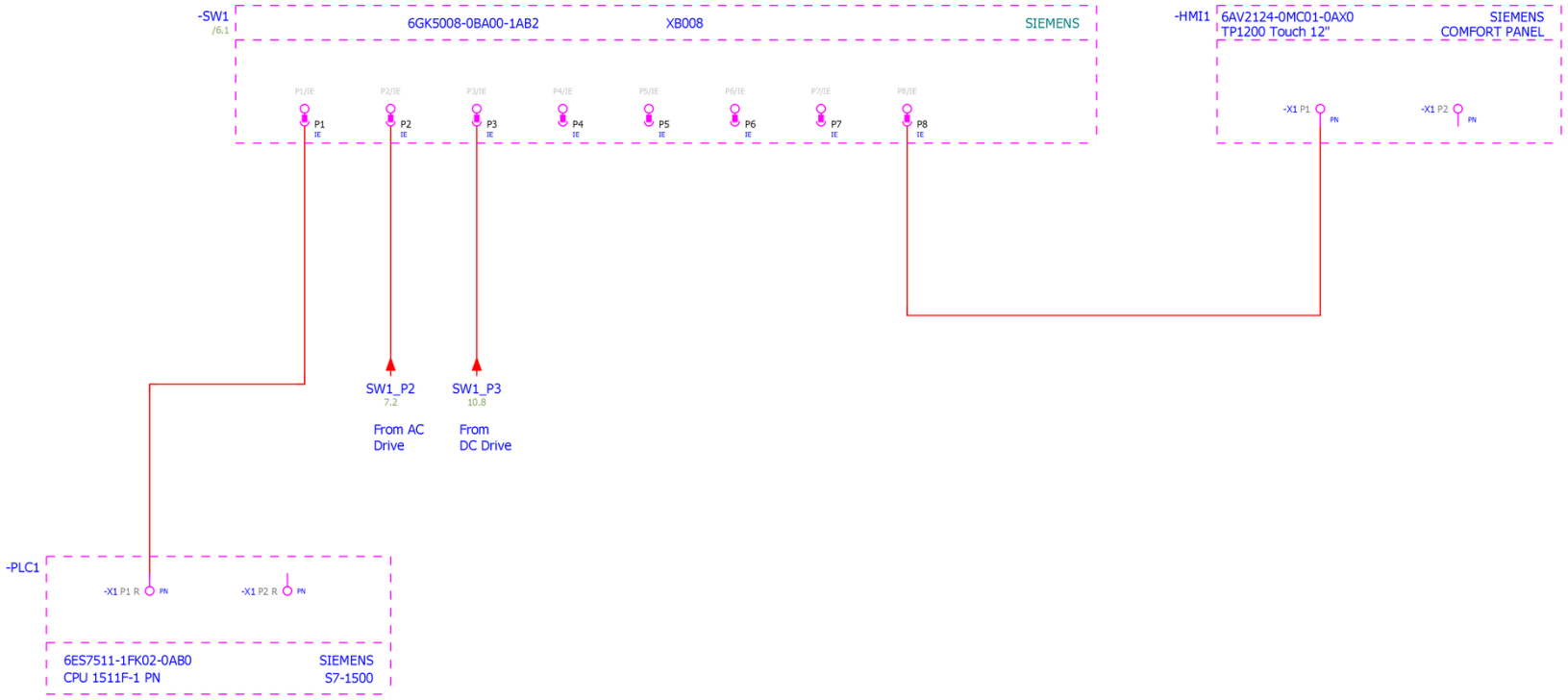
8 10

			Date	11/03/2019	Technique Services		SMC 30	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 9
Modification	Date	Name	Original		Replacement of	Replaced by		Page 10 / 17



9 11

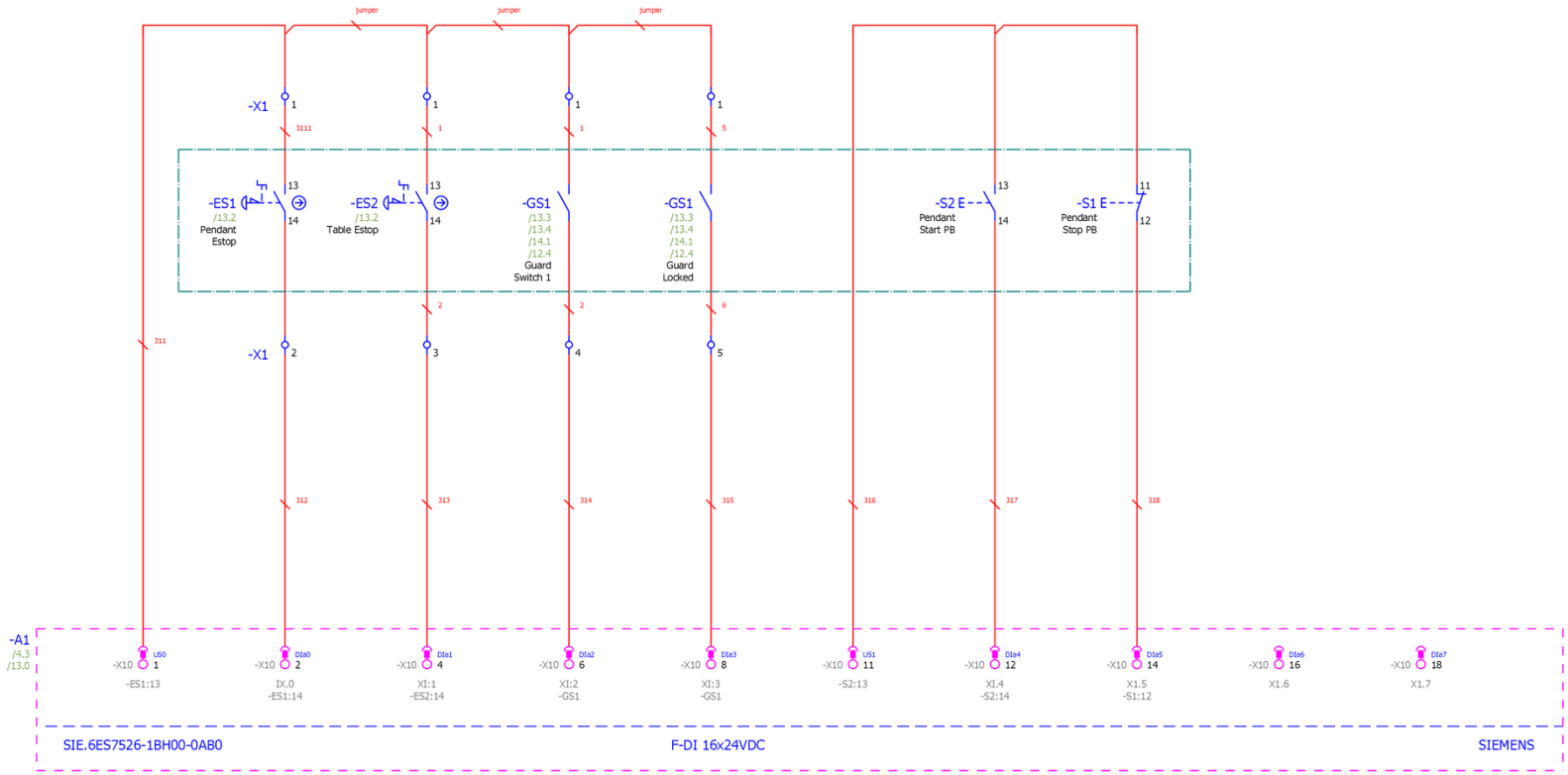
			Date	11/03/2019	Technique Services		DCM DC Drive	= CA1	
			Ed.	admin				+ EAA	
			Appr		AC/DC Test Rig			507610	Page 10
Modification	Date	Name	Original		Replacement of	Replaced by			Page 11 / 17



10

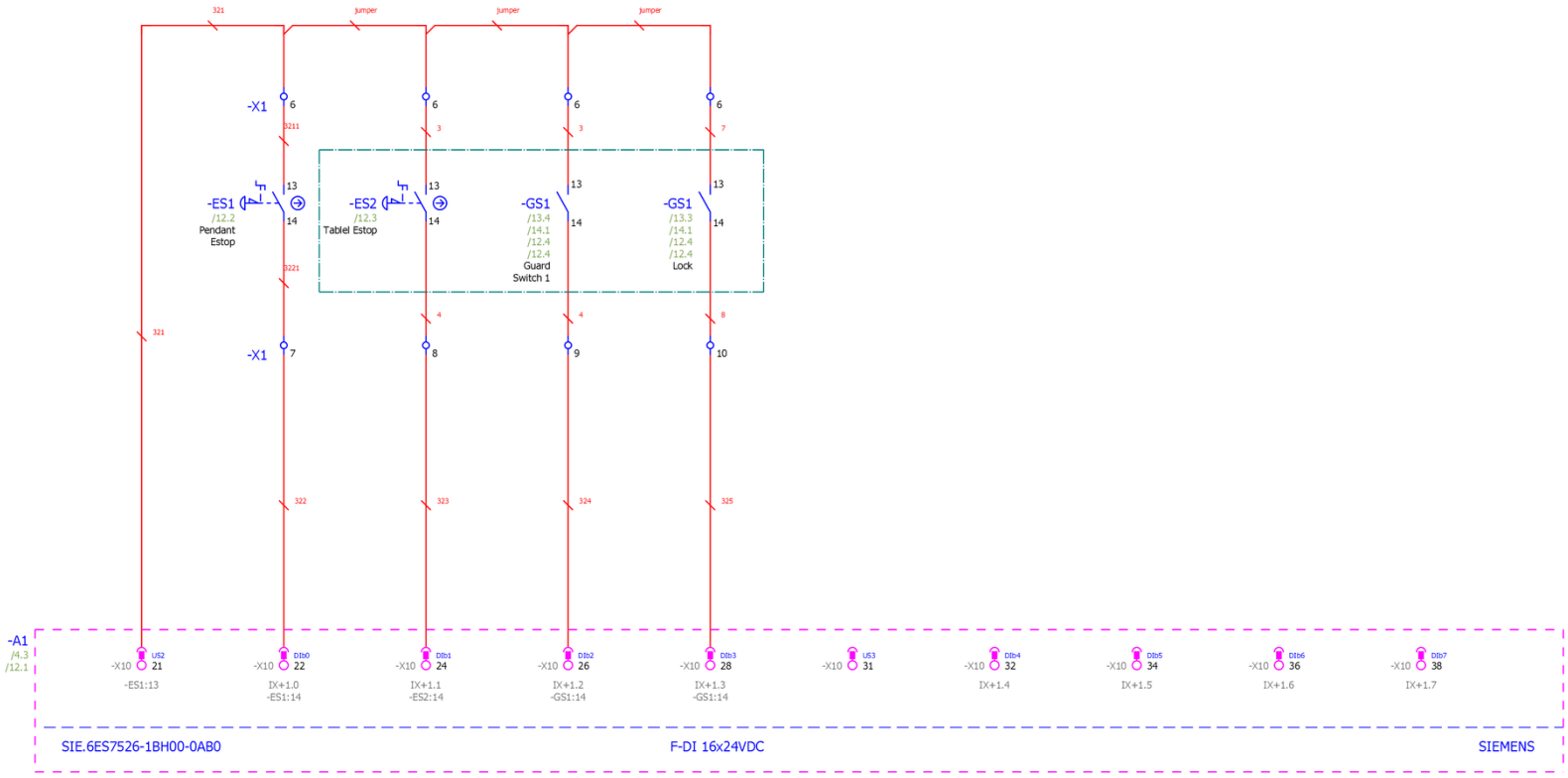
12

			Date	01/03/2019	Technique Services		Profinet	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 11
Modification	Date	Name	Original		Replacement of	Replaced by		Page 12 / 17

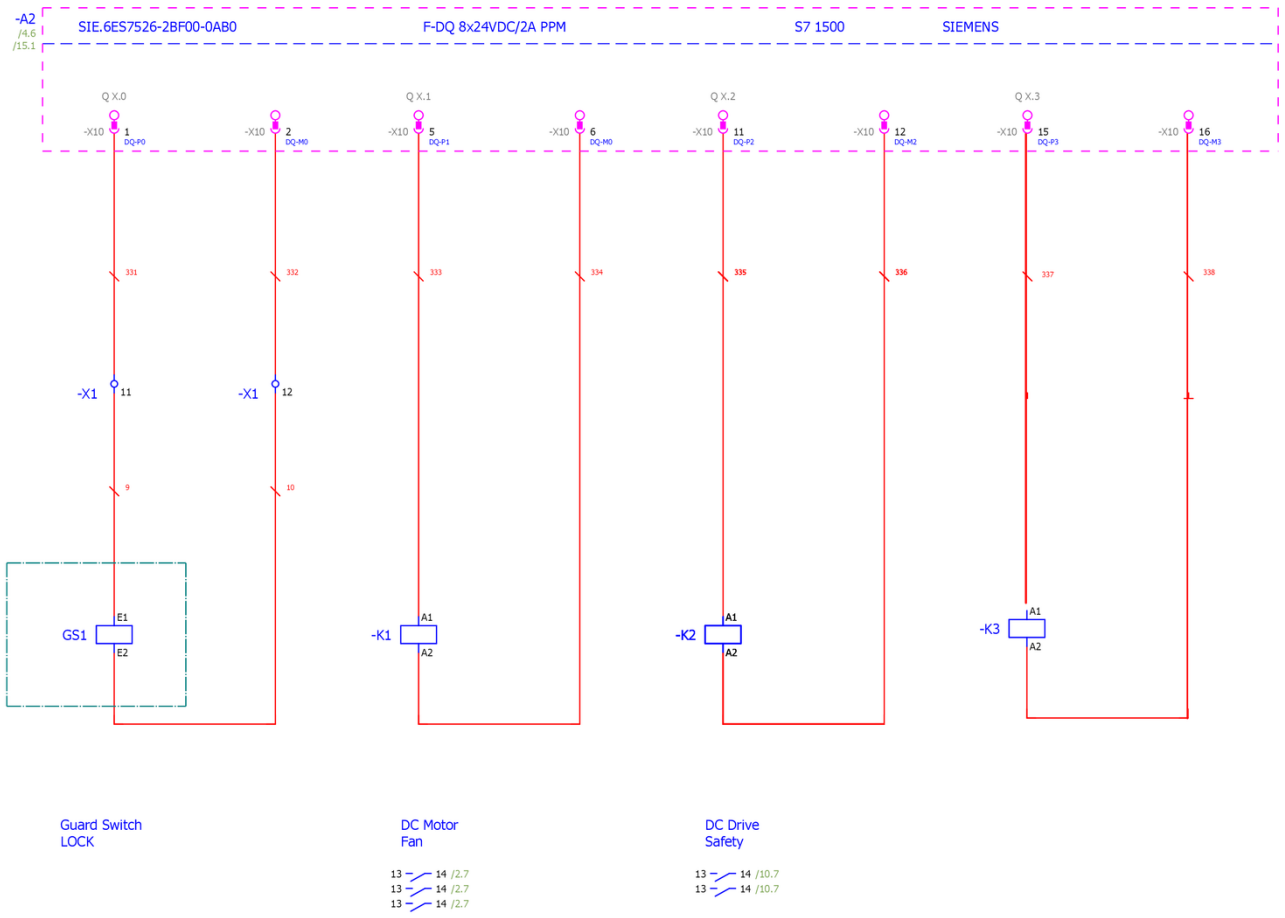


11 13

			Date	01/03/2019	Technique Services		F-DI 16x24VDC	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 12
Modification	Date	Name	Original		Replacement of	Replaced by		Page 13 / 17



			Date	01/03/2019	Technique Services		F-DI 16x24VDC	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 13
Modification	Date	Name	Original		Replacement of	Replaced by		Page 14 / 17



Guard Switch
LOCK

DC Motor
Fan

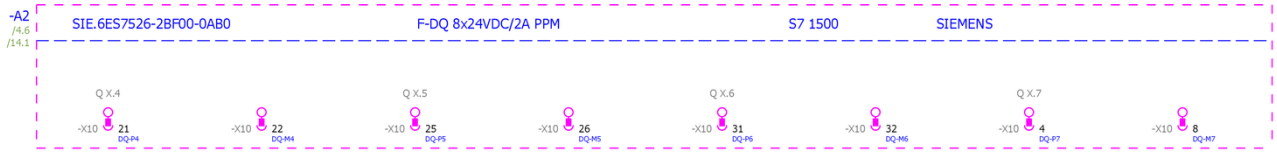
13 14 /2.7
13 14 /2.7
13 14 /2.7

DC Drive
Safety

13 14 /10.7
13 14 /10.7

13 15

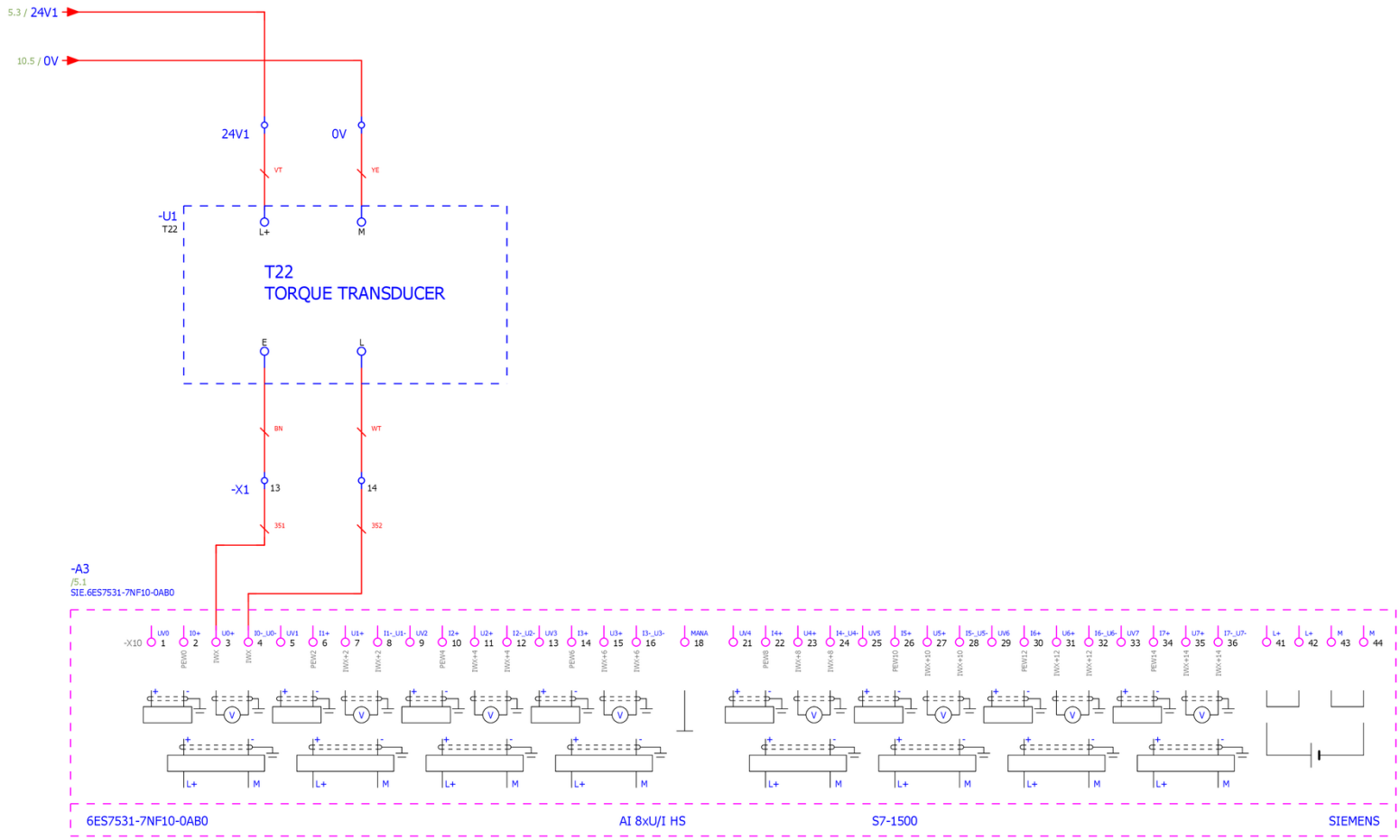
			Date	25/02/2019	Technique Services		F-DQ 8x24VDC	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 14
Modification	Date	Name	Original		Replacement of	Replaced by		Page 15 / 17



14

16

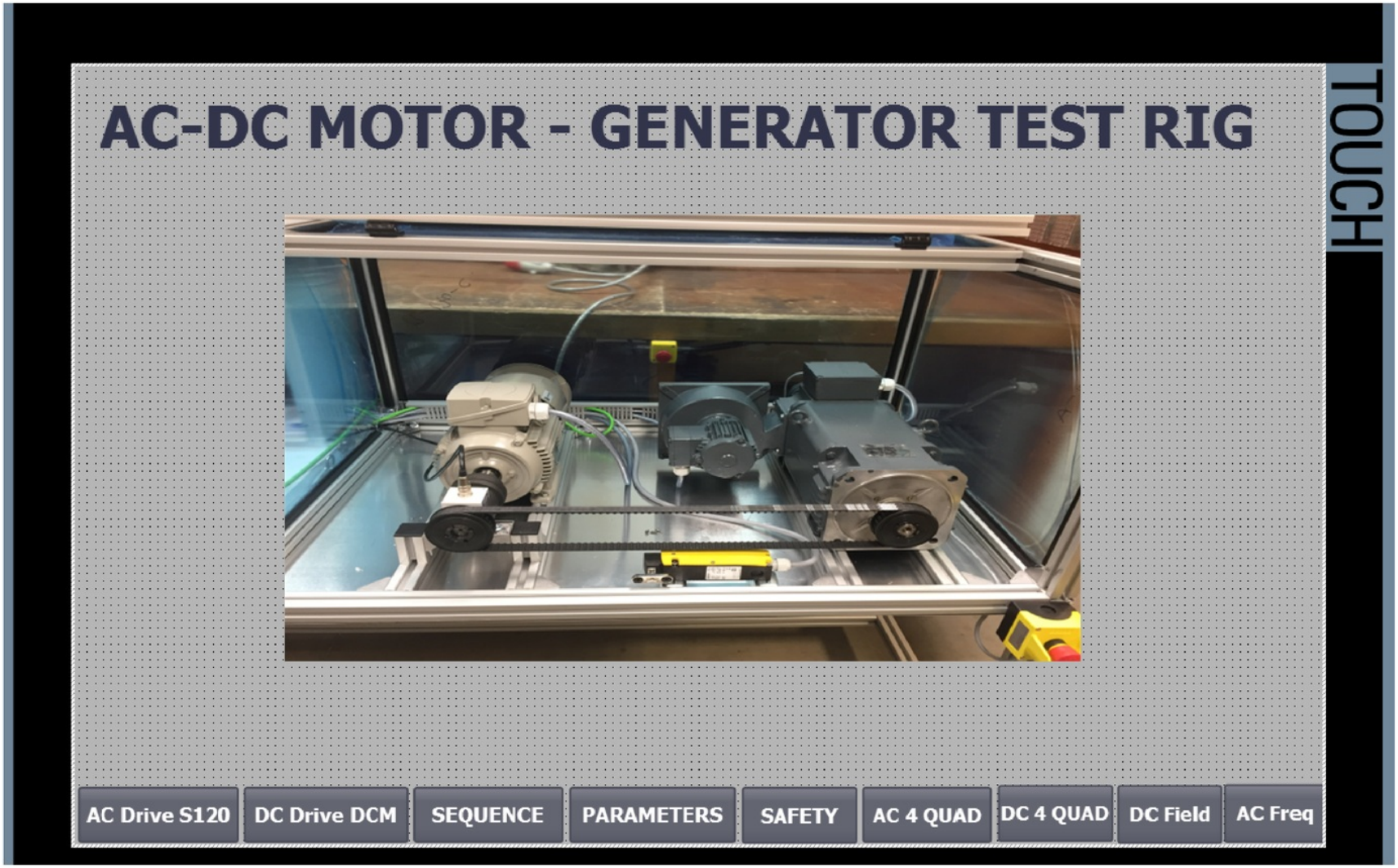
			Date	19/02/2019	Technique Services		F-DQ 8x24VDC	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 15
Modification	Date	Name	Original		Replacement of	Replaced by		Page 16 / 17



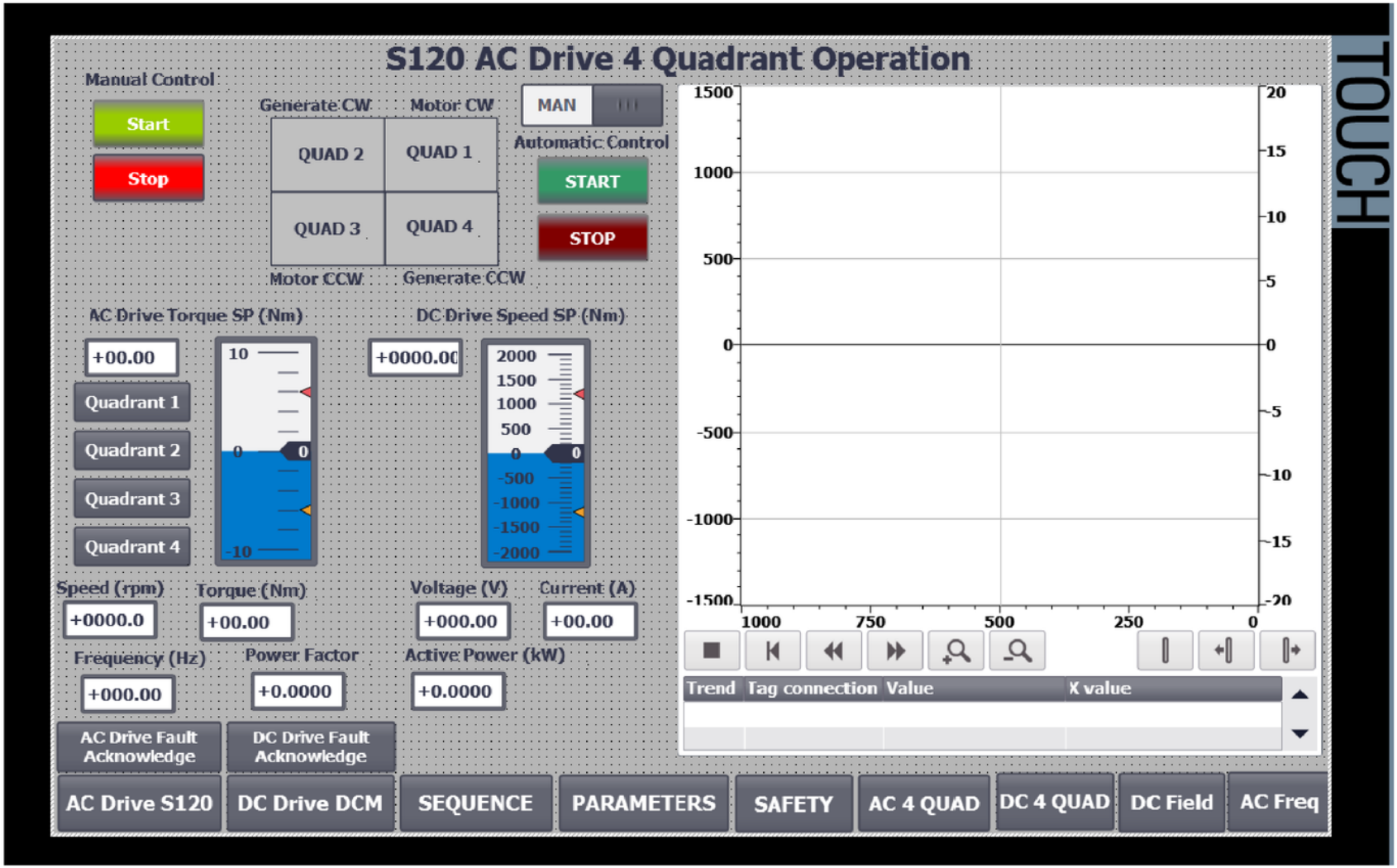
15

			Date	11/03/2019	Technique Services		AI 8xU/I HS	= CA1
			Ed.	admin				+ EAA
			Appr		AC/DC Test Rig			507610 Page 16
Modification	Date	Name	Original		Replacement of	Replaced by		Page 17 / 17

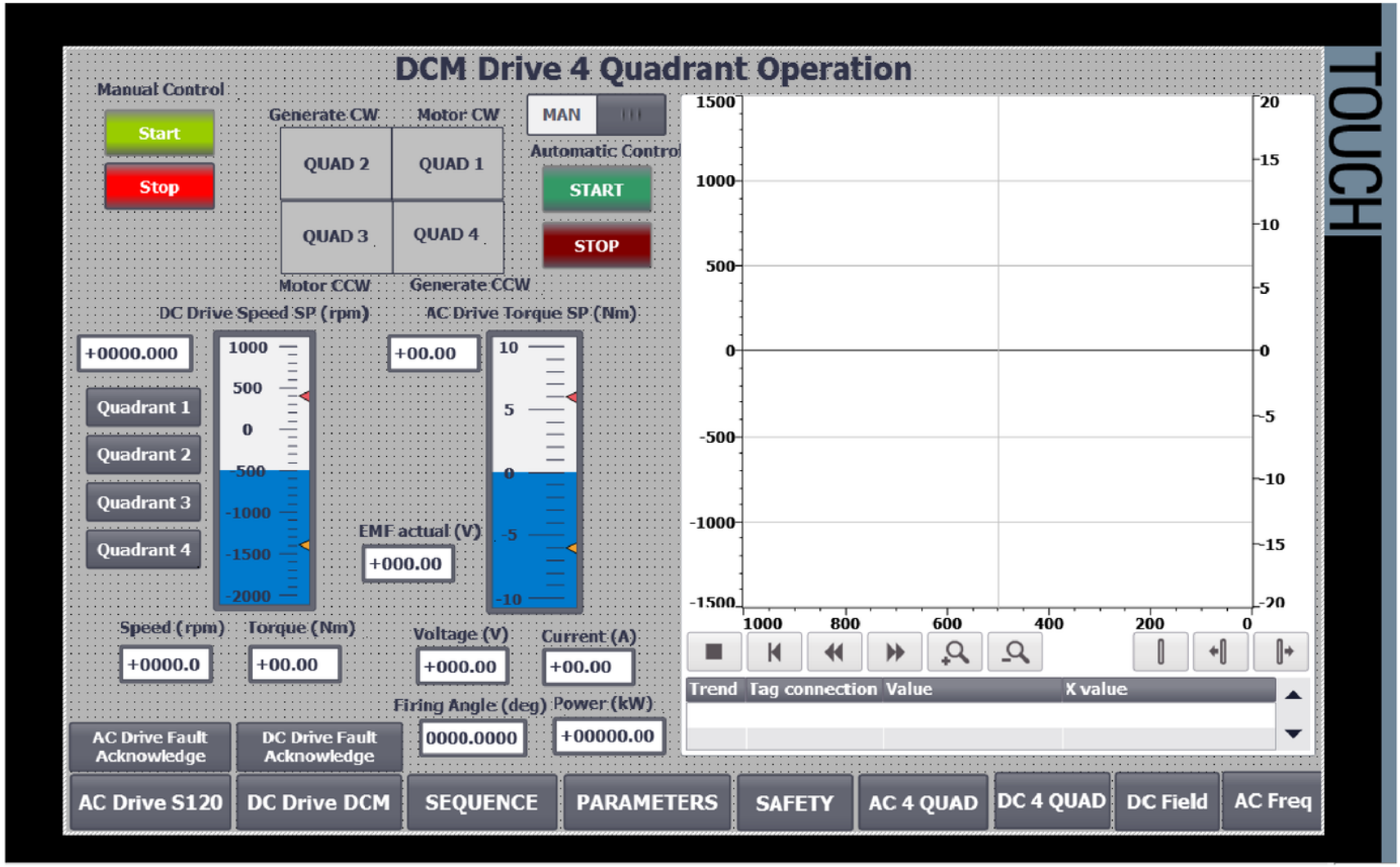
Appendix B – HMI Root Screen



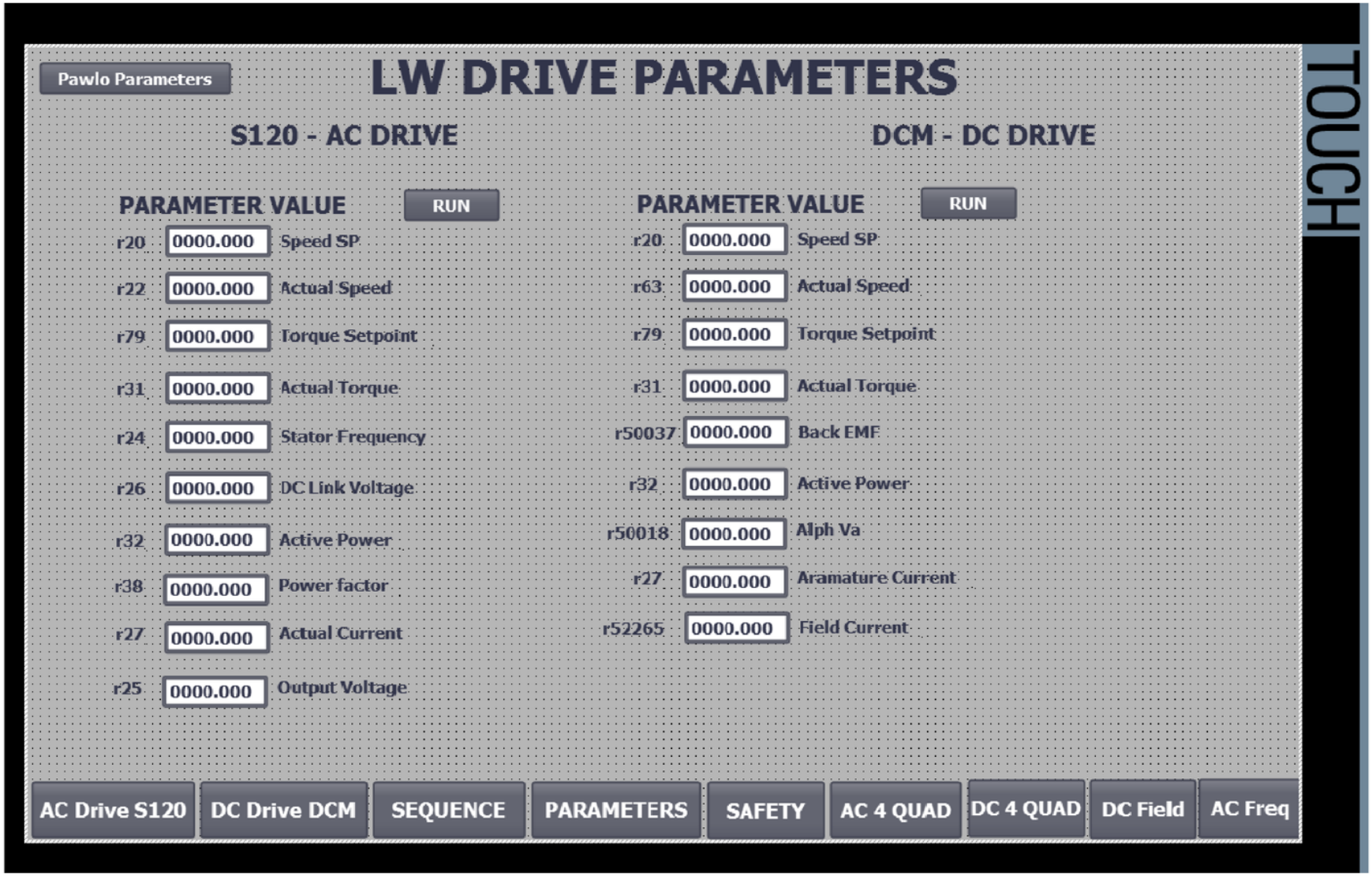
Appendix C – HMI Application Screens



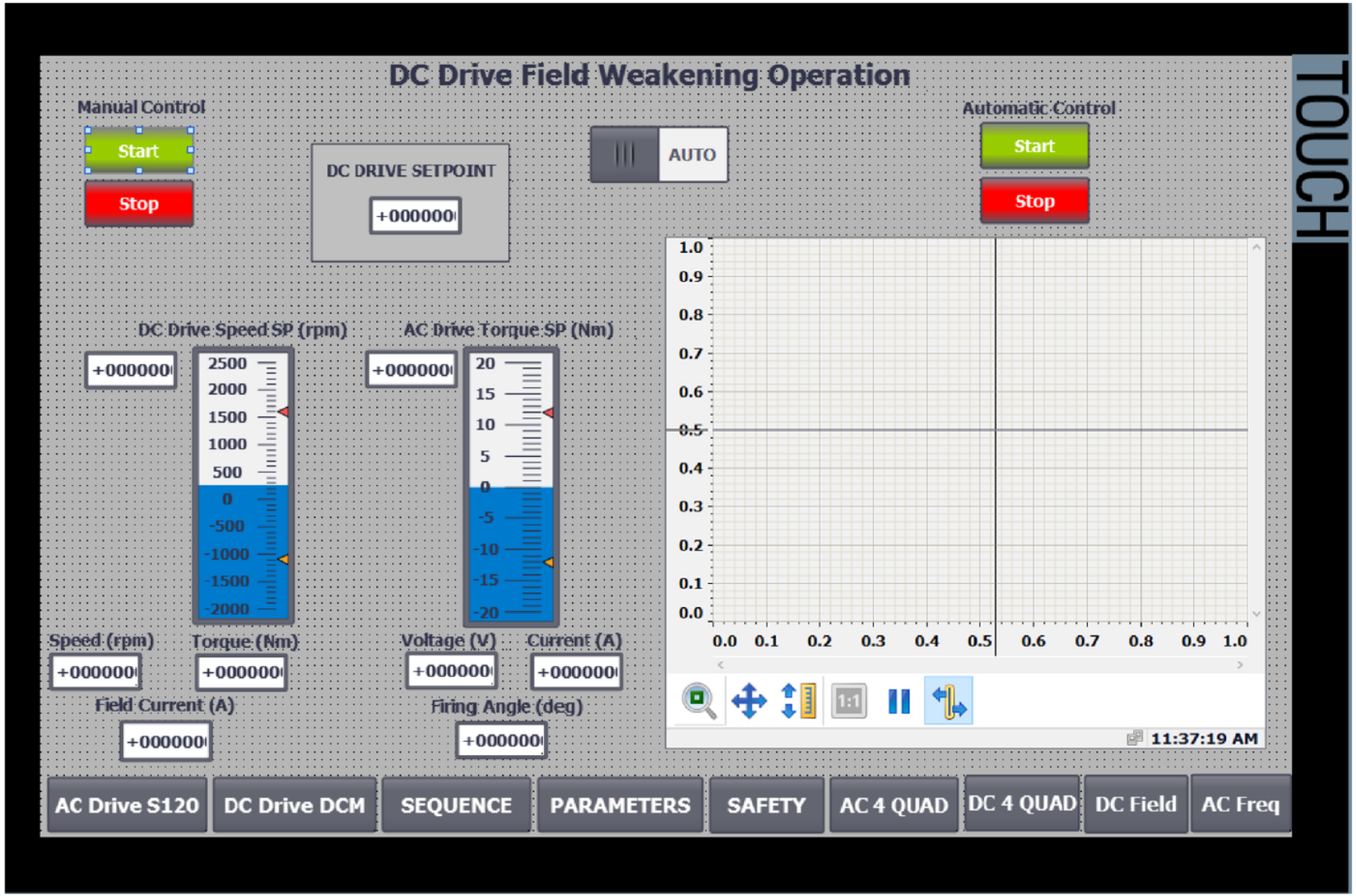
Appendix C – HMI Application Screens



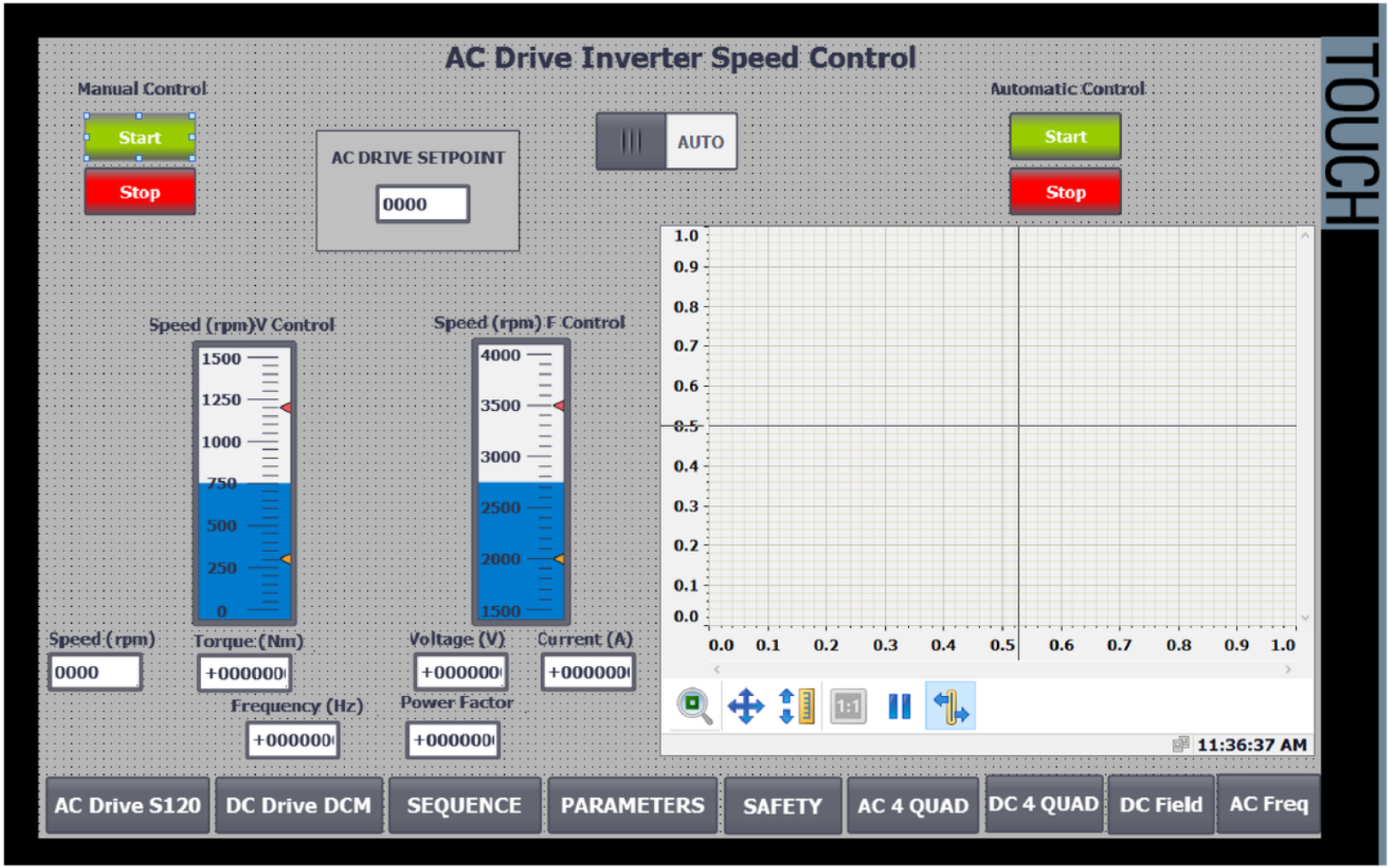
Appendix C – HMI Application Screens



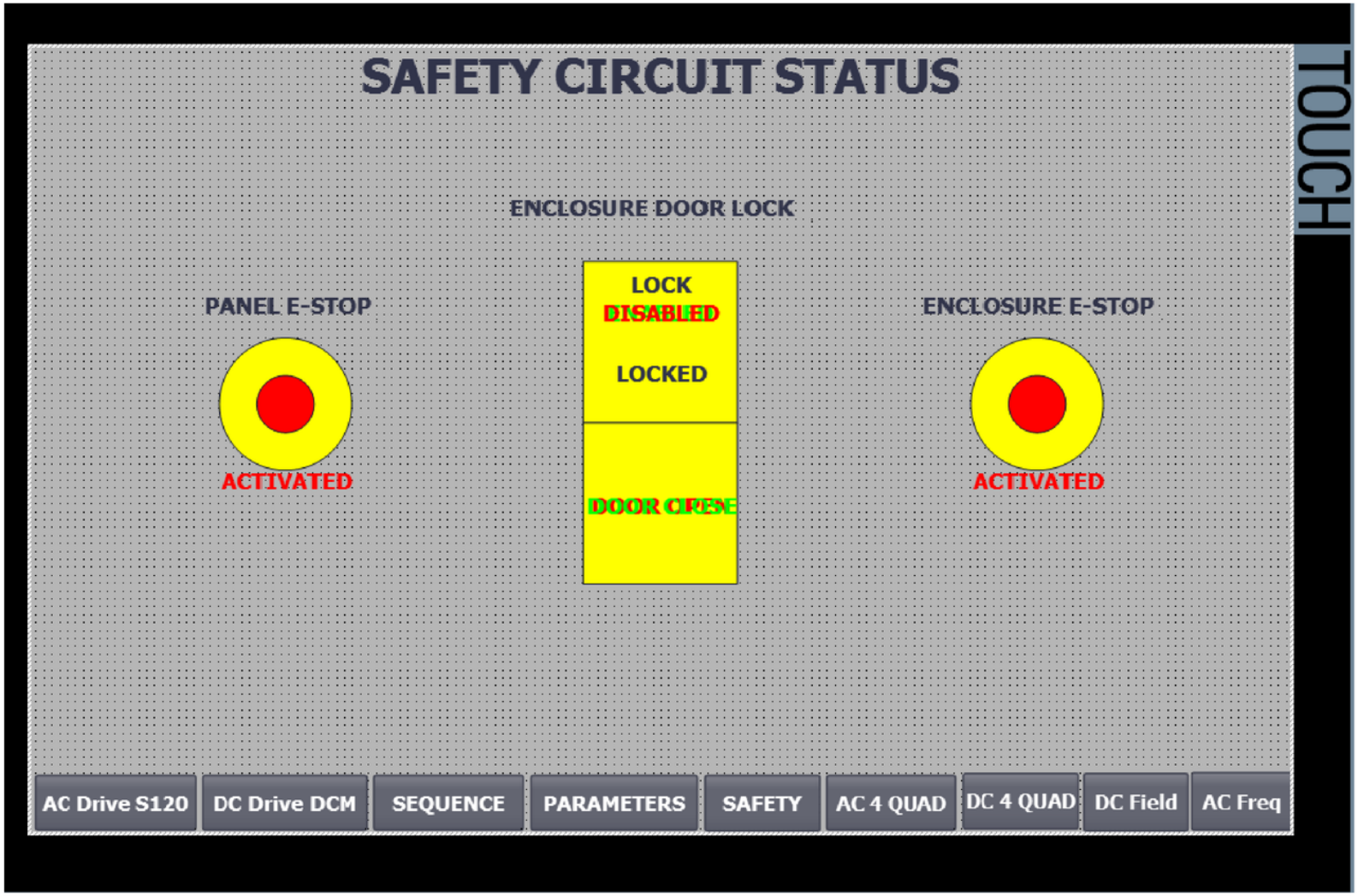
Appendix C – HMI Application Screens



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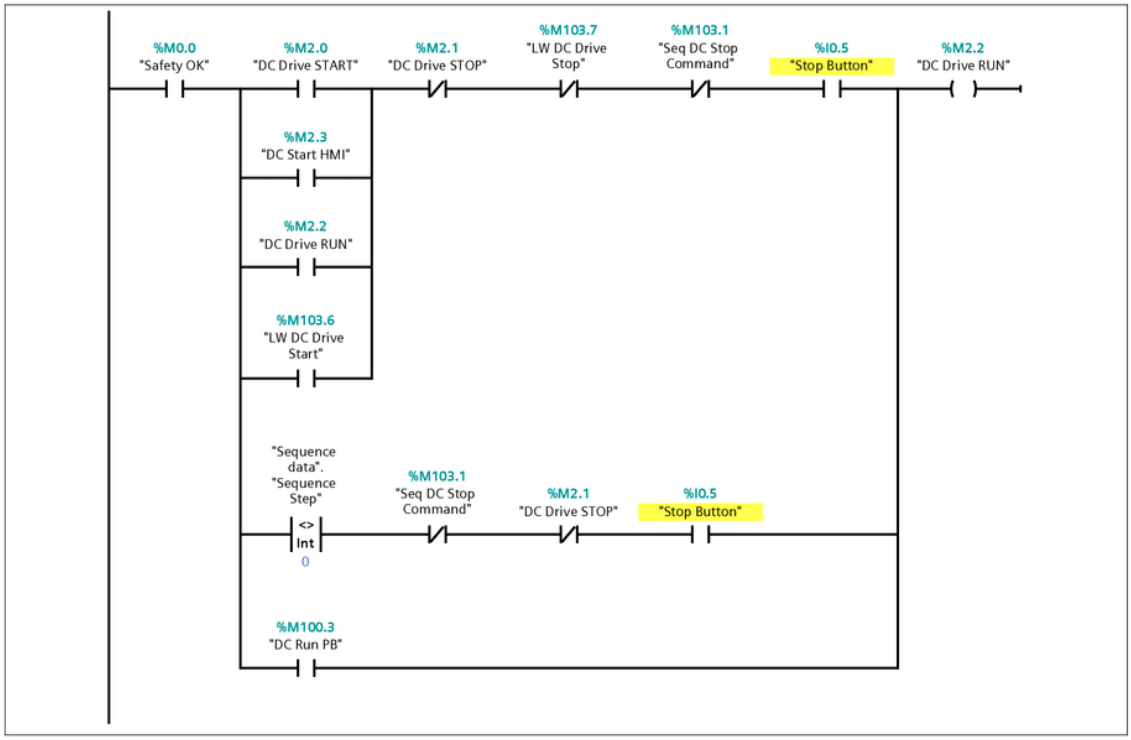
Main [OB1]

Main Properties					
General					
Name	Main	**Number**	1	**Type**	OB
Language	LAD	**Numbering**	Automatic		
Information					
Title	"Main Program Sweep (Cycle)"	**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

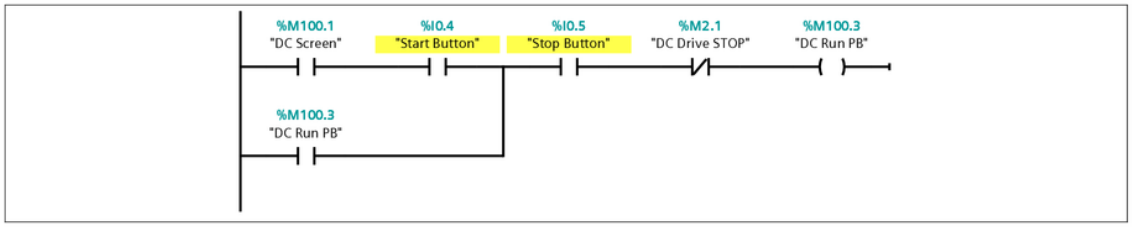
Name	Data type	Default value
▼ Input		
Initial_Call	Bool	
Remanence	Bool	
▼ Temp		
Temp_RPM	Real	
Temp_Arms	Real	
Temp_Nm	Real	
Constant		

Network 1: DC Drive Start

New controls added to start DC motor in AC 4 quadrant operation

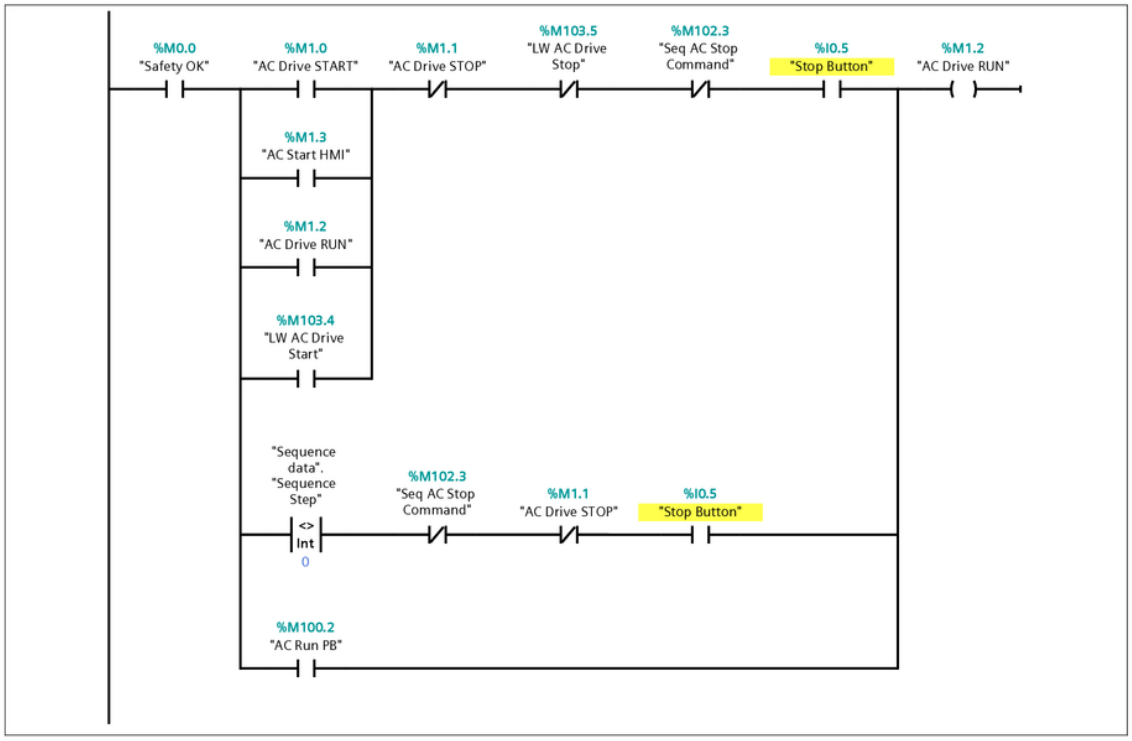


Network 2: DC PB

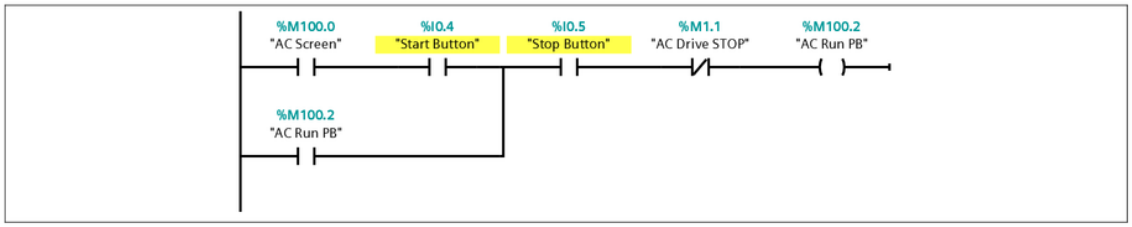


Network 3: AC Drive Start

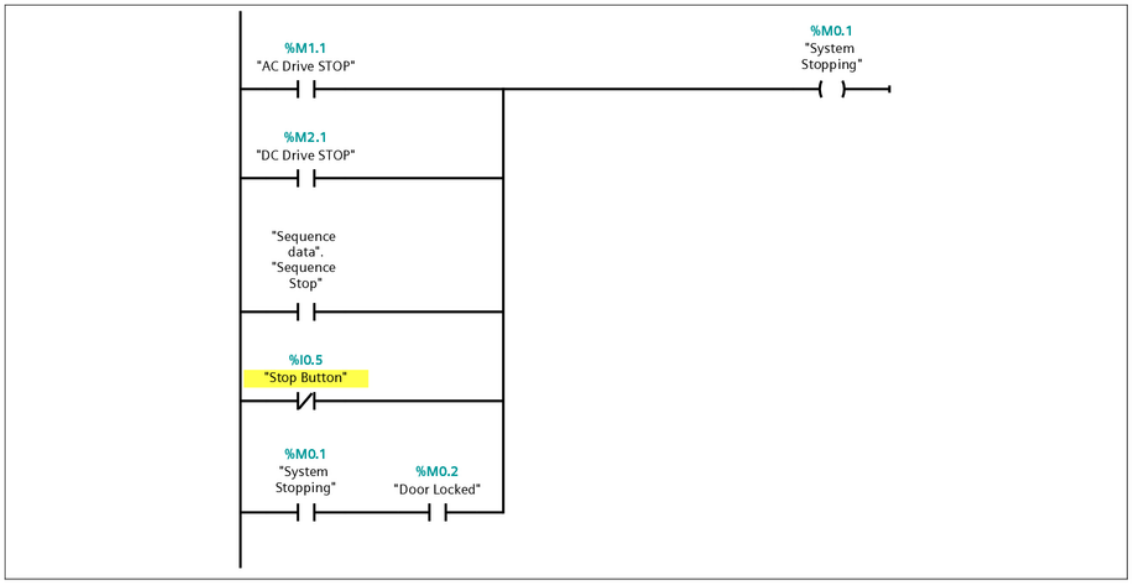
New controls added to start AC motor in AC 4 quadrant operation



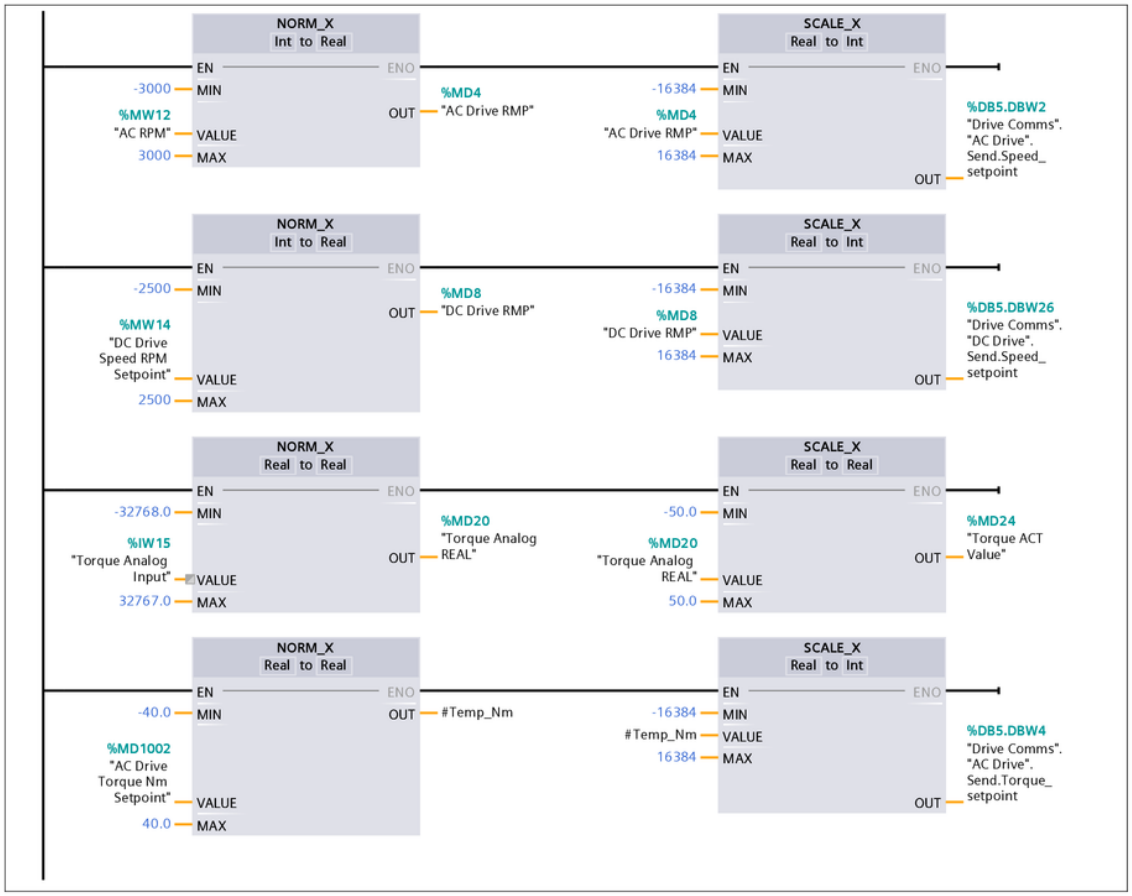
Network 4: AC PB



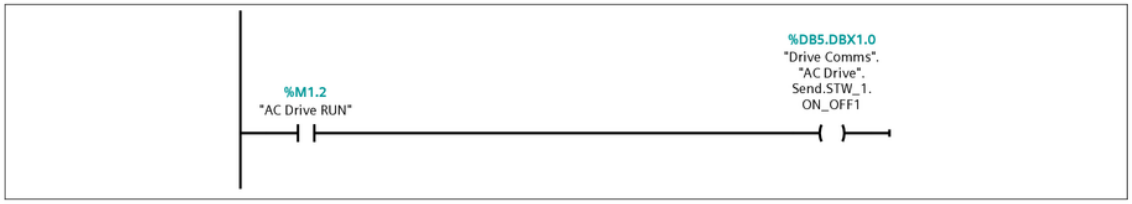
Network 5: Stopping system



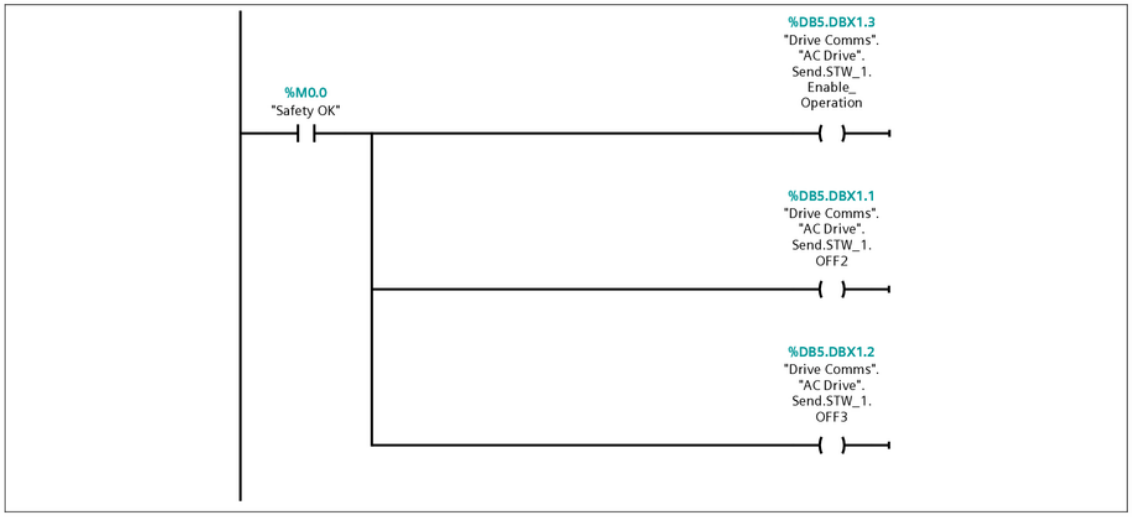
Network 6: Data Scaling



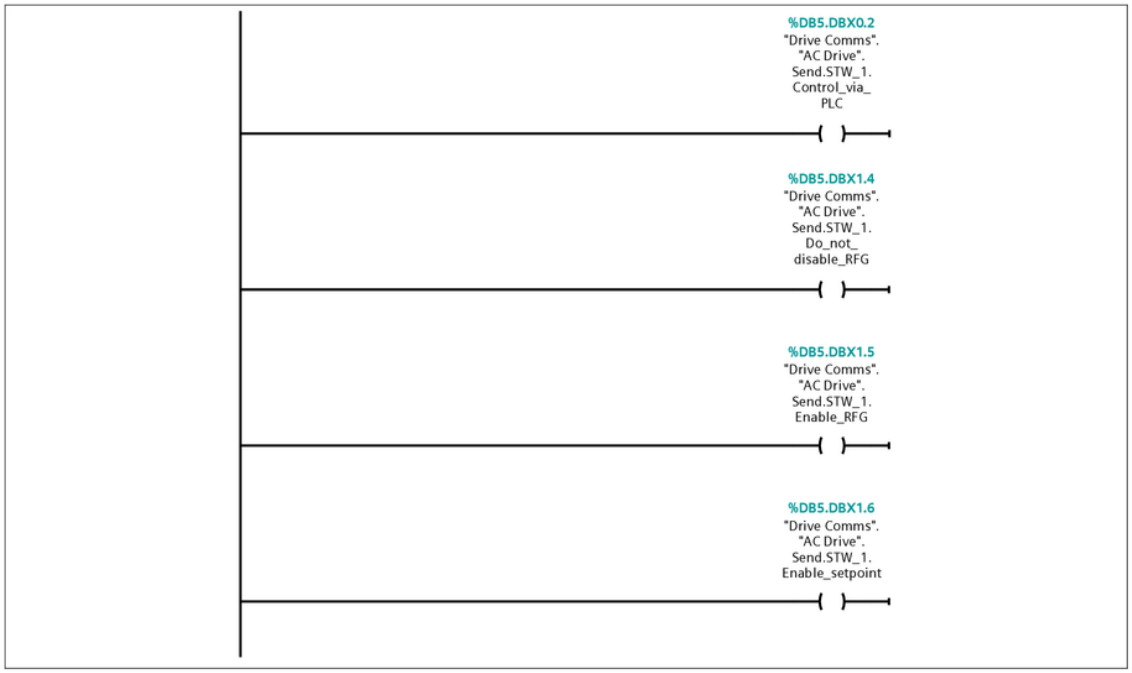
Network 7: 0 --> 1 = ON (The inverter goes to "ready "state. If, in addition bit 3 = 1 then the inverter switches on the motor), 0 = OFF1 (The motor brakes with ramp-down time p1121 of the ramp-function generator. The inverter switches off the motor an standstill) p0840[0] = r 2090.0



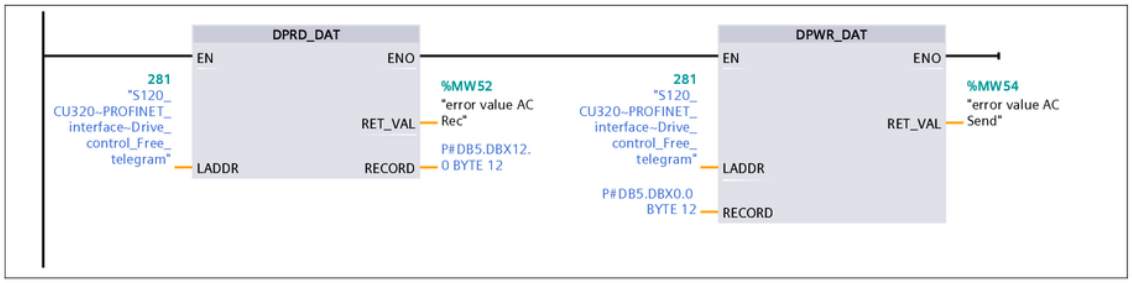
Network 8: 1 = Enable operation (Switch on motor (pulses can be enabled)), 0 = Inhibit operation (Immediately switch off motor (cancel pulses)) p 0852[0] = r 2090.3



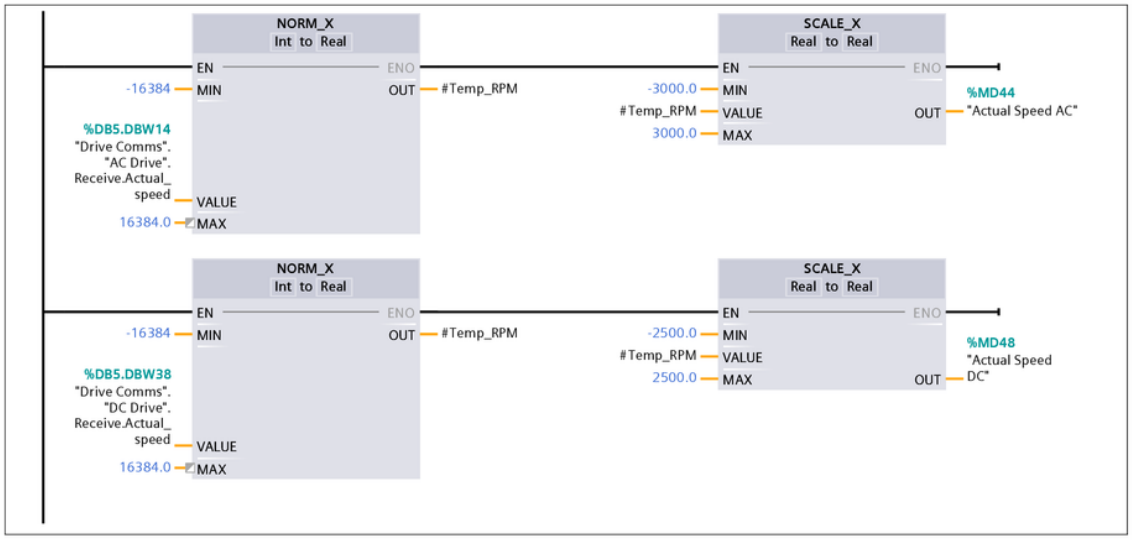
Network 9: 1 = Control via PLC (Control via fieldbus, inverter accepts the process data from the fieldbus), 0 = No control via PLC (Inverter ignores the process data from the fieldbus) p 0854[0] = r 2090.10



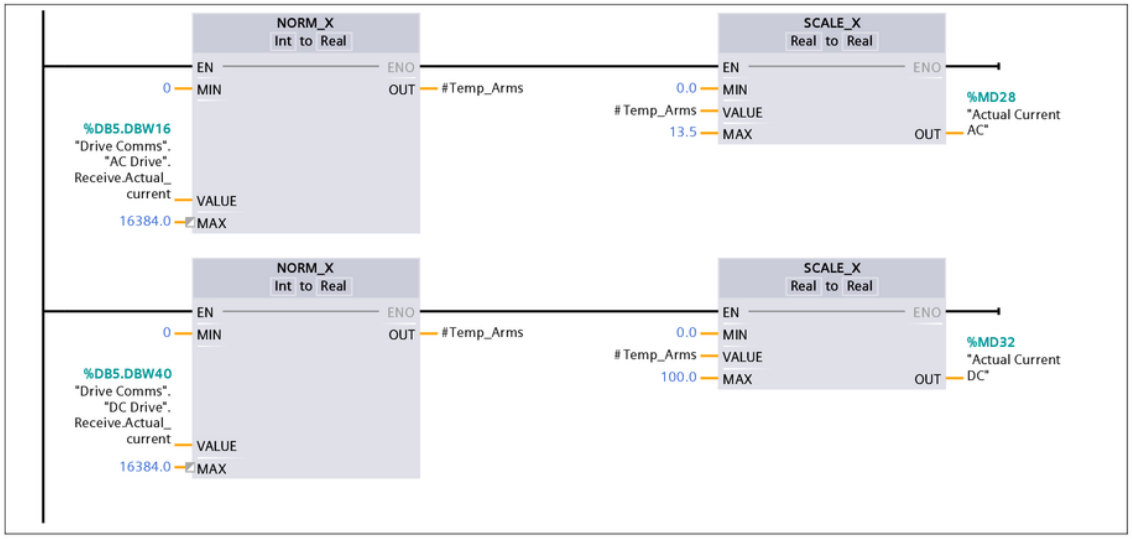
Network 10: AC Drive COMMS



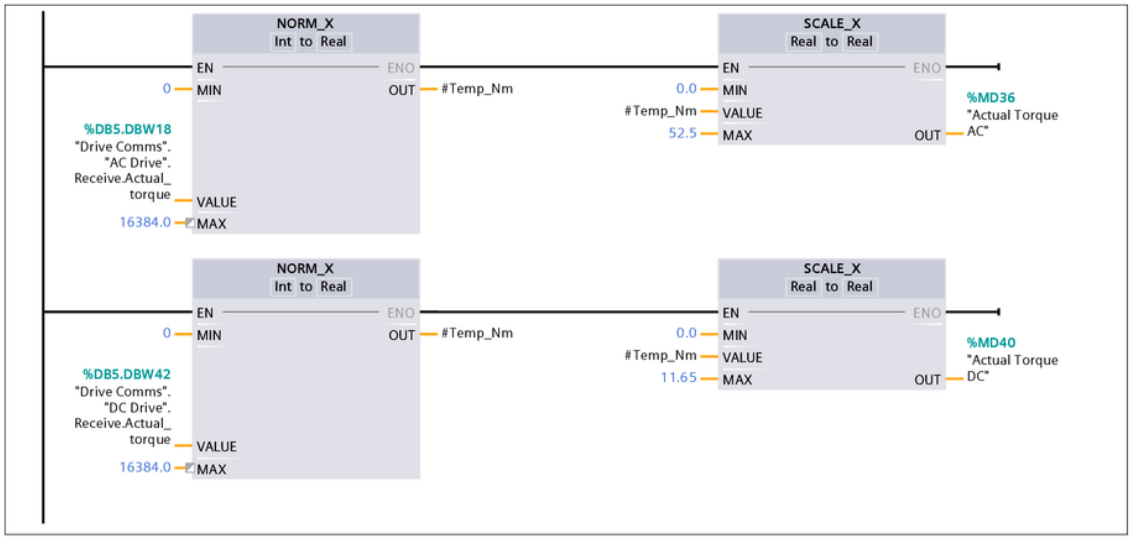
Network 11: Motor speed actual for HMI in RPM



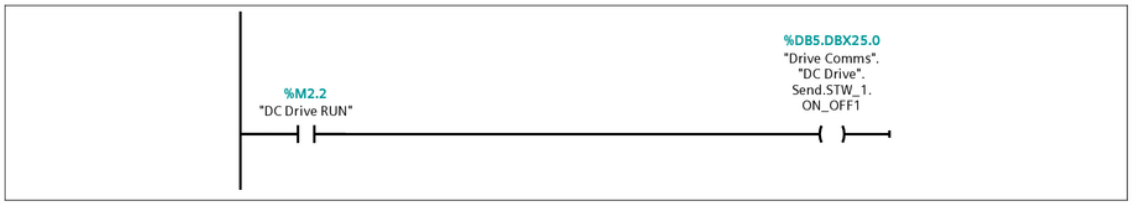
Network 12: Motor current actual for HMI in Arms



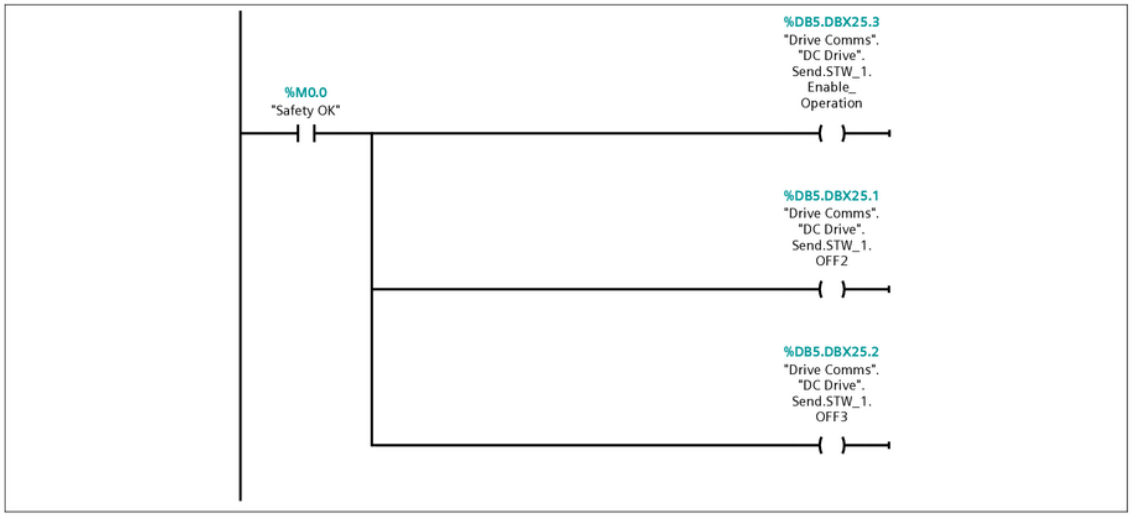
Network 13: Motor torque actual for HMI in Nm



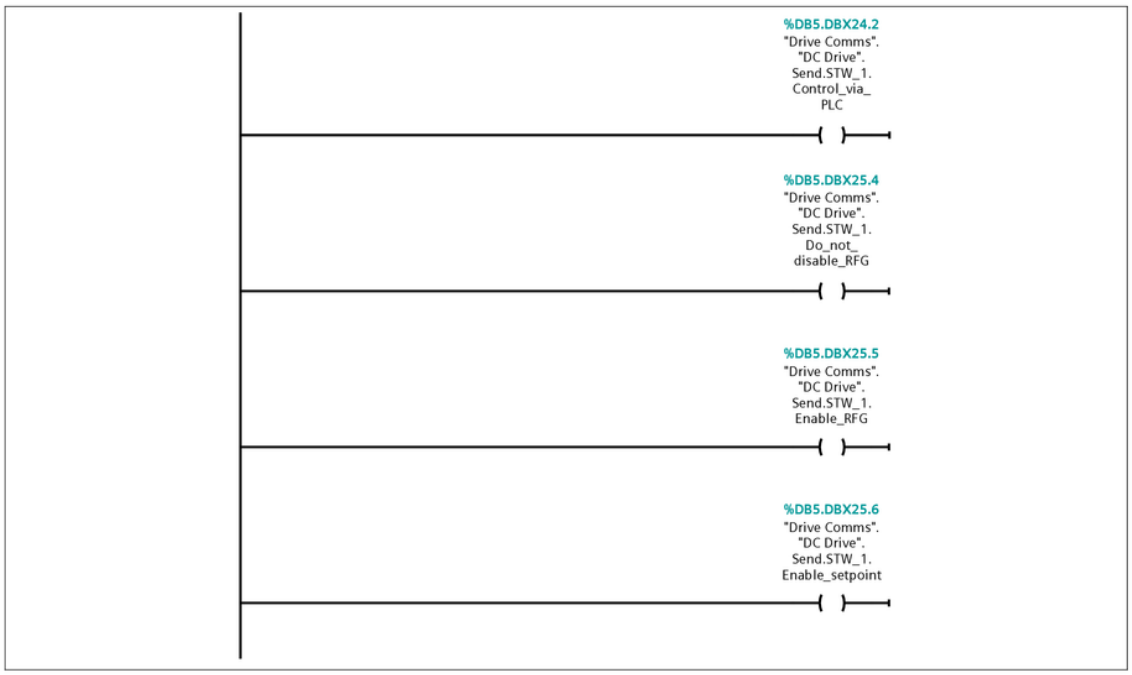
Network 14: 0 --> 1 = ON (The inverter goes to "ready "state. If, in addition bit 3 = 1 then the inverter switches on the motor), 0 = OFF1 (The motor brakes with ramp-down time p1121 of the ramp-function generator. The inverter switches off the motor an standstill) p0840[0] = r 2090.0



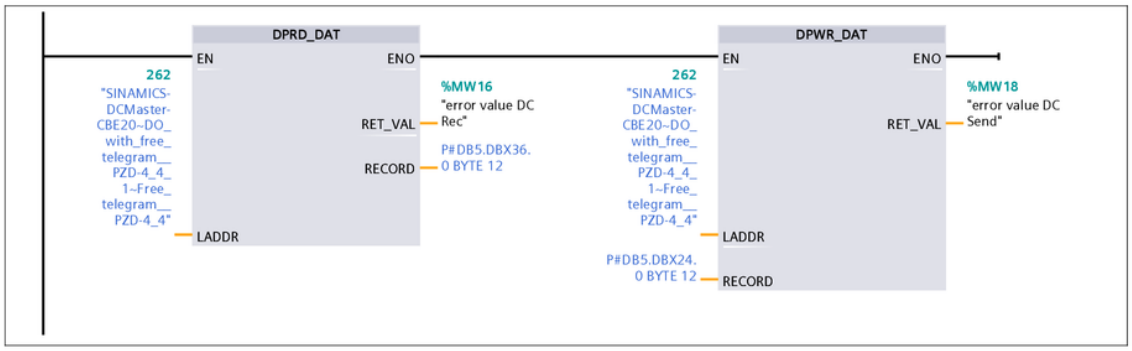
Network 15: 1 = Enable operation (Switch on motor (pulses can be enabled)), 0 = Inhibit operation (Immediately switch off motor (cancel pulses)) p 0852[0] = r 2090.3



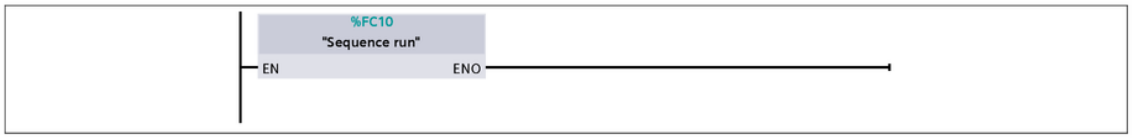
Network 16: 1 = Control via PLC (Control via fieldbus, inverter accepts the process data from the fieldbus), 0 = No control via PLC (Inverter ignores the process data from the fieldbus) p 0854[0] = r 2090.10



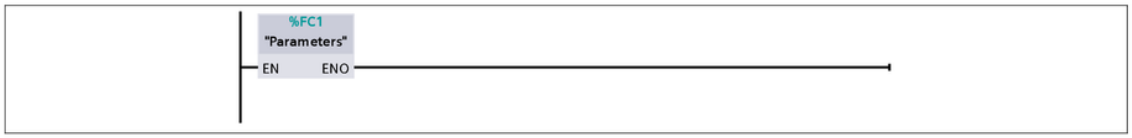
Network 17: DC Drive COMMS



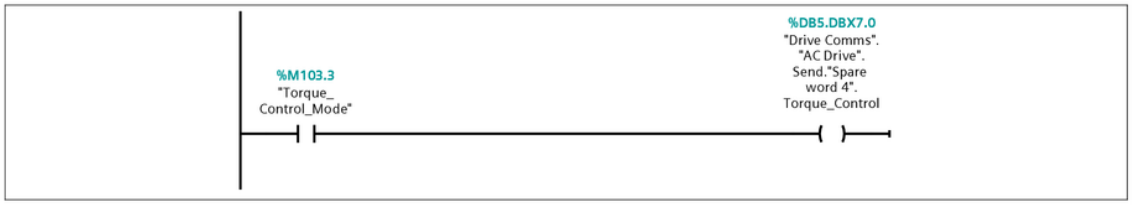
Network 18: FC10



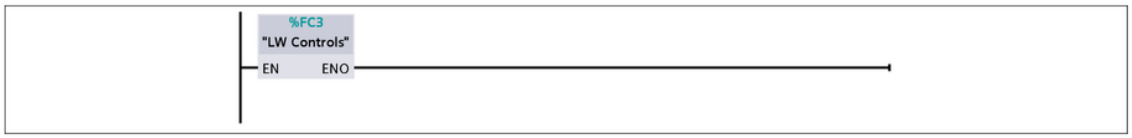
Network 19: FC1



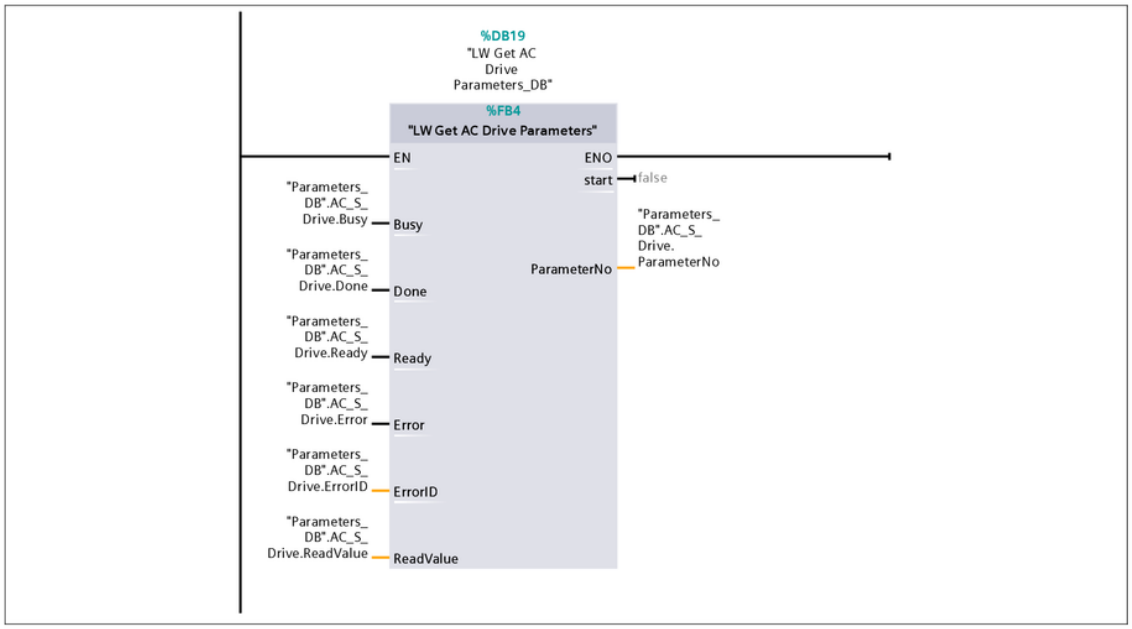
Network 20: AC Torque Control mode



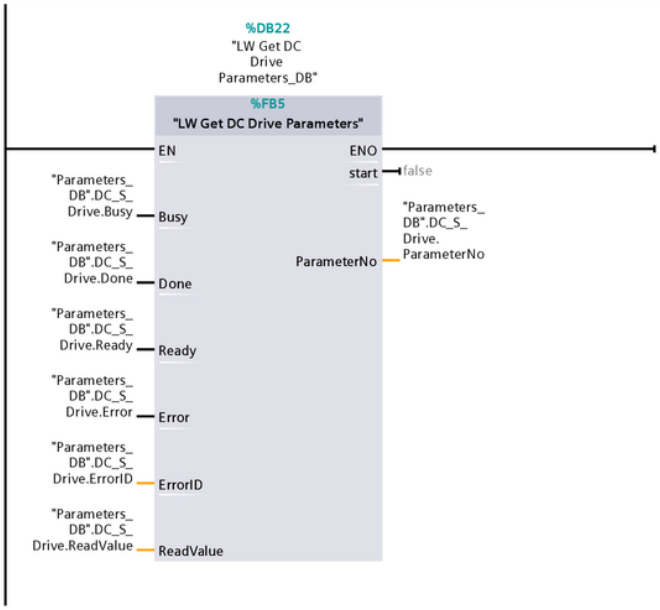
Network 21:



Network 22:



Network 23:

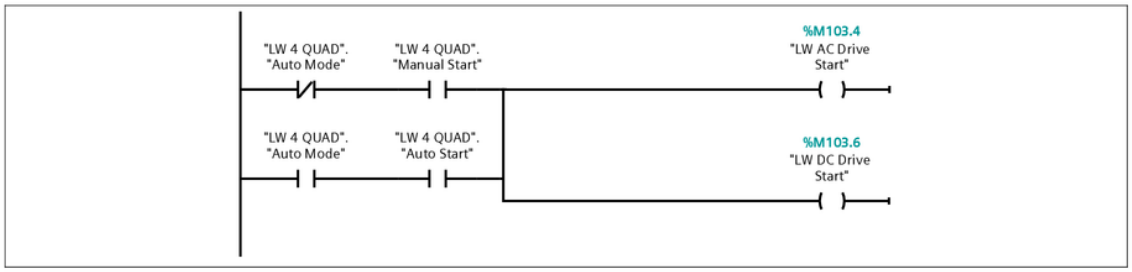

%DB22
"LW Get DC Drive Parameters_DB"
%FB5
"LW Get DC Drive Parameters"
EN
ENO
start
false
"Parameters_DB".DC_S_Drive.Busy
Busy
"Parameters_DB".DC_S_Drive.Done
Done
"Parameters_DB".DC_S_Drive.Ready
Ready
"Parameters_DB".DC_S_Drive.Error
Error
"Parameters_DB".DC_S_Drive.ErrorID
ErrorID
"Parameters_DB".DC_S_Drive.ReadValue
ReadValue
ParameterNo
"Parameters_DB".DC_S_Drive.ParameterNo

LW Controls [FC3]

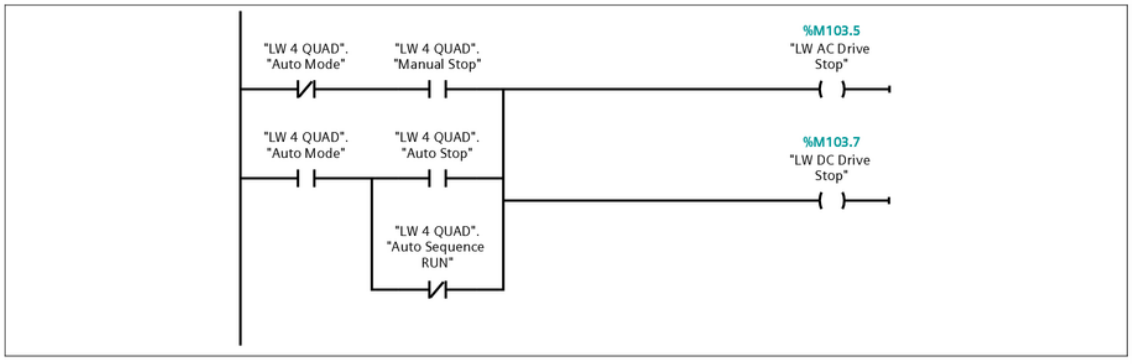
LW Controls Properties					
General					
Name	LW Controls	**Number**	3	**Type**	FC
Language	LAD	**Numbering**	Automatic		
Information					
Title	LW Controls for 4 quad-rant operation manual and automatic	**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
▼ Return		
LW Controls	Void	

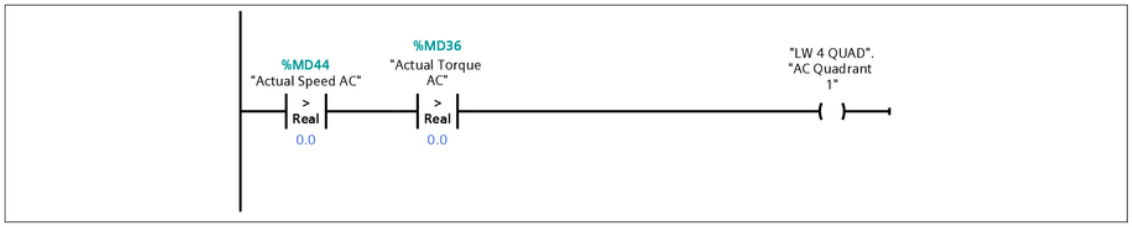
Network 1: AC and DC Drive Start



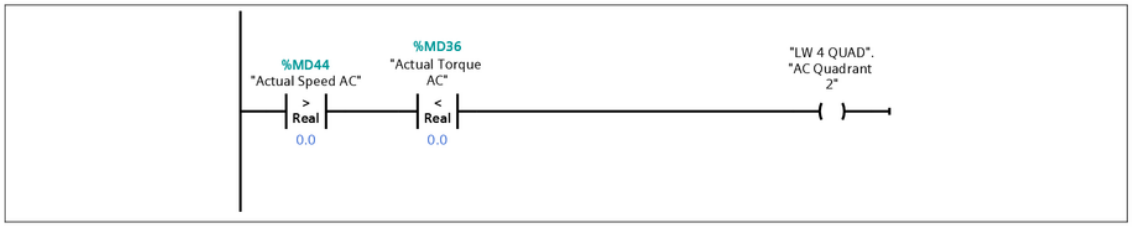
Network 2: AC and DC Drive Stops



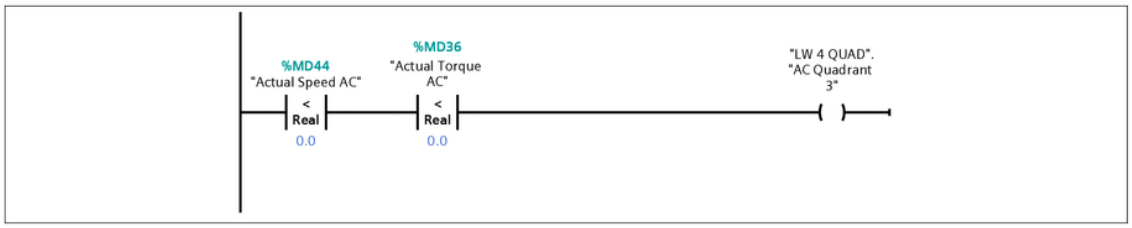
Network 3: AC Quadrant 1 Indicator light



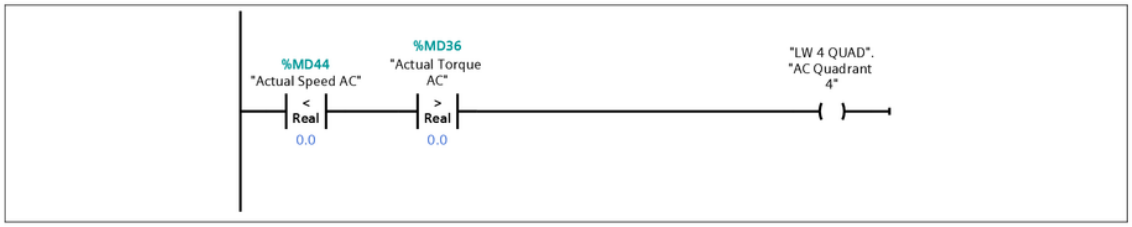
Network 4: AC Quadrant 2 indicator light



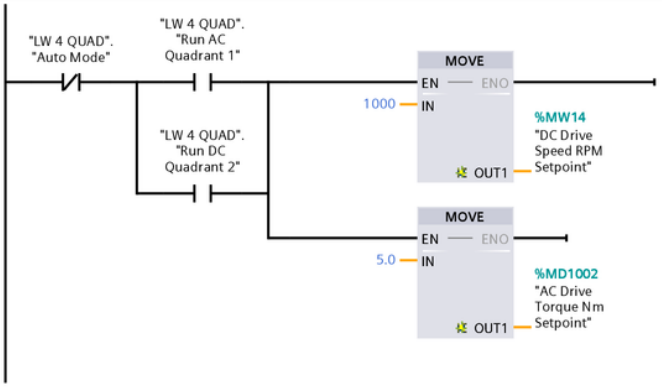
Network 5: AC Quadrant 3 Indicator light



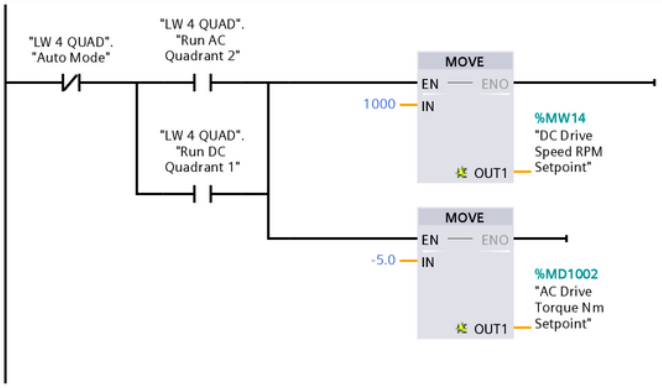
Network 6: AC Quadrant 4 indicator light



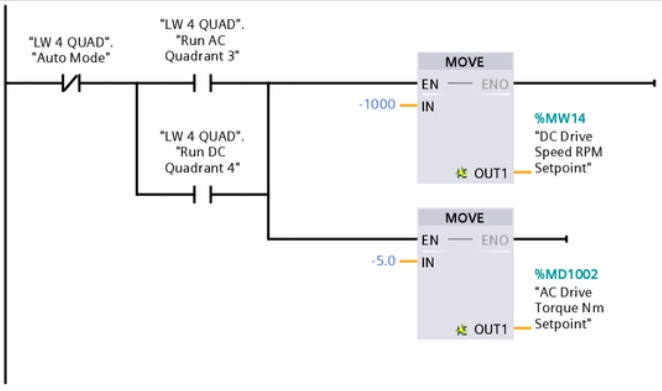
Network 7: Run AC Quadrant 1 with DC Quadrant 2 HMI control



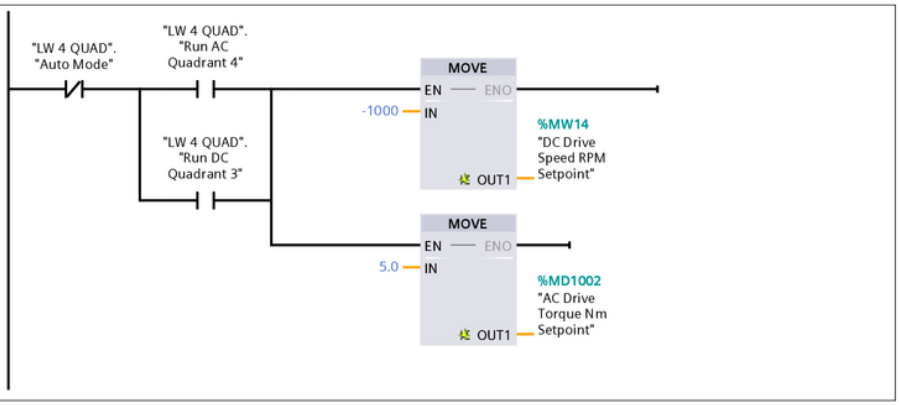
Network 8: Run AC Quadrant 2 with DC Quadrant 1 HMI control



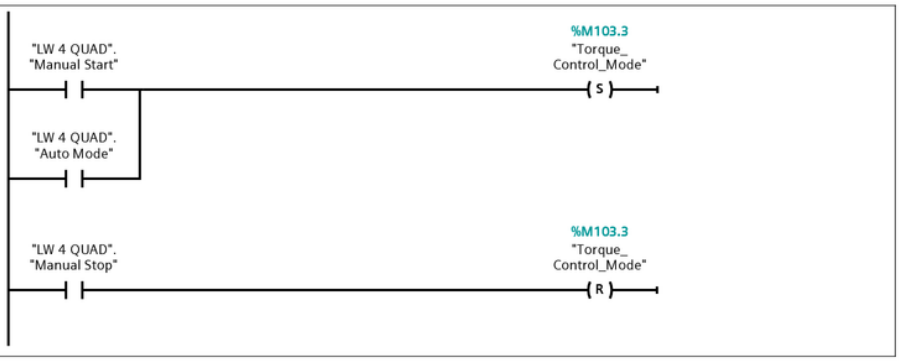
Network 9: Run AC Quadrant 3 with DC Quadrant 4 HMI controll



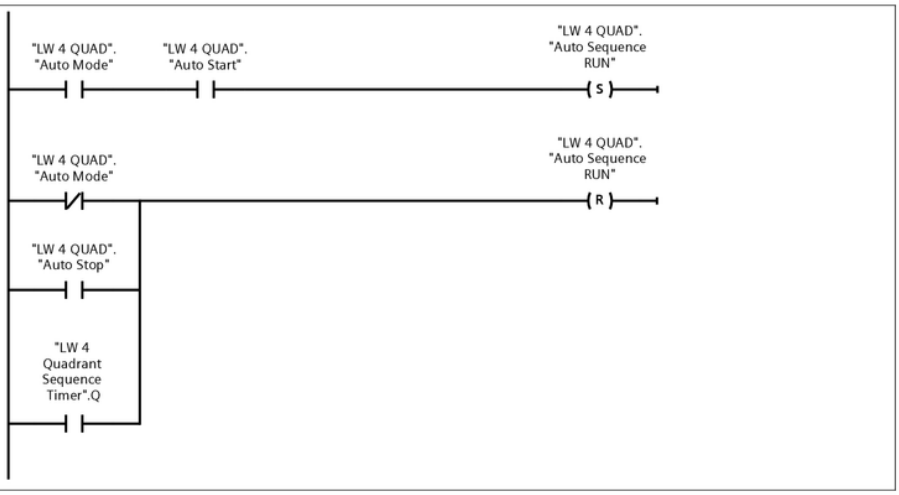
Network 10: Run AC Quadrant 4 with DC Quadrant 3 HMI control



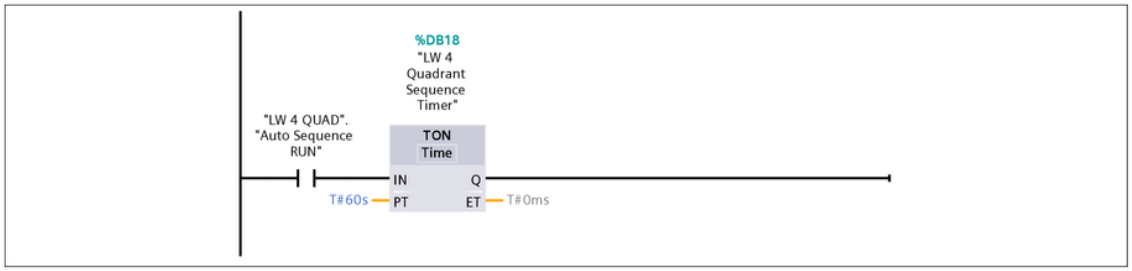
Network 11: Set AC torque mode in 4 quadrant operation



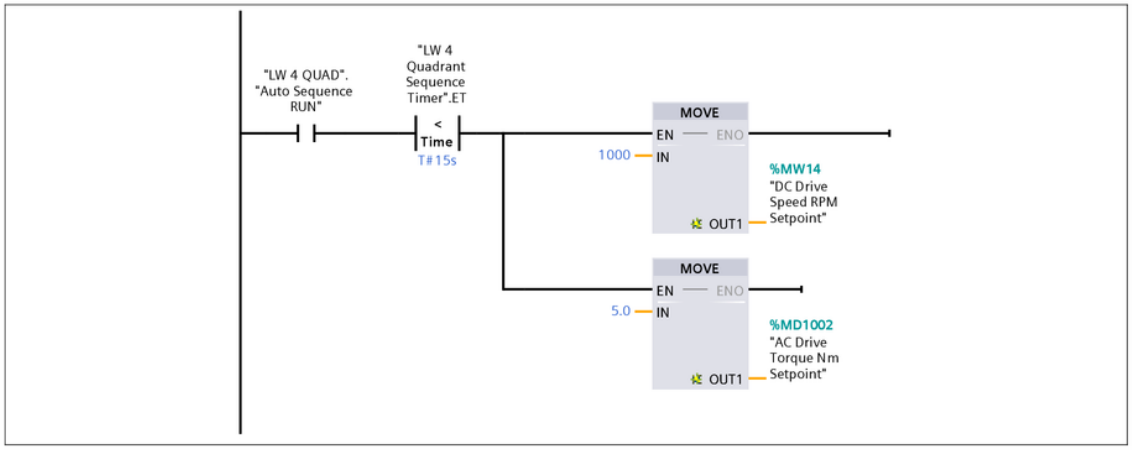
Network 12: 4 Quadrant Sequence Auto RUN



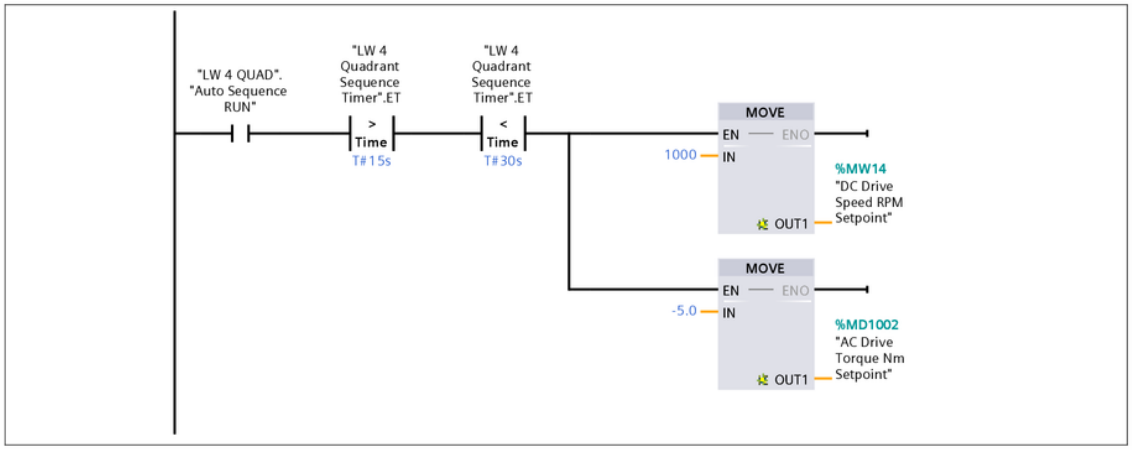
Network 13: 4 Quadrant Sequence Timer



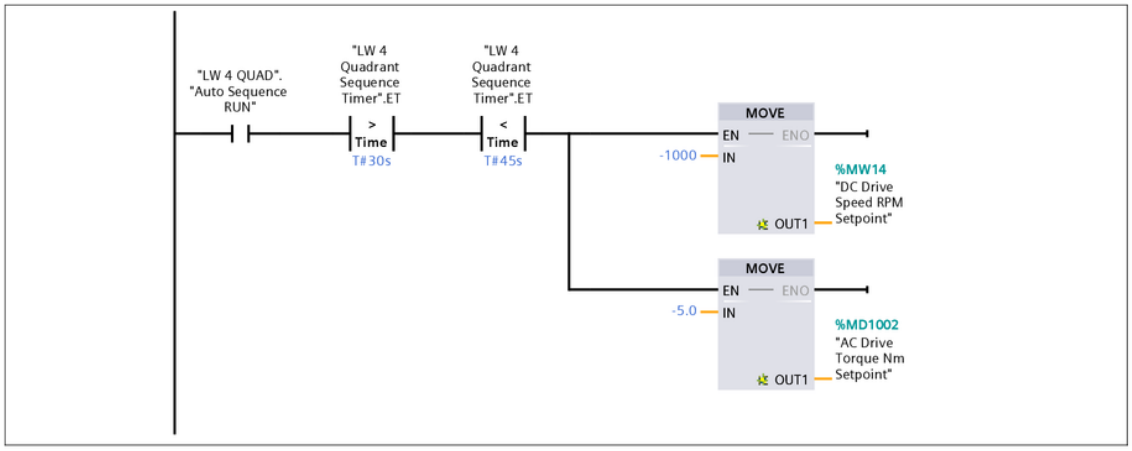
Network 14: 4 Quadrant Sequence Step 1



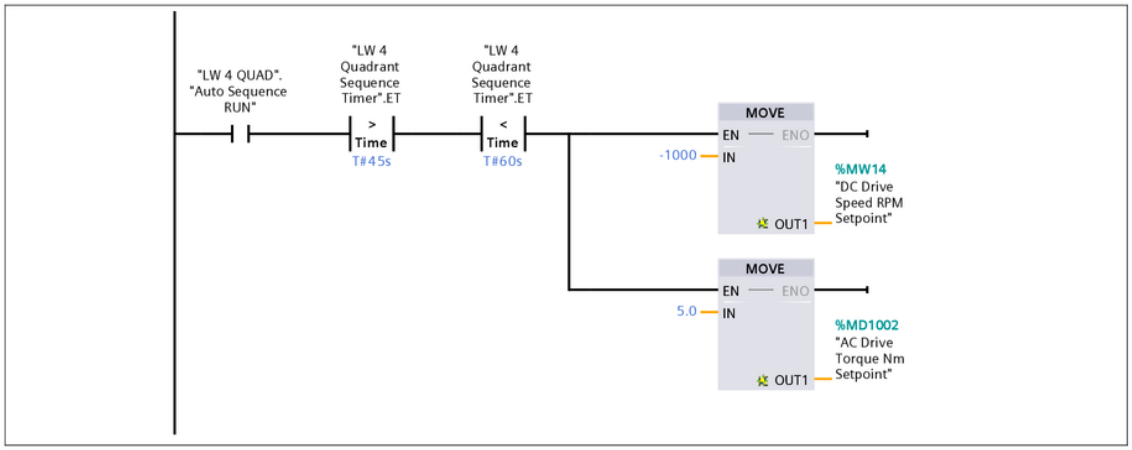
Network 15: 4 Quadrant Sequence Step 2



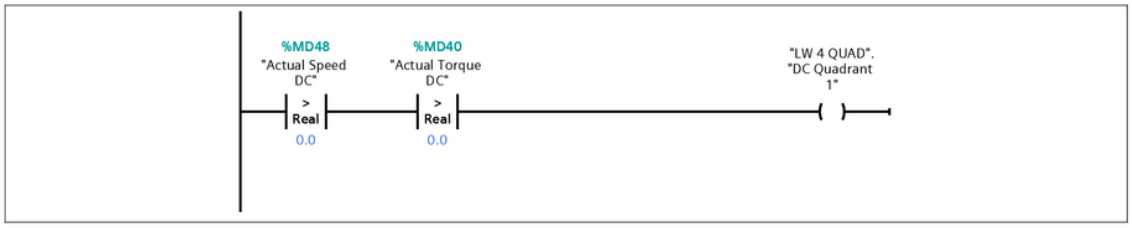
Network 16: 4 Quadrant Sequence Step 3



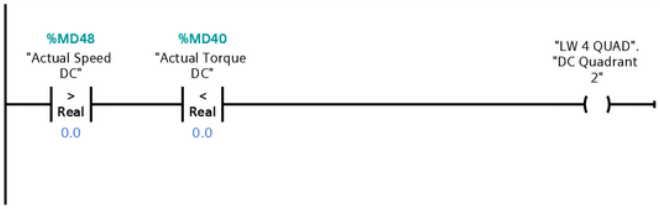
Network 17: 4 Quadrant Sequence Step 4



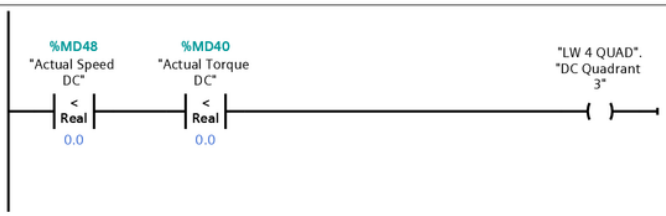
Network 18: DC Quadrant 1 indicator light



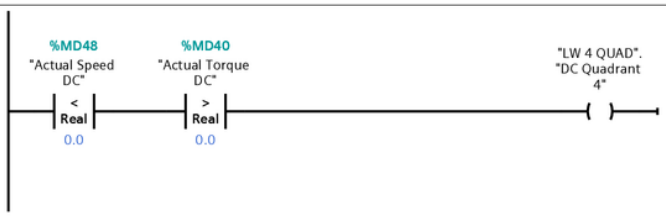
Network 19: DC Quadrant 2 indicator light



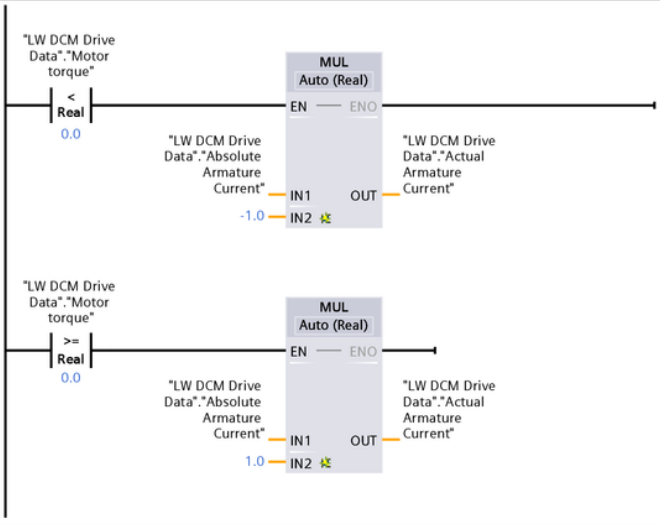
Network 20: DC Quadrant 3 indicator light



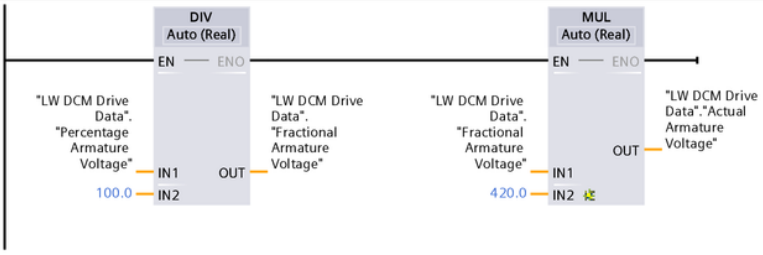
Network 21: DC Quadrant 4 indicator light



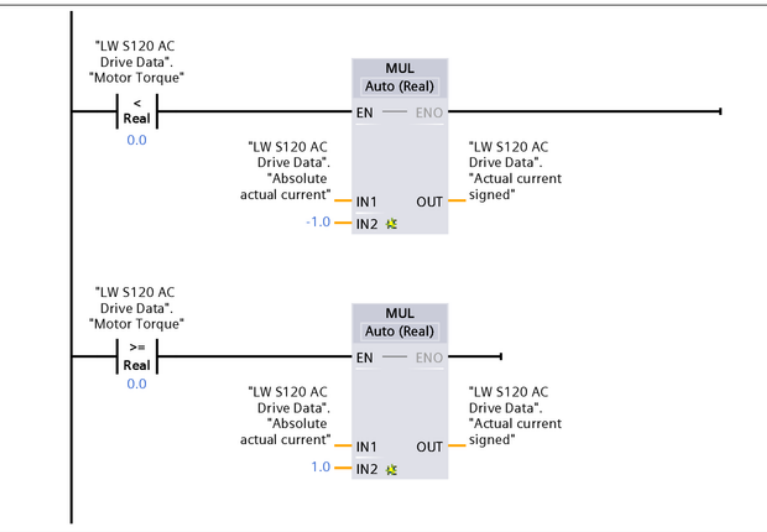
Network 22: Absolute Armature current conversion DCM



Network 23: Percentage armature voltage conversion



Network 24: Absolute Armature current conversion S120



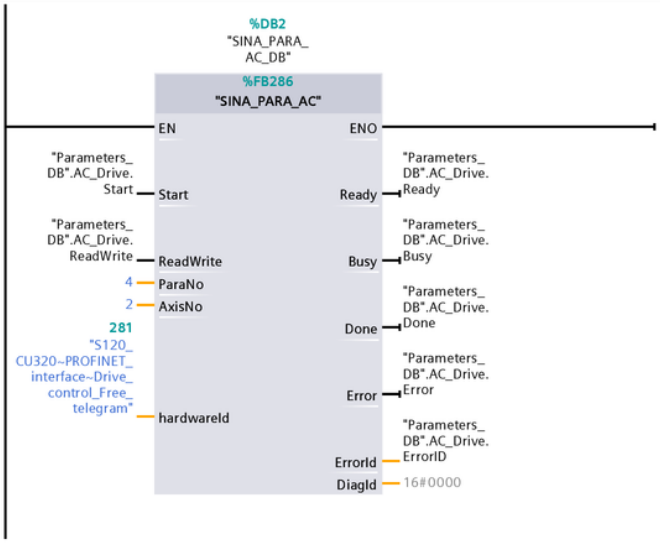
Parameters [FC1]

Parameters Properties					
General					
Name	Parameters	**Number**	1	**Type**	FC
Language	LAD	**Numbering**	Automatic		
Information					
Title	SINA_PARA	**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value
Input		
Output		
InOut		
Temp		
Constant		
▼ Return		
Parameters	Void	

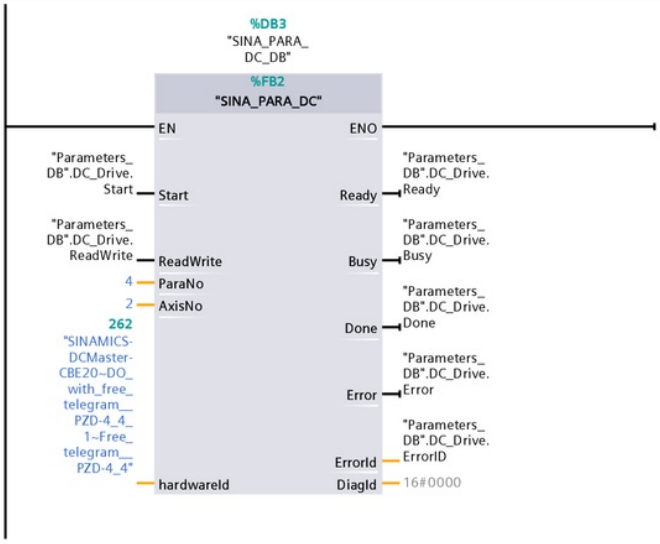
Network 1: AC Parameters

Gain, Integrl Time, Ramp Up, Ramp Down

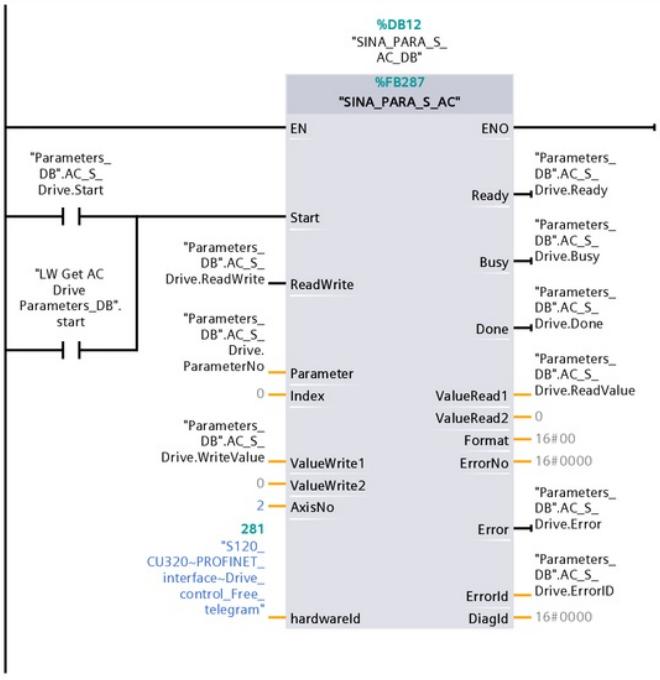


Network 2: DC Parameters

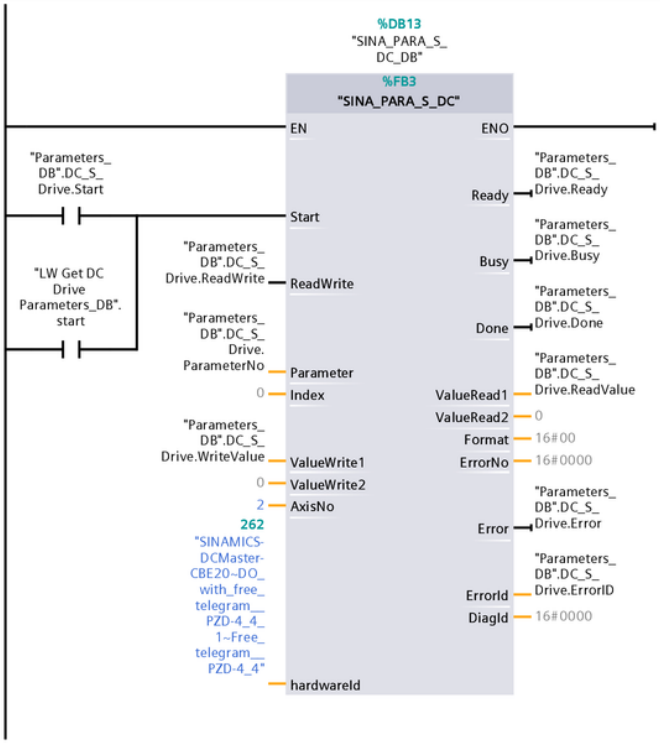
Gain, Integrl Time, Ramp Up, Ramp Down



Network 3: AC Single Parameter



Network 4: DC Single Parameter

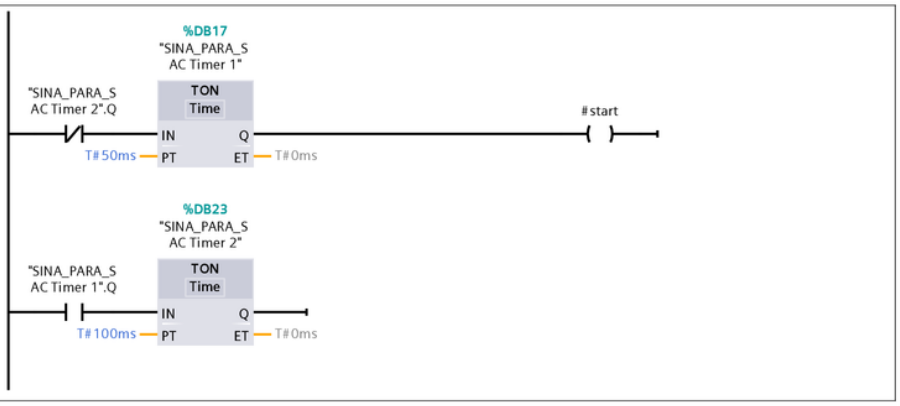

%DB13
"SINA_PARA_S_
DC_DB"
%FB3
"SINA_PARA_S_DC"
EN
ENO
"Parameters_
DB".DC_S_
Drive.Start
Start
Ready
"Parameters_
DB".DC_S_
Drive.Ready
Busy
"Parameters_
DB".DC_S_
Drive.Busy
"LW Get DC
Drive
Parameters_DB".
start
"Parameters_
DB".DC_S_
Drive.ReadWrite
ReadWrite
Done
"Parameters_
DB".DC_S_
Drive.Done
"Parameters_
DB".DC_S_
Drive.
ParameterNo
Parameter
0
Index
ValueRead1
"Parameters_
DB".DC_S_
Drive.ReadValue
ValueRead2
0
"Parameters_
DB".DC_S_
Drive.WriteValue
Format
16#00
ErrorNo
16#0000
ValueWrite1
0
ValueWrite2
2
AxisNo
Error
"Parameters_
DB".DC_S_
Drive.Error
262
"SINAMICS-
DCMaster-
CBE20~DO_
with_free_
telegram__
PZD-4_4_
1~Free_
telegram__
PZD-4_4"
ErrorId
"Parameters_
DB".DC_S_
Drive.ErrorID
DiagId
16#0000
hardwareId

LW Get AC Drive Parameters [FB4]

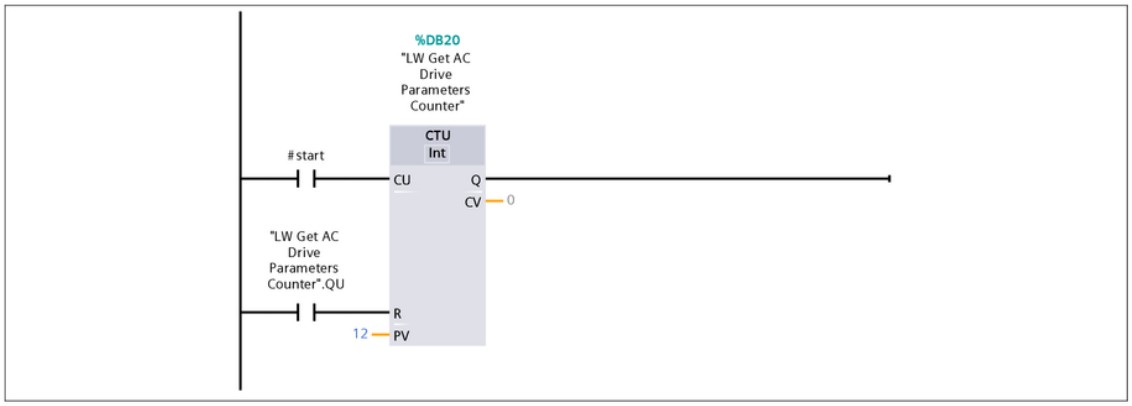
LW Get AC Drive Parameters Properties					
General					
Name	LW Get AC Drive Parameters	**Number**	4	**Type**	FB
Language	LAD	**Numbering**	Automatic		
Information					
Title	LW Get AC Drive Parameters	**Author**		**Comment**	Uses a timer and counter to individually access key parameters from the S120 via the SINA_PARA_S function block.
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
Busy	Bool	false	Non-retain
Done	Bool	false	Non-retain
Ready	Bool	false	Non-retain
Error	Bool	false	Non-retain
ErrorID	Real	0.0	Non-retain
ReadValue	Real	0.0	Non-retain
▼ Output			
start	Bool	false	Non-retain
ParameterNo	Int	0	Non-retain
InOut			
▼ Static			
run	Bool	false	Non-retain
done pulse	Bool	false	Non-retain
Temp			
Constant			

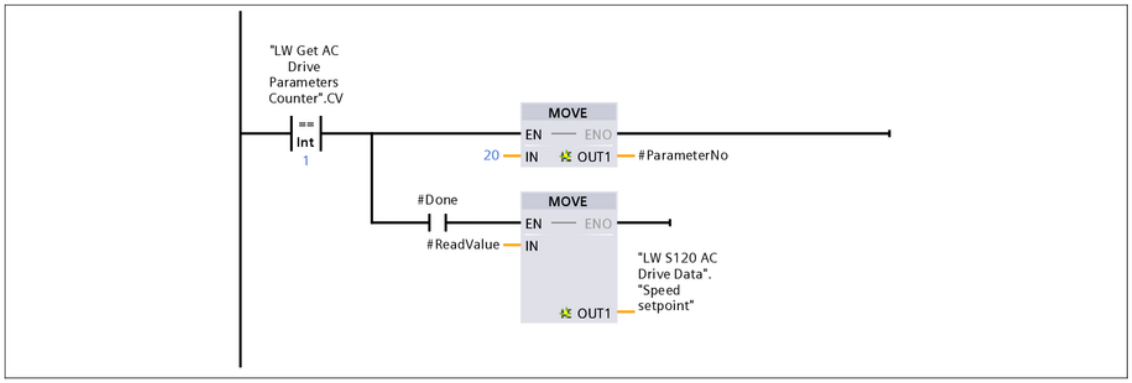
Network 1: LW Get AC Drive Parameters Timers



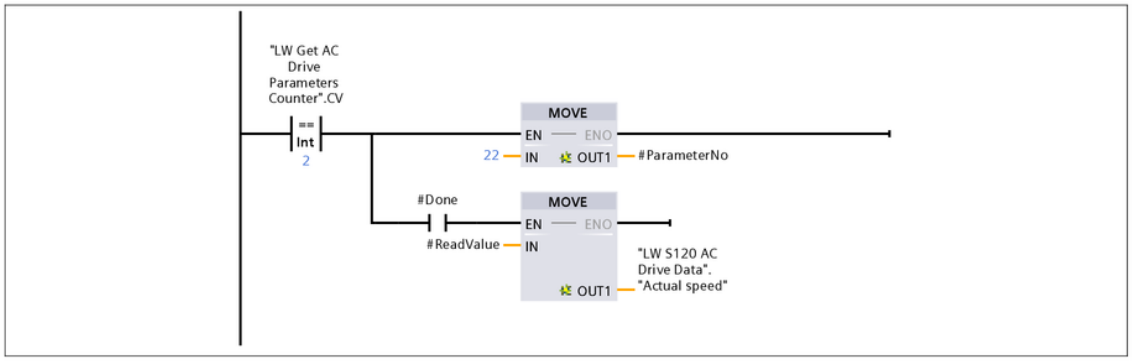
Network 2: LW Get AC Drive Parameters Counter



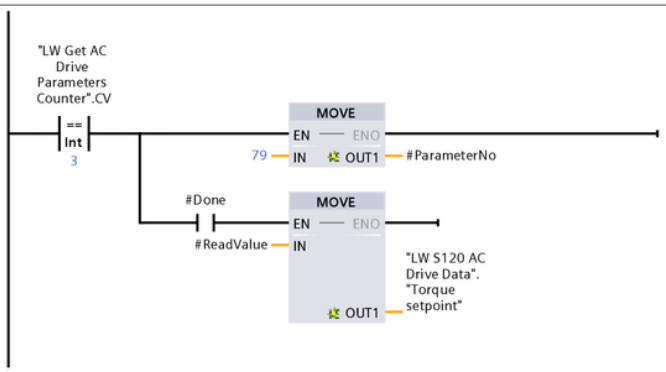
Network 3: r20 Speed SP



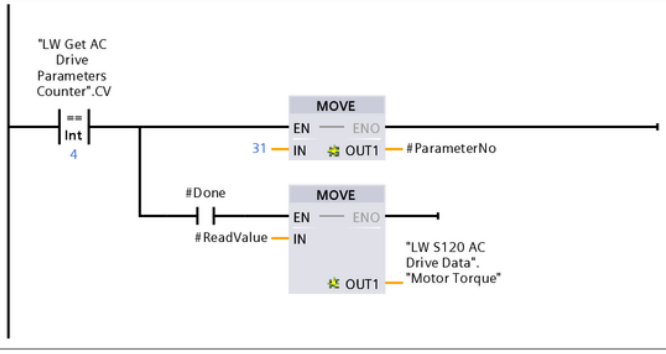
Network 4: r22 Actual Speed



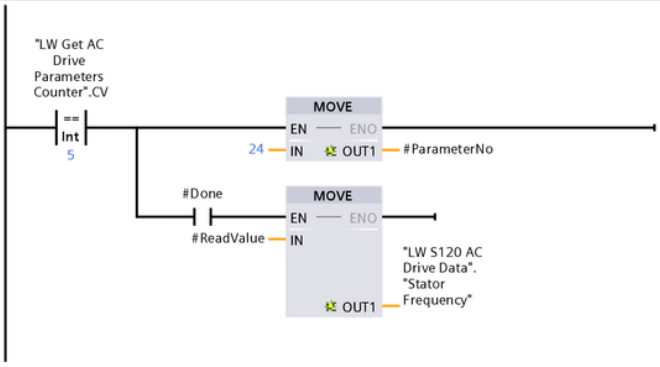
Network 5: r79 Torque SP



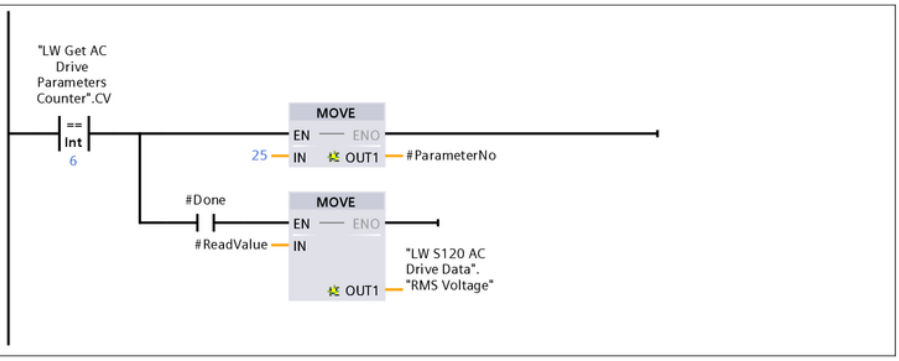
Network 6: r31 Actual Torque



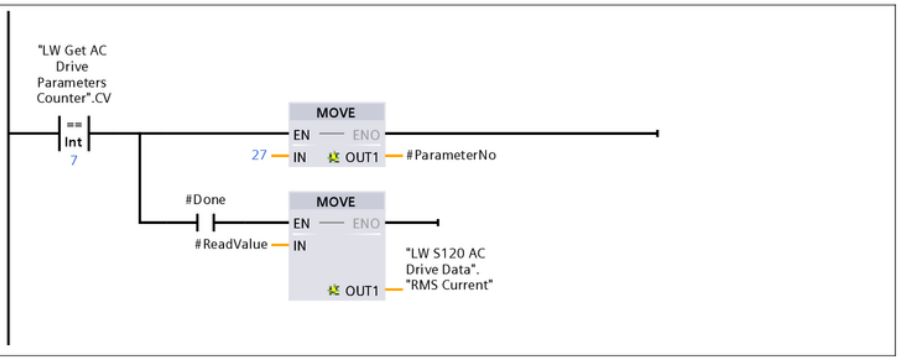
Network 7: r24 output frequency



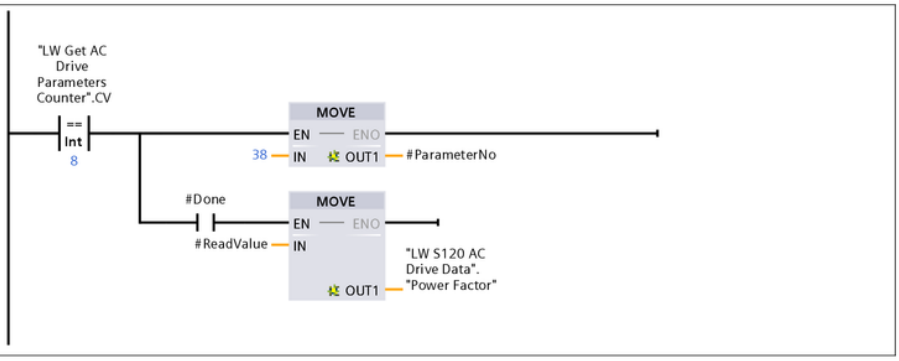
Network 8: r25 RMS Voltage



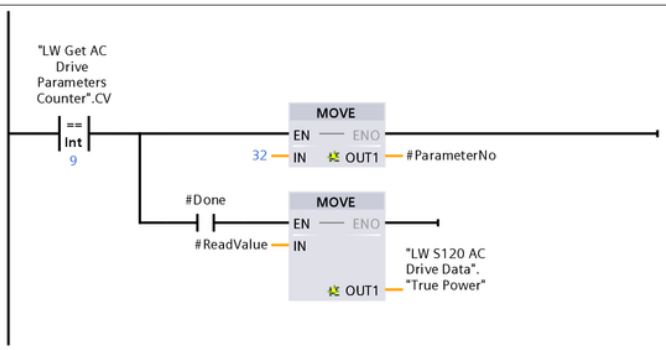
Network 9: r30 RMS Current



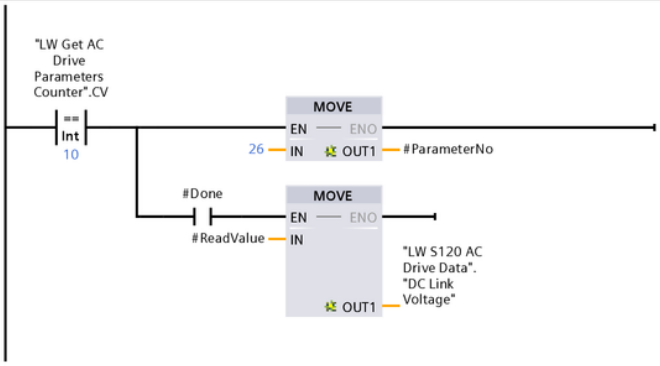
Network 10: r38 Power factor



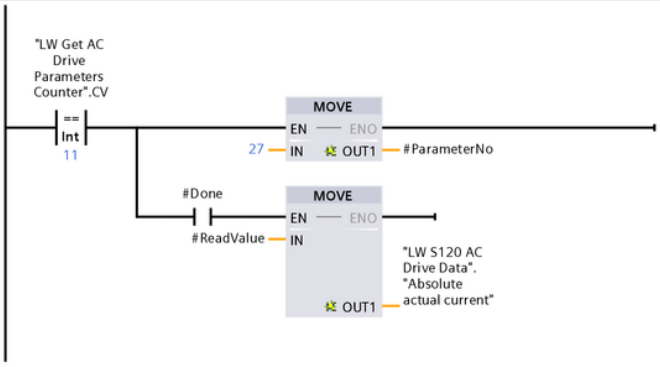
Network 11: r32 Active Power



Network 12: r26 DC Link Voltage



Network 13: r27 Absolute actual current

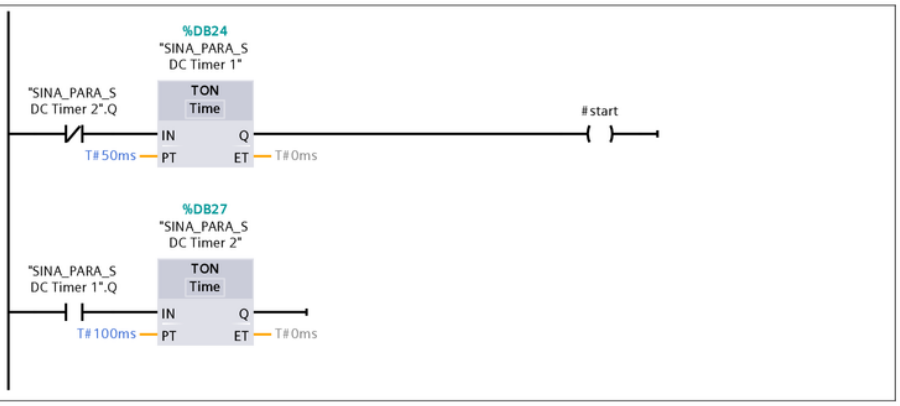


LW Get DC Drive Parameters [FB5]

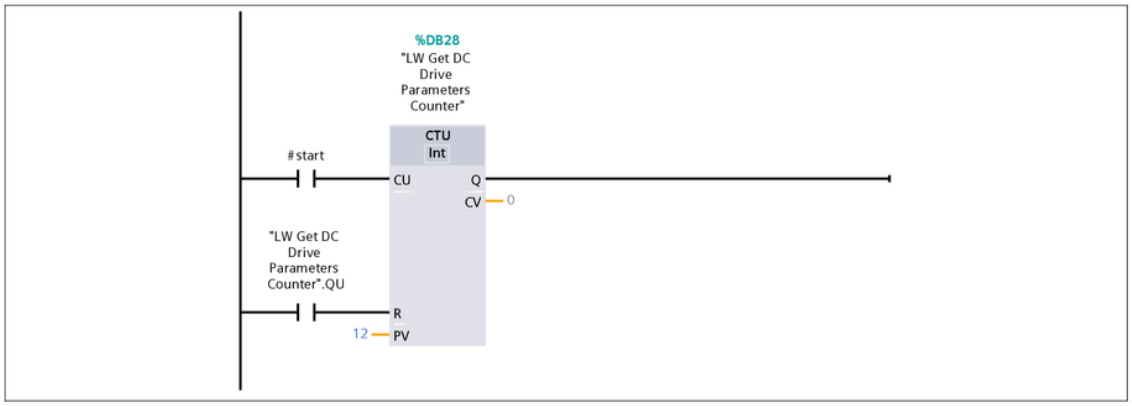
LW Get DC Drive Parameters Properties					
General					
Name	LW Get DC Drive Parameters	**Number**	5	**Type**	FB
Language	LAD	**Numbering**	Automatic		
Information					
Title	LW Get AC Drive Parameters	**Author**		**Comment**	Uses a timer and counter to individually access key parameters from the S120 via the SINA_PARA_S function block.
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
▼ Input			
Busy	Bool	false	Non-retain
Done	Bool	false	Non-retain
Ready	Bool	false	Non-retain
Error	Bool	false	Non-retain
ErrorID	Real	0.0	Non-retain
ReadValue	Real	0.0	Non-retain
▼ Output			
start	Bool	false	Non-retain
ParameterNo	Int	0	Non-retain
InOut			
▼ Static			
run	Bool	false	Non-retain
done pulse	Bool	false	Non-retain
Temp			
Constant			

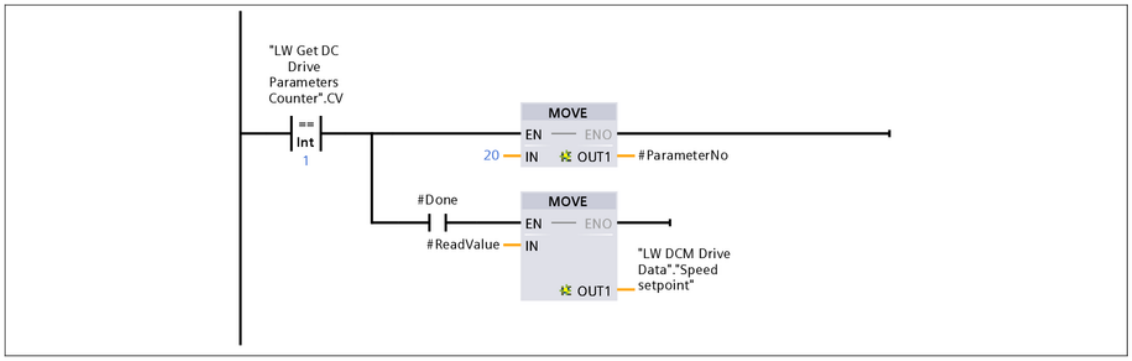
Network 1: LW Get DC Drive Parameters Timers



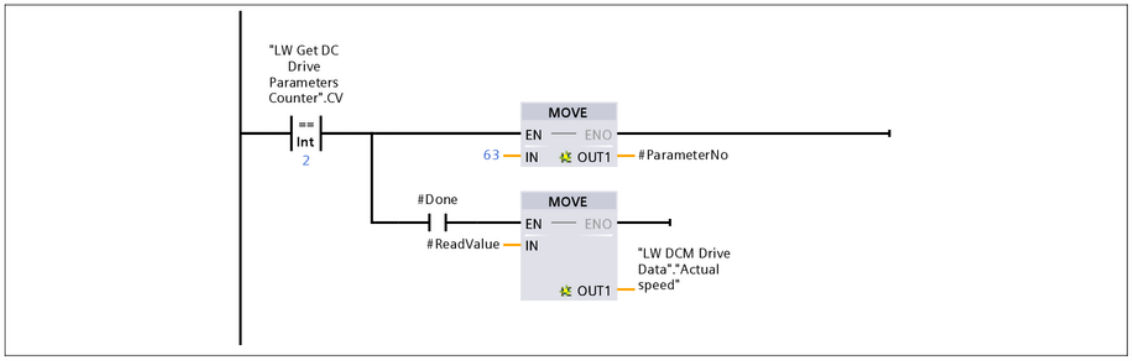
Network 2: LW Get DC Drive Parameters Counter



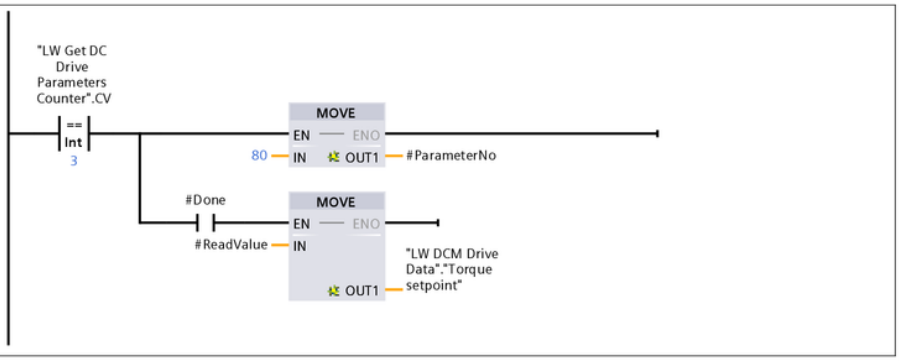
Network 3: r20 Speed SP



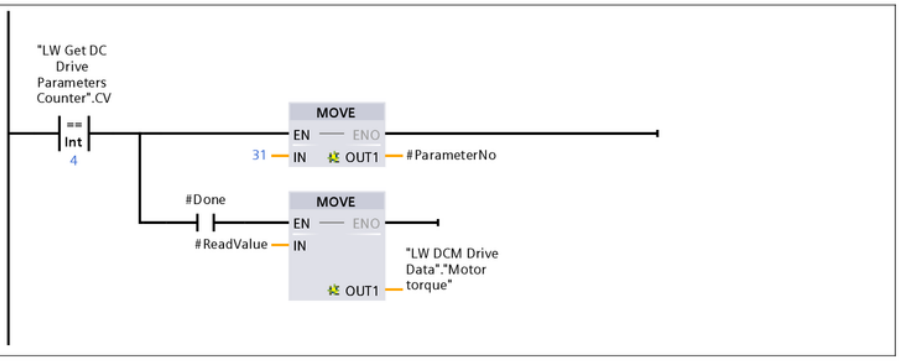
Network 4: r63 Actual Speed



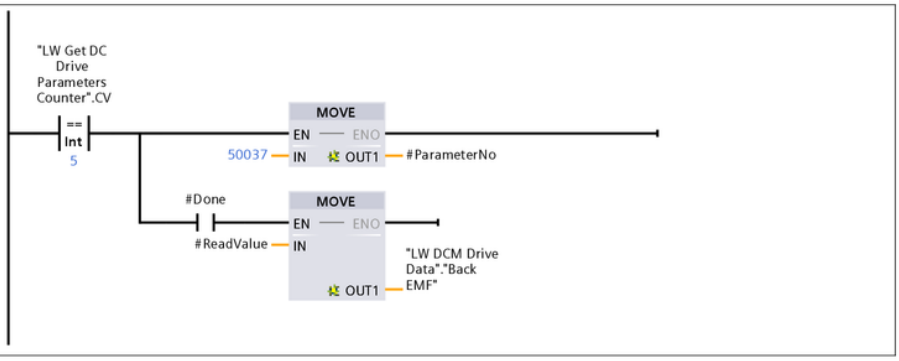
Network 5: r80 Torque SP



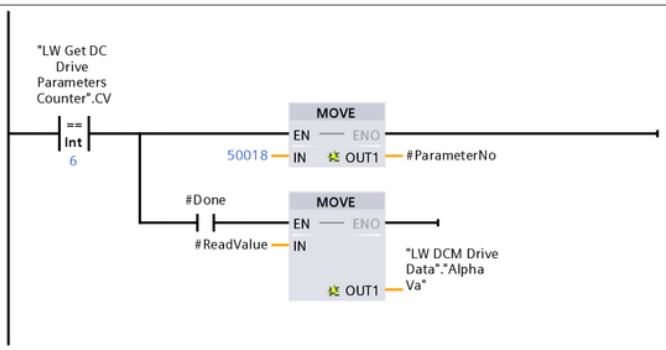
Network 6: r31 Actual Torque



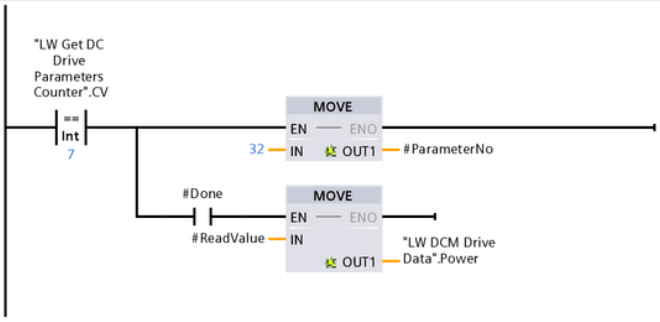
Network 7: r50037 Back EMF



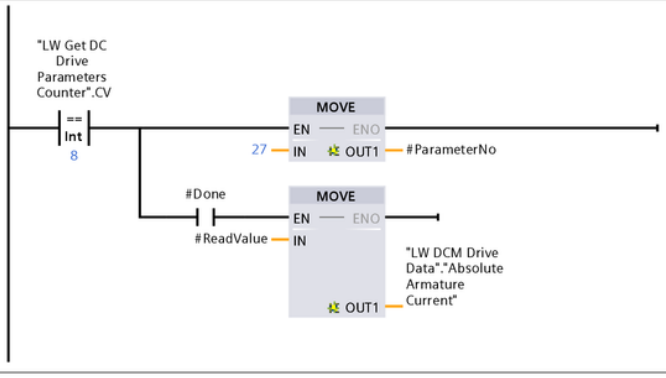
Network 8: r50018 Alpha Va



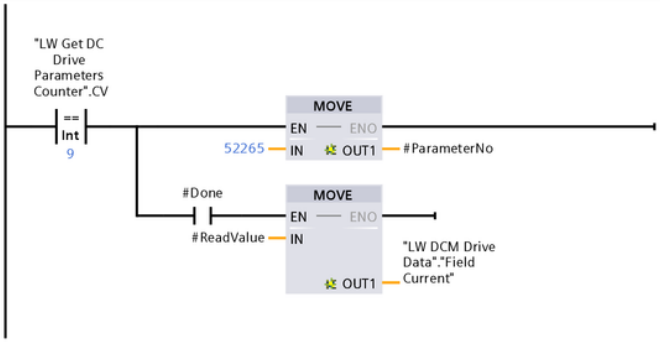
Network 9: r32 Power



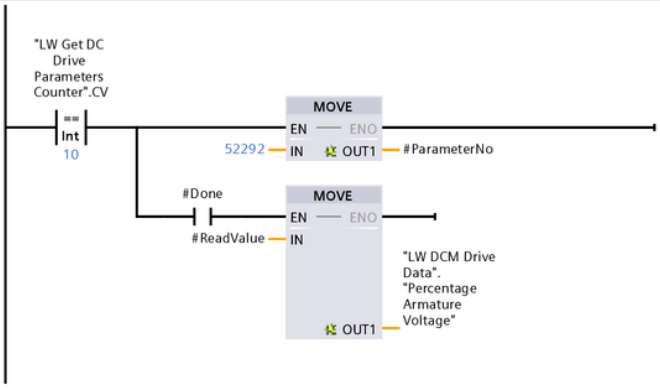
Network 10: r27 Absolute Actual Current



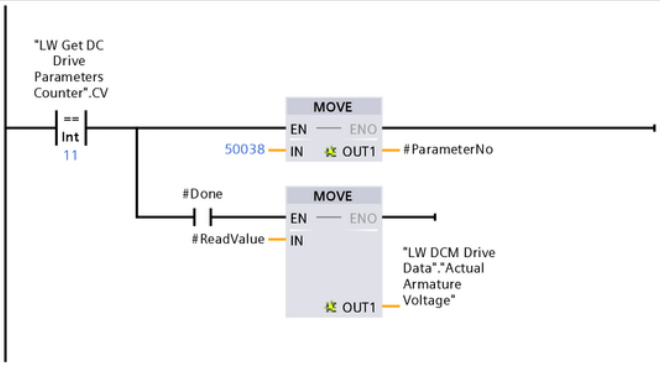
Network 11: r52265 Field Current



Network 12: r52292 armature voltage %



Network 13: r50038 Armature voltage actual



Drive Comms [DB5]

Drive Comms Properties					
General					
Name	Drive Comms	**Number**	5	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
AC Drive	"FreeTelegram"		False
DC Drive	"FreeTelegram"		False
AC Safety	Struct		False

LW 4 QUAD [DB16]

LW 4 QUAD Properties					
General					
Name	LW 4 QUAD	**Number**	16	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
Manual Start	Bool	false	False
Manual Stop	Bool	false	False
AC Quadrant 1	Bool	false	False
AC Quadrant 2	Bool	false	False
AC Quadrant 3	Bool	false	False
AC Quadrant 4	Bool	false	False
Run AC Quadrant 1	Bool	false	False
Run AC Quadrant 2	Bool	false	False
Run AC Quadrant 3	Bool	false	False
Run AC Quadrant 4	Bool	false	False
Auto Sequence RUN	Bool	false	False
Auto Start	Bool	false	False
Auto Stop	Bool	false	False
Auto Mode	Bool	false	False
DC Quadrant 1	Bool	false	False
DC Quadrant 2	Bool	false	False
DC Quadrant 3	Bool	false	False
DC Quadrant 4	Bool	false	False
Run DC Quadrant 1	Bool	false	False
Run DC Quadrant 2	Bool	false	False
Run DC Quadrant 3	Bool	false	False
Run DC Quadrant 4	Bool	false	False

LW DCM Drive Data [DB15]

LW DCM Drive Data Properties					
General					
Name	LW DCM Drive Data	**Number**	15	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
Speed setpoint	Real	0.0	False
Actual speed	Real	0.0	False
Torque setpoint	Real	0.0	False
Load torque	Real	0.0	False
Motor torque	Real	0.0	False
Average DC Voltage	Real	0.0	False
Percentage Armature Voltage	Real	0.0	False
Fractional Armature Voltage	Real	0.0	False
Actual Armature Voltage	Real	0.0	False
Alpha Va	Real	0.0	False
Alpha Vf	Real	0.0	False
Max Line Voltage	Real	0.0	False
Absolute Armature Current	Real	0.0	False
Actual Armature Current	Real	0.0	False
Power	Real	0.0	False
Field Current	Real	0.0	False
Back EMF	Real	0.0	False
Manual Start	Bool	false	False
Manual Stop	Bool	false	False
Run	Bool	false	False
Auto Four Quad Sequence	Bool	false	False
Auto Field Weaken Seqence	Bool	false	False
Auto Start	Bool	false	False
Auto Stop	Bool	false	False

LW S120 AC Drive Data [DB14]

LW S120 AC Drive Data Properties					
General					
Name	LW S120 AC Drive Data	**Number**	14	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Start value	Retain
▼ Static			
Speed setpoint	Real	0.0	False
Actual speed	Real	0.0	False
Torque setpoint	Real	0.0	False
Load torque	Real	0.0	False
Motor Torque	Real	0.0	False
Stator Frequency	Real	0.0	False
RMS Voltage	Real	0.0	False
RMS Current	Real	0.0	False
Absolute actual current	Real	0.0	False
Actual current signed	Real	0.0	False
Power Factor	Real	0.0	False
PWM Frequency	Real	0.0	False
Duty Cyle	Real	0.0	False
Phase voltages	Real	0.0	False
True Power	Real	0.0	False
DC Link Voltage	Real	0.0	False
Apparent Power	Real	0.0	False
Manual Start	Bool	false	False
Manual Stop	Bool	false	False
Run	Bool	false	False
Auto Four Quad Sequence	Bool	false	False
Auto Inverter Speed Sequence	Bool	false	False
Auto Start	Bool	false	False
Auto Stop	Bool	false	False

Parameters_DB [DB4]

Parameters_DB Properties					
General					
Name	Parameters_DB	**Number**	4	**Type**	DB
Language	DB	**Numbering**	Automatic		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

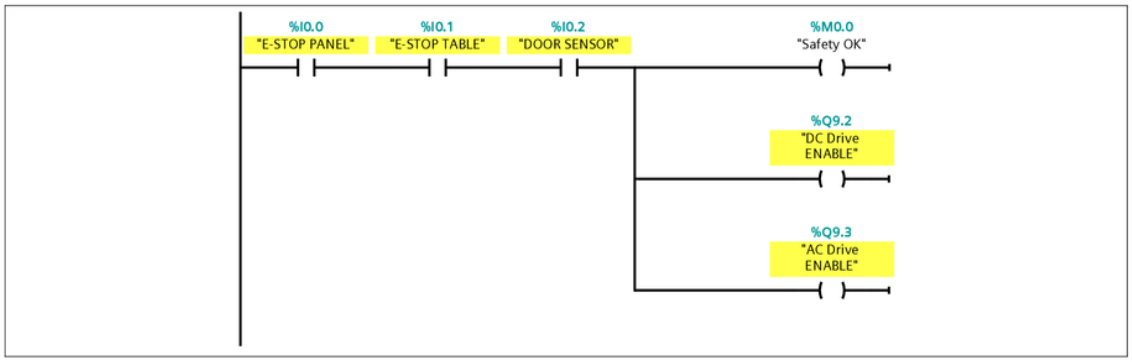
Name	Data type	Start value	Retain
▼ Static			
AC_Drive	"Parameter"		False
AC_S_Drive	"Parameter"		False
DC_Drive	"Parameter"		False
DC_S_Drive	"Parameter"		False

Main_Safety_RTG1 [FB1]

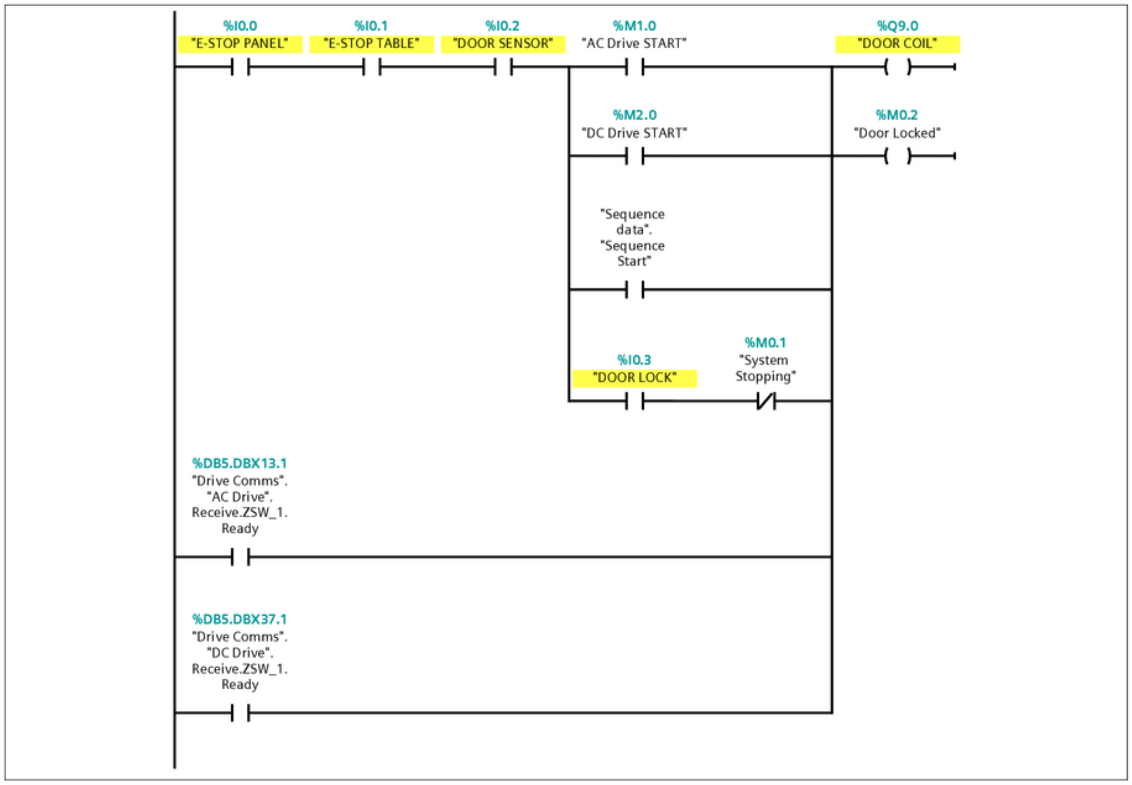
Main_Safety_RTG1 Properties					
General					
Name	Main_Safety_RTG1	**Number**	1	**Type**	FB
Language	LAD	**Numbering**	Manual		
Information					
Title		**Author**		**Comment**	
Family		**Version**	0.1	**User-defined ID**	

Name	Data type	Default value	Retain
Input			
Output			
InOut			
Static			
Temp			
Constant			

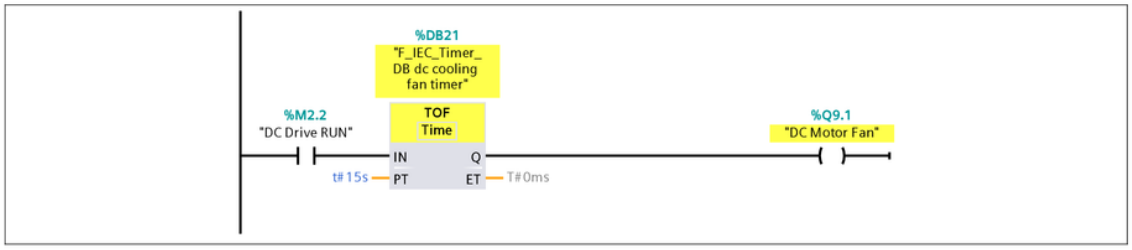
Network 1:



Network 2:

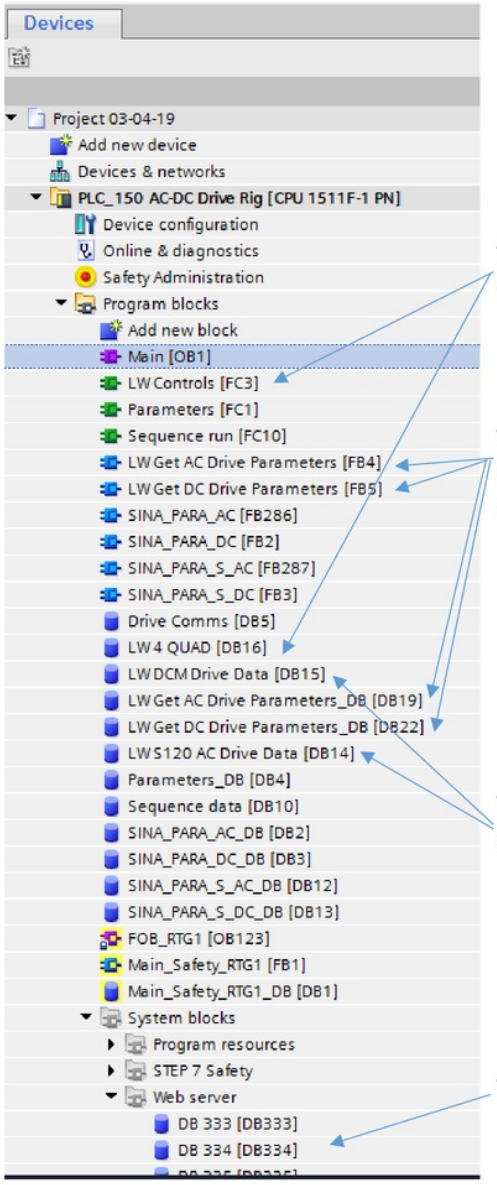

%I0.0
"E-STOP PANEL"
%I0.1
"E-STOP TABLE"
%I0.2
"DOOR SENSOR"
%M1.0
"AC Drive START"
%Q9.0
"DOOR COIL"
%M2.0
"DC Drive START"
%M0.2
"Door Locked"
"Sequence data".
"Sequence Start"
%I0.3
"DOOR LOCK"
%M0.1
"System Stopping"
%DB5.DBX13.1
"Drive Comms".
"AC Drive".
Receive.ZSW_1.
Ready
%DB5.DBX37.1
"Drive Comms".
"DC Drive".
Receive.ZSW_1.
Ready

Network 3:


%DB21
"F_IEC_Timer_
DB dc cooling
fan timer"
%M2.2
"DC Drive RUN"
TOF
Time
IN
Q
t#15s
PT
ET
T#0ms
%Q9.1
"DC Motor Fan"

Appendix E – Code technical explanation

The project tree shows the overall structure which will be broken down to explain each part.



Project 17-04-19 Main [OB1]

Network 1: DC Drive Start. This ladder program controls the DC Drive start via various contacts.

M2.2 DC Drive RUN coil energised and latched under following conditions:

M0.0 safety ok

M2.0 or M2.3 N/O contacts pushbutton start and HMI start respectively.

M2.1 and M103.1 N/C contacts push button stop and sequence stop respectively.

I0.5 N/O contact the safety input button, these safety contacts are always doubled for another layer of protection in the event of a failure.

M100.3 N/O contact the DC Run push button, which will operate when DC screen is selected.

Network 2: DC Push Button. This ladder program controls the DC Drive start via the DC pushbutton which is linked to the DC screen.

M100.3 DC Run PB coil is energised when M100.1 N/O contact for the DC screen is closed.

I0.4 and 5 N/O contacts are the safety input buttons Start and Stop respectively.

NOTE the same stop PB is used to stop both motors regardless of which screen is active. (Network 5)

Both network 2 and 4 have been modified to add start and stop controls for each drive via HMI from LW controls for 4 quadrant operation.

Network 3: AC Drive Start. This ladder program controls the AC Drive start via various contacts.

M1.2 AC Drive RUN coil is energised and latched via M0.0 safety ok. M1.0 or M1.3 N/O contacts are pushbutton start and HMI start respectively.

M1.1 and M102.3 N/C contacts are pushbutton stop and sequence stop respectively.

I0.5 N/O contact is the safety input button, these safety contacts are always doubled for another layer of protection in the event of a failure.

M100.2 N/O contact is the AC Run pushbutton which will operate when AC screen is selected.

Network 3 and 5 have been modified to allow HMI to stop drive.

Network 4: AC Push Button. This ladder program controls the AC Drive start via the AC pushbutton which is linked to the AC screen.

M100.2 AC Run PB coil is energised when M100.0 N/O contact for the AC screen is closed.

I0.4 and 5 N/O contacts are the safety input buttons Start and Stop respectively.

Network 5: Stopping system. This system operates the safety stopping and is interlocked to the motor enclosure door lock by a power to lock system.

M0.1 System Stopping coil energised and retained via:

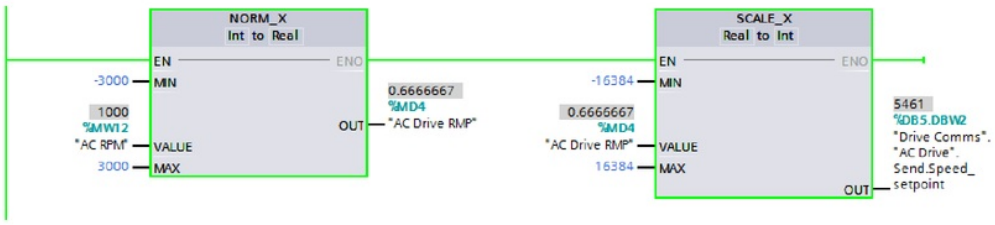
M1.1 AC Drive STOP or M2.1 DC Drive STOP or Sequence Stop or I0.5 Stop Safety Button or M0.2 Door Locked.

Network 6: Data scaling. This system normalises and scales data for use by the drives.

NORM_X is a function block used to normalize the value of a tag at the value input by mapping to a linear scale 0 to 1. Result is stored as a floating-point number.

In the example below the AC speed setpoint MW12 AC RPM was chosen to be 1000 rpm thus the output is given by:

OUT = (VALUE-MIN)/(MIN-MAX) = 1000-(-3000)/(3000-(-3000)) = 0.6666667



SCALE_X is a function block used to scale the value of a tag by mapping to a specified range defined by MIN and MAX parameters. Result is an integer stored in the OUT output. By applying the equation

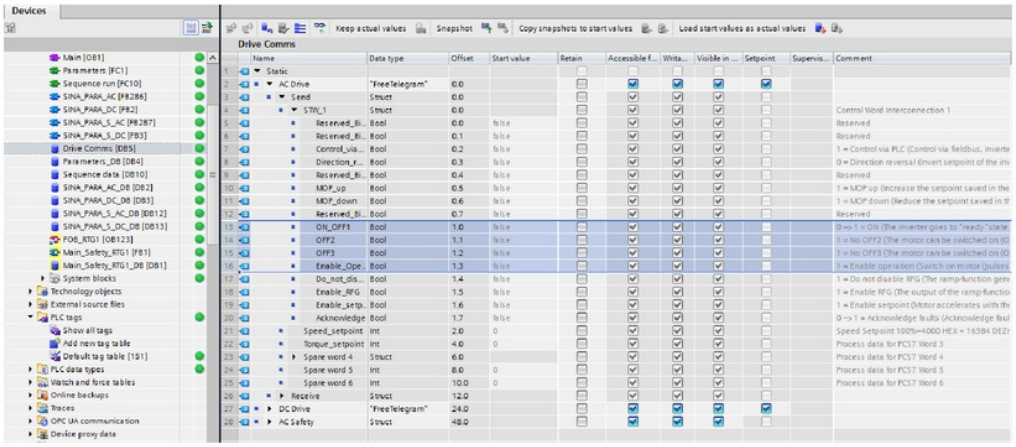
OUT = [VALUE*(MAX-MIN)] +MIN

to the above example the conversion becomes

OUT = [0.6666667*(16384- (-16384)]+-16384 = 5461.33333 as an integer is 5461.

Network 7: 0 →1 = ON. This is the AC Drive Comms which controls the state of the inverter i.e. ready, on or off which brakes the motor with a ramp-down time.

The remote address location DB5.DBX1.0 can be found in the Drive Comms data block as shown below by expanding the AC Drive Free Telegram, Send and STW_1 structure it is a Bool named ON_OFF1 and is controlled by M1.2 AC Drive RUN.



Network 8: Enable operation.

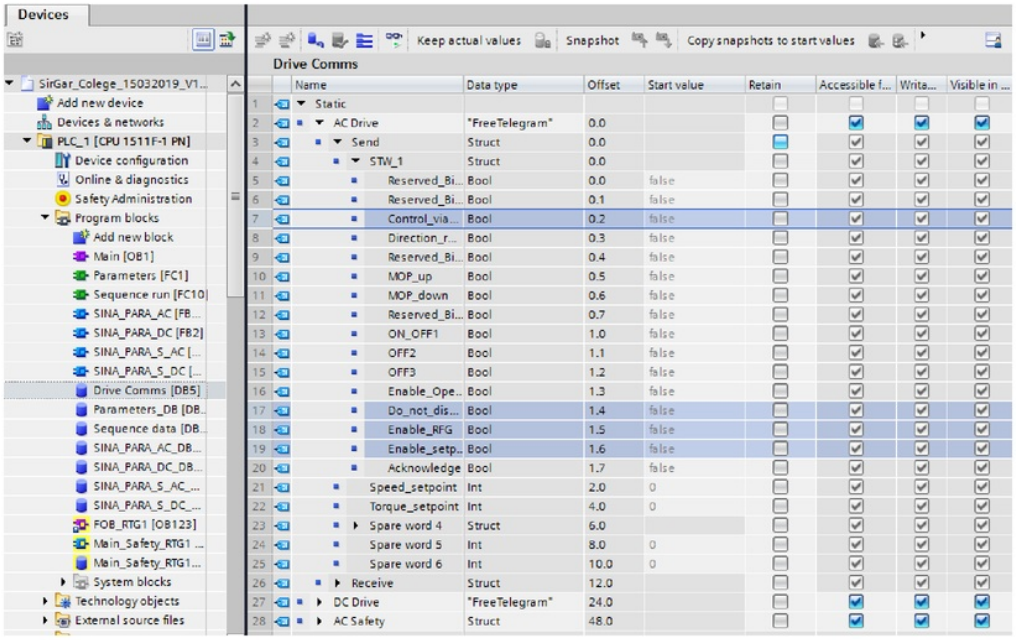
The data block above also shows Enable_Operation a Bool used to switch on pulses (motor ON) or cancel pulses (motor OFF), OFF2 a Bool used to switch off the motor which will coast to a stop and OFF3 a Bool used to switch off the motor at a prescribed ramp-down rate.



Hovering will produce more information as shown above P 0852[0] = r2090.3 refers to the drive parameters which can only be explored via STARTER software.

Network 9: Control via PLC. This either allows inverter to accept data via fieldbus or ignores the data from the fieldbus.

The same data block contains 4 more Bools i.e. Control_via_PLC, Do_not_disable_RFG, Enable_RFG and Enable_setpoint as shown below. AC Drive telegram control by Ramp Function generator (RFG).



Network 10: AC Drive COMMS.

http://www.diit.unict.it/users/scava/dispense/II/ComandiPLCS7MasterDP.pdf

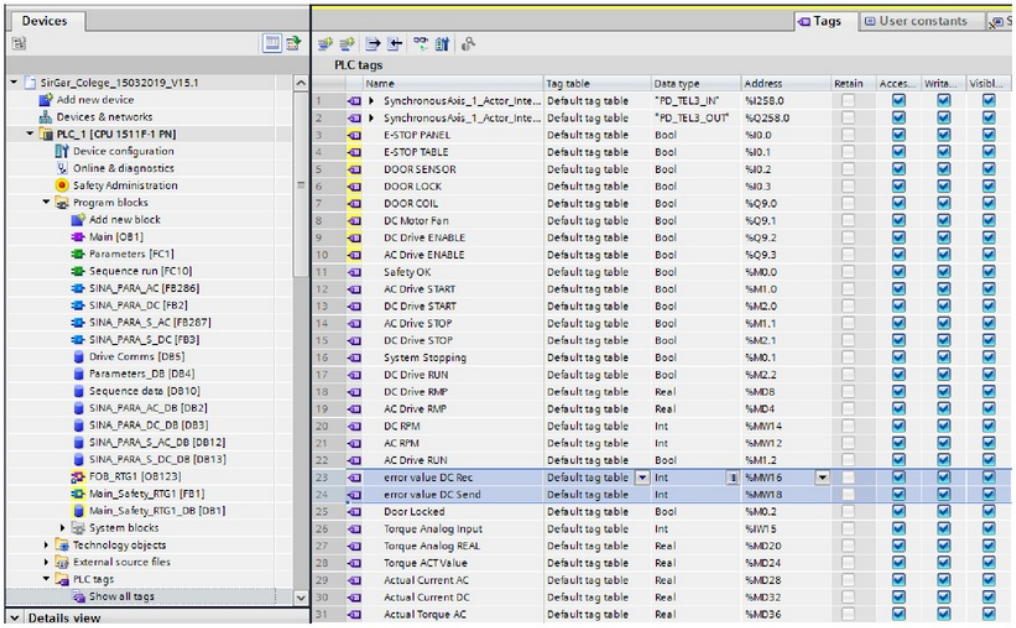
The PROFIBUS DP (distributed I/O) protocol has user data displayed as cyclic data image and works as a master-slave system.

The DPWR_DAT/DPRD_DAT (Read (RD)/Write(WR) DATA) user interface block will consistently either transfer data from source area to addressed DP standard slave and into process image (WR) or consistently read out data of a DP standard slave (RD) and has a byte limit.

"S120_CU320~PROFINET_interface~Drive_control_Free_telegram" is the configured start address from the input area of the module from which it is to be read or written to.

P#DB5.DBX12.0 BYTE 12 is the source or destination area for the user data to be read or written. Lengths must correspond.

MW16 is an integer called “error value DC Rec”, MW18 is an integer called “error value DC Send”, and both are contained in the PLC tag list (see below) and hold any error codes generated during function processing.



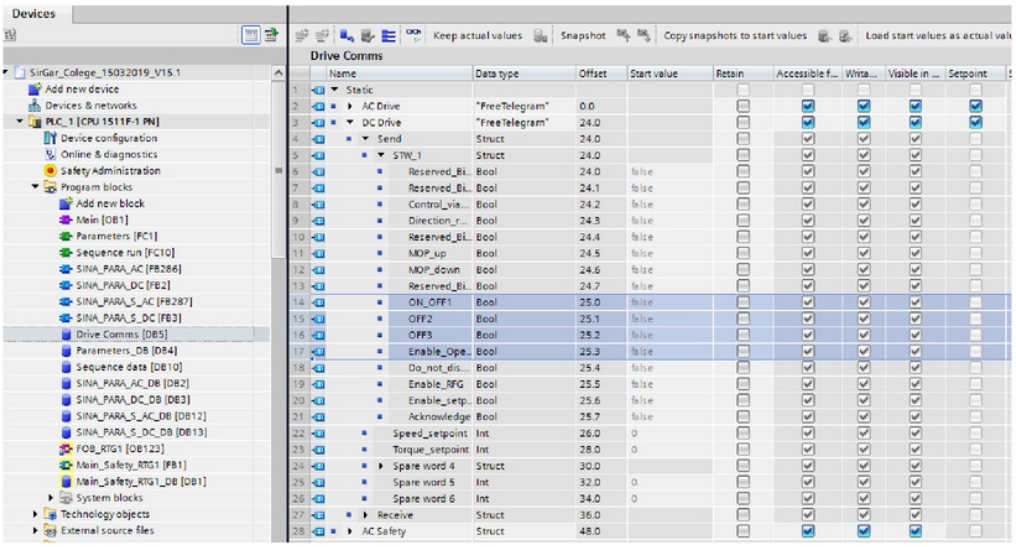
MW16 and 18 error value DC Rec and Send were the same for DC and AC comms so added AC Rec and Send to rectify error signals.

Network 11-13: Motor speed(rpm), current(A) and torque(Nm) actual for HMI

These three networks handle the scaling of these values back from the drive for display on the HMI. Details on function block operation can be seen in Network 6 explanation.

Modified to scale the torque max value to calculated 11.65 from motor data.

Network 14 to 17 for DC Drive COMMS, Enabling, PLC control and PROFIBUS are equivalent to 7 to 10 for AC.

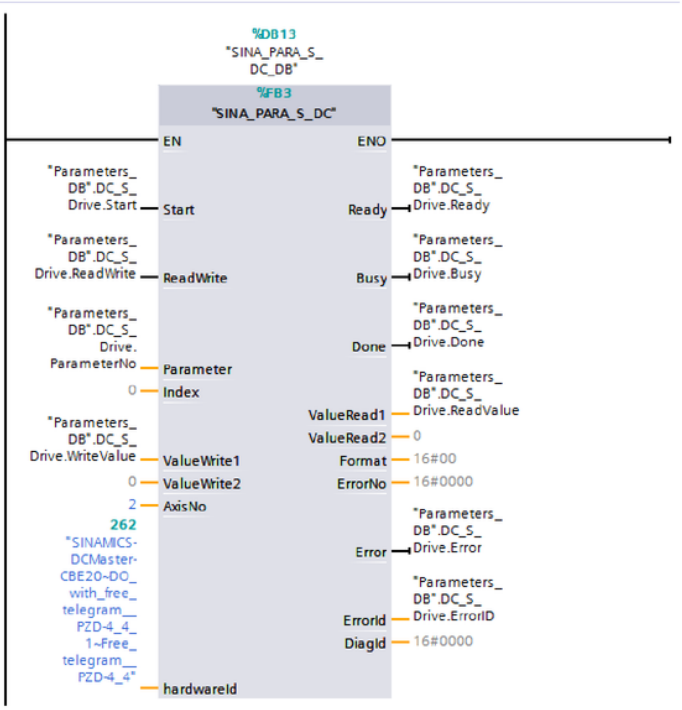


The above shows the FreeTelegram and location in DB5 of the bits for the DC Drive.

Network 18: Function Call 10 (FC10). This is the LADDER networks for the sequence HMI screen.

The function block FC10 has associated data block DB10. The function contains 22 networks of ladder rungs which controls the action of the sequence HMI screen.

Network 19: Function Call 1 (FC1). This contains the four LADDER networks for the parameters HMI screen and uses standard function block SINA_PARA and SINA_PARA_S.

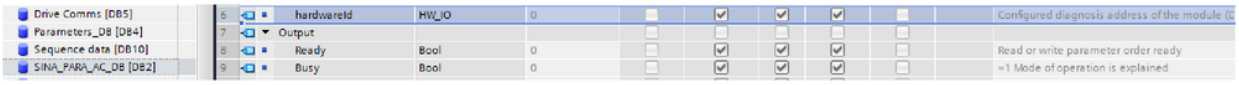


There are two types SINA_PARA and SINA_PARA_S the former being for acyclic communication up to 16 parameters and the latter for acyclic communication of one parameter (SINGLE) which can be read or written to a SINAMICS S/G drive.

The associated data block for FC1 is DB4.

https://cache.industry.siemens.com/dl/files/044/109475044/att_835664/v1/SINAMICS_Blocks_TIAP_V12SP1_V13.pdf

"SINAMICS-DCMaster-CBE20~DO_with_free_telegram__PZD-4_4_1~Free_telegram__PZD-4_4" goes to SINA_PARA_AC_DB[DB2] Input harwareId data type HW_IO configured diagnosis address of the module (DEC) for WRREC and RDREC.



The data accessed according to PROFIdrive profile dataset 47. The ParaNo input is specified to be read or written at the ReadWrite input to the block and is initiated by an edge-triggered Start input. Parameter data must be contained as REAL or DINT in the global DB creating an array of 16 UDT type entries called ‘SinaParameter’.

Input and Output interface of SINA_PARA defined in the information system in TIA.

Read action results in the parameter value and format being read from the drive and written and saved into the parameter structure, Busy is set to 1. Erroneous parameters cause an associated error number in the structure and sets the error bit. Successful read operations end with 1->0 edge on the Busy bit and 0->1 edge on the Done bit. Write action is similar but the parameter value set is sent to the drive after being first read from the drive.

SINA_PARA_S_DC

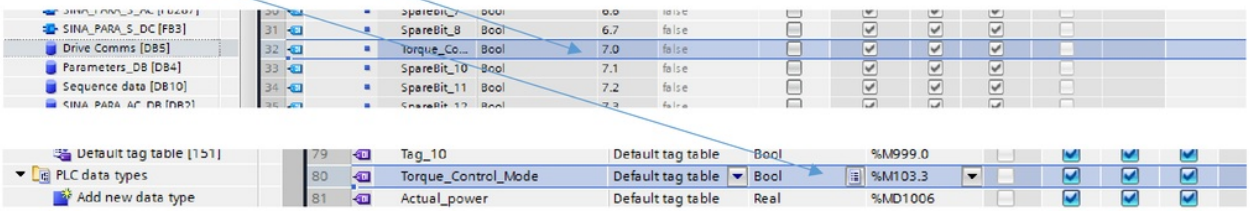
	Name	Data type	Default value	Retain	Accessible f...	Write...	Visible in ...	Setpoint	Supervis...	Comment
1	Input									
2	Start	Bool	0	Non-retain	☑	☑	☑	☐		Start command for read or write parame...
3	ReadWrite	Bool	0	Non-retain	☑	☑	☑	☐		Type of job 0 = read parameter, 1 = writ...
4	Parameter	Int	1	Non-ret...	☑	☑	☑	☐		Number of parameter (number 1..65535)
5	Index	Int	0	Non-retain	☑	☑	☑	☐		Subindex (number 0..65535)
6	ValueWrite1	Real	0.0	Non-retain	☑	☑	☑	☐		Value of the write parameter (byte, wor...
7	ValueWrite2	DInt	0	Non-retain	☑	☑	☑	☐		Value of the write parameter (dint)
8	AxisNo	Byte	16#01	Non-retain	☑	☑	☑	☐		Object ID of drive
9	hardwareId	HW_IO	0	Non-retain	☑	☑	☑	☐		Configured diagnosis address of the mo...
10	Output				☐	☐	☐	☐		
11	Ready	Bool	0	Non-retain	☑	☑	☑	☐		Read or write parameter order ready
12	Busy	Bool	0	Non-retain	☑	☑	☑	☐		Mode of operation is explained
13	Done	Bool	1	Non-retain	☑	☑	☑	☐		Mode of operation without mistake finis...
14	ValueRead1	Real	0.0	Non-retain	☑	☑	☑	☐		Value of the read parameter (byte, word...
15	ValueRead2	DInt	0	Non-retain	☑	☑	☑	☐		Value of the read parameter (dint)

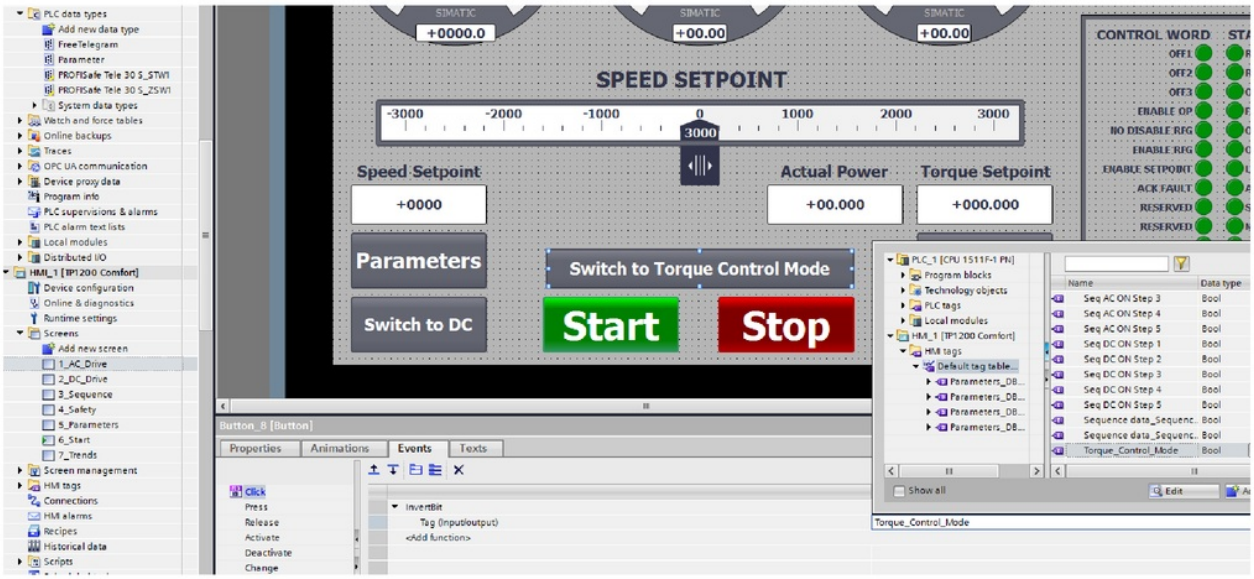
Data structure of the Parameter variable is identifiable from the associated data block.

Parameter is an Int (value range 1..65535)

Network 20: AC Torque Control Mode.

DB5.DBX7.0 "Drive Comms"."AC Drive".Send."Spare word 4".Torque_Control is energised when M103.3 tagged to the Torque Control Switch in the AC HMI screen is pressed.





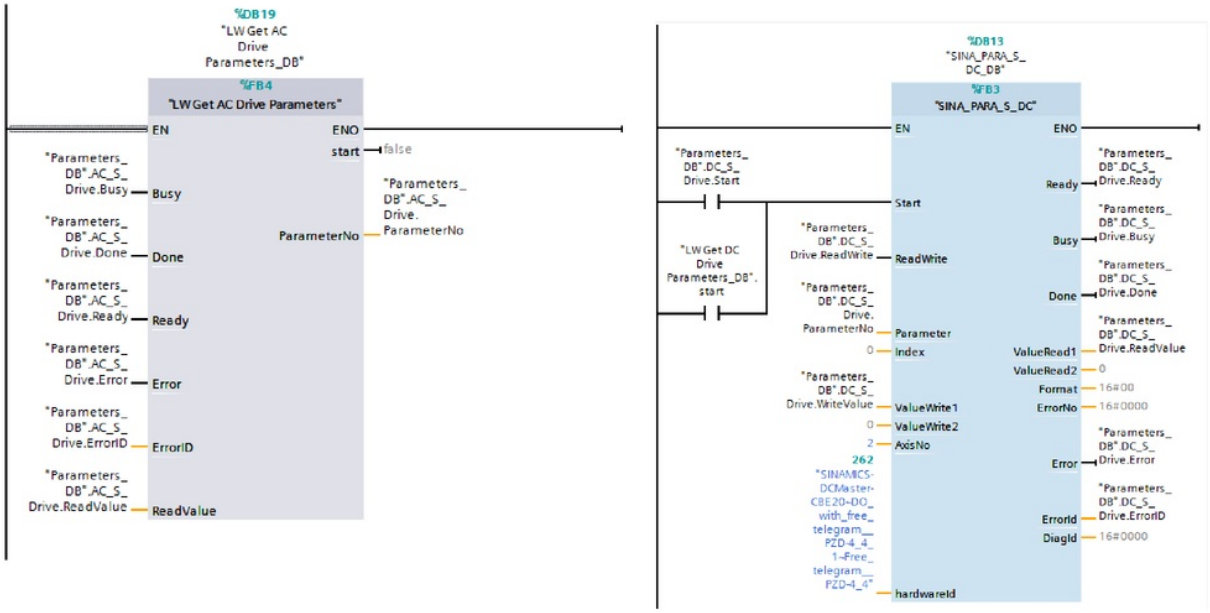
CAUTION! It is important that when in Torque mode the DC drive is on and will have a speed set point to hold the torque if the DC drive is off the AC drive will try to reach torque set point under no load and the motor will run away!

Network 21: LW Controls [FC3]

The function call LW controls which enables 4 quadrant manual and automatic operation.

Network 22 and 23: LW Get Parameters [FB4 and 5]

The function calls for automating the SINA_PARA_S sequence for both AC and DC drives. This block links to the SINA_PARA_S block taking the start output from a counter in conjunction with two timers to sequence through parameter values and move them to the drive data blocks for display.



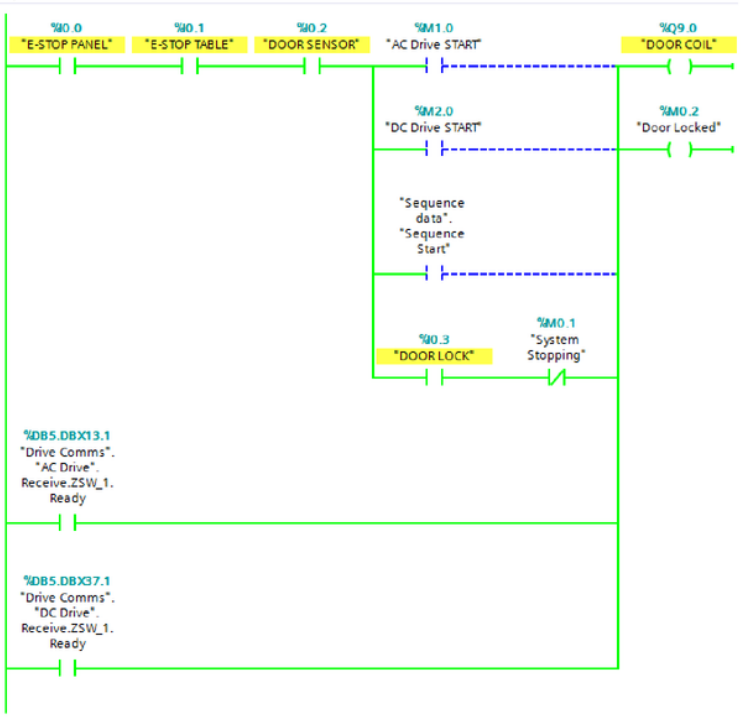
Main_Safety_RTG1 [FB1]

Network 1: Ladder rung for M0.0 Safety OK.

N/O contacts I0.0, I0.1 and I0.2 for Panel, Table and Motor enclosure door lock must be made, otherwise Safety is Not OK and drives will not be enabled.

Network 2: Ladder rung for Q9.0 DOOR COIL Safety.

N/O contacts M1.0 or M2.0 for AC and DC Drive START or “Sequence Start”or I0.3 DOOR LOCK will allow Q9.0 and M0.2 to energise thus keeping power on the Door Coil preventing opening of the motor enclosure. M0.1 system stopping must also be closed. As seen below both drives are activated along with their associated communications channels and the power to lock on the motor enclosure.



Network 3: DC Motor Fan.

This puts power to the DC fan motor when the DC drive is started. Modified to include a 5 second timer to delay the fan when the motor stops.

Sequence run [FC10] Consists of five steps where S120 and DCM motor speed can be selected.

Network 1 to 5: Handles the sequence step time.

Converts sequence timing from milliseconds to seconds for display in the elapsed time window. For each of the five sequence steps.

Network 6: If Safety OK starts sequence in Step 1.

Uses the 'Move value' block to transfer the INT at the IN input to the operand at the OUT1 output when enabled.

Network 8, 10, 12, 14 and 17: Evaluate sliders on/off.

Ladder program checks step number and evaluates HMI slider and puts relevant drive on or off.



Network 7, 9, 11, 13 and 15: Moves data to drive under control of timers for each step.

For each step starts the timer and shows the elapsed time, after which moves to next step, also moves the sequence speed SP to the drive.

Network 16: Sequence done.

Energises the sequence done command upon detection of a positive signal edge 0 to 1 change.

Network 18: Ends the sequence, cancels all.

Stopped by either completion of sequence or HMI stop or Push Button Stop or Safety OK via E-Stop.

Network 19: Stops both drives via HMI stop or sequence done.

Looks for a positive signal edge on 'sequence stop' or 'sequence done'.

Network 20 and 21: Stops individual step using slider control.

Control to put drive on or off at each step of the sequence

LW Controls [FC3]

Network 1: AC and DC Drive Start

Allows user to start both drives when in either manual or auto mode.

Network 2: AC and DC Drive Stops

Allows user to stop both drives when in either manual or auto mode or when sequence ends.

Network 3 to 6: AC Quadrant indicator lights.

Puts conditions on the AC 4 quadrant indicators to tie them to each appropriate quadrant.

Network 7 to 10: Manual Quadrant selection buttons.

Uses the Move function block to put data into both drives to demonstrate each quadrant at will when not in auto mode.

Network 11: Set AC Torque mode in 4 quadrant operation.

Automatically switches mode on AC drive by set and reset of the bit for Torque Control mode when demonstrating the quadrants.

Network 12: Sequence Auto RUN

When in Auto mode starts and stops 'Auto Sequence RUN' by set and reset of the bit, uses sequence end HMI Auto Stop or Auto mode to stop the sequence.

Network 13: 4 Quadrant Sequence Timer.

A 20 second timer for the Auto sequence RUN.

Network 14 to 17: Step 1 to 4 of the 4 Quadrant Sequence.

Moves the values for speed and torque set points every 5 seconds to demonstrate each quadrant for both motors on an automatic sequence.

Network 18 to 21: DC Quadrant indicator lights.

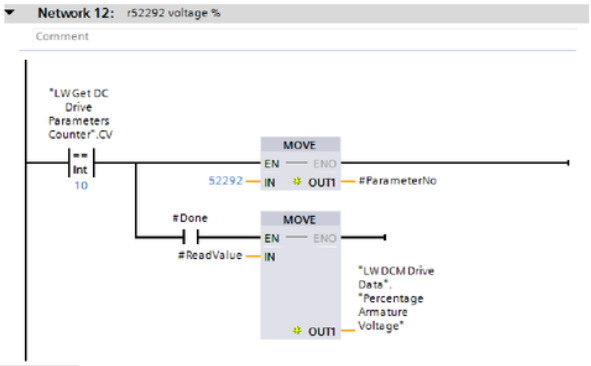
Puts conditions on the DC 4 quadrant indicators to tie them to each appropriate quadrant.

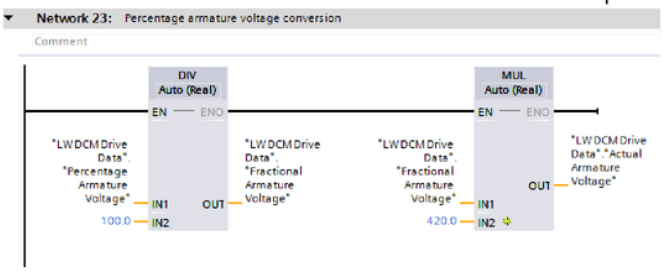
Network 22: Absolute armature current conversion.

A comparison instruction used to mirror the sign of the torque parameter

Network 23: Armature voltage conversion

Network 12 from the LW Get AC and DC Drive Parameters shows parameter r52292 being loaded at count 10. This value is converted to an actual value.





LW Get AC and DC Drive Parameters [FB 4 and 5]

Uses a counter and two timers along with the required move blocks to read key parameters from both drives via the SINA_PARA_S blocks.

Network 1: Timers

The start output will be pulsed by the two timers.

Network 2: Counter

When the start output is energised the counter increments and resets at a count of 12, allowing a total of 11 parameters to be read.

Network 3 to 12: Parameters Read from Drives.

A comparator checks the count value and moves the selected parameter number into the parameter number of the SINA_PARA_S block, when the done bit goes high the parameter number is read and the value moved to the drive data block.

Appendix F1 and F2 - 4-quadrant tests of DCM and S120

S120

Function	Quad	Vrms (V) r25	I (A)* r27 r27	I (A) r30 ** r30	N (rpm) r22	Tm (Nm) r31	P(kW) r32	pf r38	f(Hz) r24
Fwd Mot	1	250.9	3.08	2.14	1003.1	6.69	0.694	0.64	33.97
	1	246.7	2.45	1.07	1004.7	3.4	0.348	0.43	33.77
Fwd Gen	2	233.29	3.13	-2.13	1003.5	-6.85	-0.683	-0.59	32.81
	2	237.46	2.44	-1.07	1003.1	-3.3	-0.349	-0.35	33.73
Rvs Mot	3	257.01	3.1	-2.12	-1002.2	-6.8	0.691	0.65	-33.89
	3	245.8	2.45	-1.06	-1004.3	-3.2	0.348	0.43	-33.72
Rvs Gen	4	233.01	3.13	2.13	-1003	6.79	-0.691	-0.59	-32.95
	4	237.67	2.44	1.07	-1004.7	3.3	-0.346	-0.36	-33.26

Calculated values from measured data			
w(rad/s)	Pm (W)	Pe (r27)	Ploss
105.058	702.8381	856.6023	153.7642
105.2256	357.767	450.1441	92.37714
105.0999	-719.934	-746.174	26.24011
105.058	-346.691	-351.234	4.542313
-104.964	713.7535	896.9598	183.2063
-105.184	336.5878	448.5019	111.9141
-105.048	-713.273	-745.279	32.0061
-105.226	-347.244	-361.588	14.34406

* absolute value ** incorrect or suspected incorrect value

Results	**Theory**
V and f slight reduction at lower torque when motoring	V/f ratio maintained
V and f slight increase at lower torque when generating	V/f ratio maintained
I(r27) absolute value reduces at reduced torque	T/I ratio maintained, absolute value used for Power calculations
Power and pf increase at higher torque and both display correct sign	Negative when generating, proportional to torque in constant torque region
Pe(r27) larger than Pm when motoring (1.732 Vlcosphi)	Input Pe greater than output Pm giving a positive P loss that increases at higher torque
Pe(r27) more negative than Pm when generating	Input Pm greater than output Pe giving a positive P loss that increases at higher torque
Speed displays correct sign for appropriate quadrant	Forward CW and reverse CCW direction
Torque displays correct sign for appropriate function	Same sign as speed when motoring, opposite sign when generating

DCM

Function	Quad	Vav (V) r52292	Ia (A) r27*	N (rpm) r63	Tm (Nm) r31	P(kW) r32	α (deg) r50018	Eb (V) r50037	Va (V) r50038
Fwd Mot	1	146.6	5.22	1000.3	6.69	1.02	68.75	178.1	196.3
	1	140.35	2.76	1000.1	3.52	0.52	75.1	178.9	190.4
Fwd Gen	2	121.41	-3.77	996.8	-4.92	-0.62	107.85	179.3	165.1
	2	128.5	-1.6	998.9	-2.1	-0.28	114.8	179.2	173.3
Rvs Mot	3	-146.3	-5.11	-1000.1	-6.68	1.01	68.57	-178.9	-197.4
	3	-140.5	-2.78	-1000.3	-3.58	0.54	75.8	-179.2	-191.1
Rvs Gen	4	-120.7	3.78	-1000.1	4.95	-0.62	107.76	-177	-164.3
	4	-128.31	1.64	-1000.2	2.12	-0.28	115.5	-178.6	-172.3

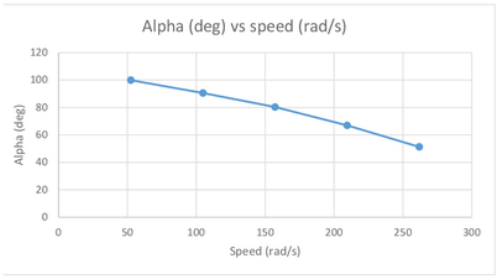
Calculated values from measured data									
w (rad/s)	Pm (W)	Pe (W)	Ploss (W)	alpha (rad)	cos alpha	Vav (V)	Va ABS	Eb ABS	Va-Eb (V)
104.7648	700.8762	765.252	64.3758002	1.200069444	0.362293029	145.2862	196.3	178.1	18.2
104.7438	368.6982	387.366	18.6678005	1.310912222	0.25696855	103.0491	190.4	178.9	11.5
104.3982	-513.639	-457.716	55.9233784	1.882581667	-0.306758388	-123.016	165.1	179.3	-14.2
104.6181	-219.698	-205.6	14.098066	2.003897778	-0.419687906	-168.303	173.3	179.2	-5.9
-104.744	699.6886	747.593	47.9043715	1.196927444	0.365219781	146.4599	197.4	178.9	18.5
-104.765	375.0578	390.59	15.5321831	1.323131111	0.245141085	98.3061	191.1	179.2	11.9
-104.744	-518.482	-456.246	62.235843	1.881010667	-0.305262752	-122.416	164.3	177	-12.7
-104.754	-222.079	-210.428	11.6506736	2.016116667	-0.430747	-172.737	172.3	178.6	-6.3

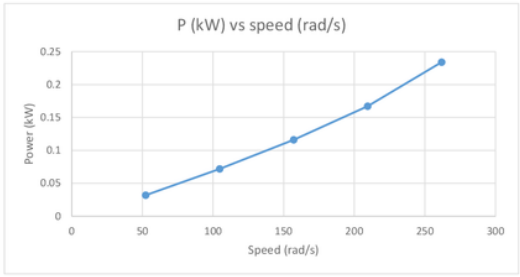
* absolute value

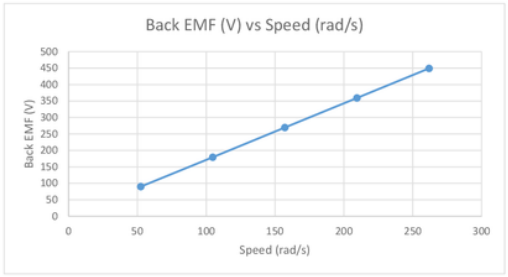
Results	Theory
Speed and Vav correct sign for appropriate quadrant	Forward CW and reverse CCW direction
Va reduces at lower torque when motoring	Speed and thus Eb are constant, Ra is constant (V = Eb + IaRa)
Va increases at lower torque when generating	Speed and thus Eb are constant, Ra is constant (V = Eb - IaRa)
Pe larger than Pm when motoring	Input Pe greater than output Pm giving a positive P loss that increases at higher torque
Pe absolute less than Pm when generating	Input Pm greater than output Pe giving a positive P loss that increases at higher torque
Ia and P display correct sign for appropriate quadrant	Negative power and current flow when genrating
Alpha increases at lower torque.	Increases the delay of the firing angle
Alpha >90 when geneating	When alpha >90 inversion occurs this makes cos alpha and hence Vav change sign
Vav calculations are close match at 5Nm	Vav = 3Vmax(line) cos alpha/pi
Va correct sign and reduces with reduced torque	Forward CW and reverse CCW direction
Eb correct sign and remains constant with speed	Forward CW and reverse CCW direction
Va>Eb when motoring (Q1 and Q3)	V=Eb + IaRa
Va<Eb when generating (Q2 and Q4)	V=Eb - IaRa

Appendix F3 - DCM off load tests

										Calculated values from measured data				
N (rpm)	w (rad/s)	T (Nm)	Eb (V)	P (kW)	Alpha (deg)	Alpha (rads)	Ia (A)	If (A)	V av (V)	ke	km	cos alpha	Pm (W)	Ploss (W)
500	52.36667	0.43	89.838	0.032	99.88	1.743460889	0.342	18.649	67.82	1.715557	1.25731	-0.1718079	22.51767	9.482333
1000	104.7333	0.54	179.159	0.072	90.55	1.580600556	0.401	18.666	134.78	1.710621	1.346633	-0.0098041	56.556	15.444
1500	157.1	0.6	269.342	0.116	80.35	1.402553889	0.441	18.668	200.02	1.714462	1.360544	0.16744986	94.26	21.74
2000	209.4667	0.65	359.227	0.167	66.929	1.168282878	0.48	18.664	266.73	1.71496	1.354167	0.39173215	136.1533	30.84667
2500	261.8333	0.76	449.147	0.234	51.257	0.894719411	0.541	18.674	332.23	1.715393	1.404806	0.62573771	198.9933	35.00667







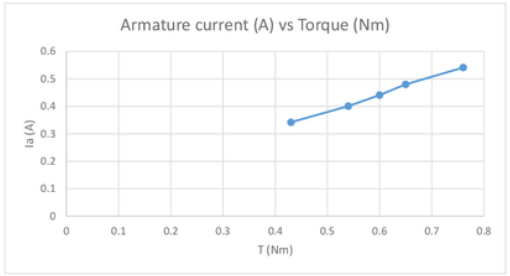
Ratings

3.05kW, 420V, 8.7A, 2500 rpm

W = 2*pi*2500/60 = 261.8 rad/s

T = 3050/261.8 = 11.65Nm

Km = Tr/Ia = 11.65/8.7 = 1.34



The low torque can be attributed to the friction, windage and inertia
Back EMF increases lineraly with speed
Power increases linearly with speed
Alpha decreases linearly with speed demonstrating theory that the delay angle influences the voltage average
Armature current is proportional to torque
Field current is constant in this range - field weakening not reached
Average armature voltage increases with speed
ke = 1.71 consistently
km = approximately 1.3 which matches the value from ratings
Mechanical power increses with speed
Power loss is positive and increases with speed

Appendix F4 - S120 No load test

N(rpm)	Torque (Nm)	frequency (Hz)	Voltage (V)	DC Link (V)	Power (kW)	p.f.	Current (A)
500	0.6	16.7	121.3	600	0.03	0.15	0.2
1000	0.8	33.4	242.6	595	0.08	0.147	0.25
1500	0.84	50	363	592	0.13	0.14	0.27
2000	0.81	66.78	358	590	0.17	0.22	0.35
2500	0.82	83.5	359	589	0.21	0.35	0.44

V/f	T/I
7.263473	3
7.263473	3.2
7.26	3.111111111
5.360886	2.314285714
4.299401	1.863636364

Ratings

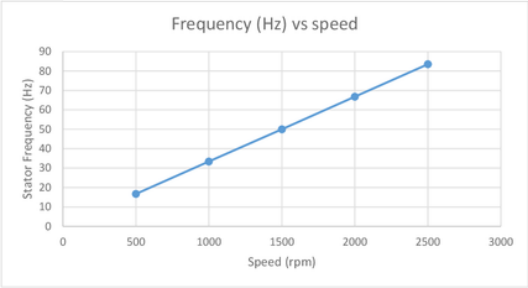
3kW, 415V, 5.7A, 1460 rpm

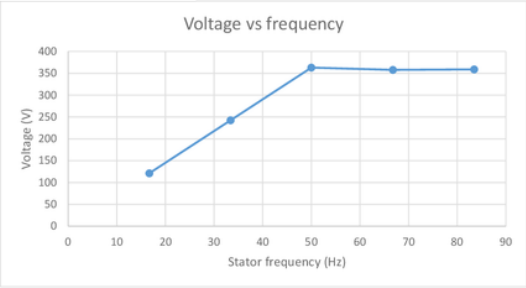
W = 2* pi* 1460/60 = 151.8 rad/s

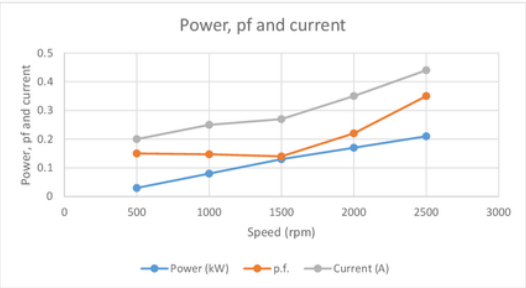
T = 3000/151.8 = 19.76Nm

K = Tr/I = 19.76/5.7 = 3.46

The low torque is attributed to the friction, windage and inertia of the DC motor
The V/f ratio is 7.26 up to base speed above this the ratio reduces as V is maximum
DC Link remains constant
Power increses linearly with increasing speed
Power factor is low due to the low load torque
Current is low due to low torque it increases with increasing speed.

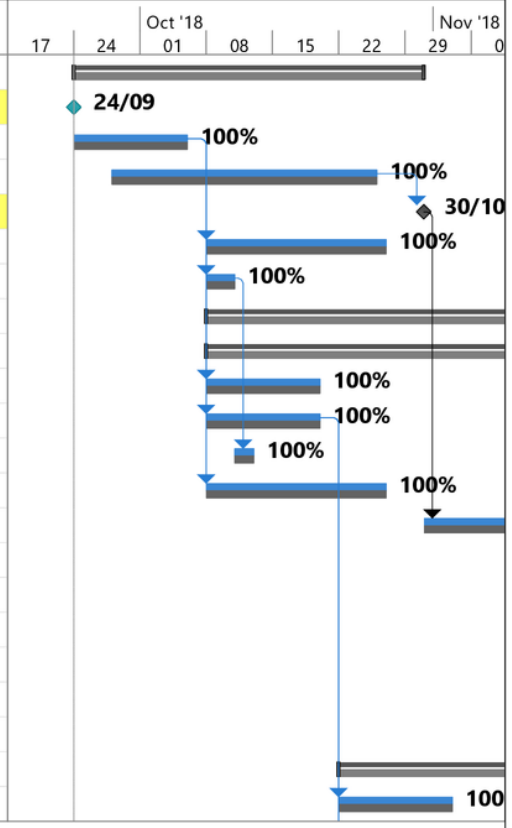






10Appendix G - Project Plan v3

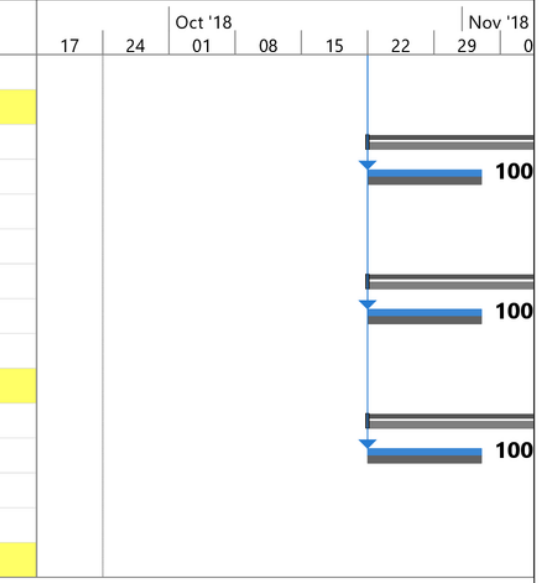
ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		**Definition**	**27 days**	**Mon 24/09/1**	**Tue 30/10/18**	
2		Start	0 days	Mon 24/09/1	Mon 24/09/18	
3		Initial Investigation	10 days	Mon 24/09/1	Fri 05/10/18	
4		Quotations	20 days	Fri 28/09/18	Thu 25/10/18	
5		FDS acceptance	3 days	Fri 26/10/18	Tue 30/10/18	4
6		Planning and monitoring	15 days	Mon 08/10/1	Fri 26/10/18	3
7		Regulations	3 days	Mon 08/10/1	Wed 10/10/18	3
8		**Execution (TS/CSG)**	**117 days**	**Mon 08/10/1**	**Tue 02/04/19**	
9		**Execution (TS)**	**113 days**	**Mon 08/10/1**	**Wed 27/03/19**	
10		Mechanical design	10 days	Mon 08/10/1	Fri 19/10/18	3
11		Electrical design	10 days	Mon 08/10/1	Fri 19/10/18	3
12		Safety design	2 days	Thu 11/10/18	Fri 12/10/18	7
13		Software design	15 days	Mon 08/10/1	Fri 26/10/18	3
14		Mechanical build	25 days	Wed 31/10/1	Tue 04/12/18	5
15		Electrical build	5 days	Wed 20/02/1	Tue 26/02/19	14FS+45 days
16		Programming	21 days	Wed 27/02/1	Wed 27/03/19	15
17		Test	2 days	Thu 28/03/19	Fri 29/03/19	16
18		Handover	2 days	Mon 01/04/1	Tue 02/04/19	17
19		**Delivery**	**2 days**	**Thu 07/03/19**	**Fri 08/03/19**	
20		Install and Test at CSG	2 days	Thu 07/03/19	Fri 08/03/19	18,15
21		**HMI 1**	**116 days**	**Mon 22/10/1**	**Mon 15/04/19**	
22		HMI design DC motor	10 days	Mon 22/10/1	Fri 02/11/18	11



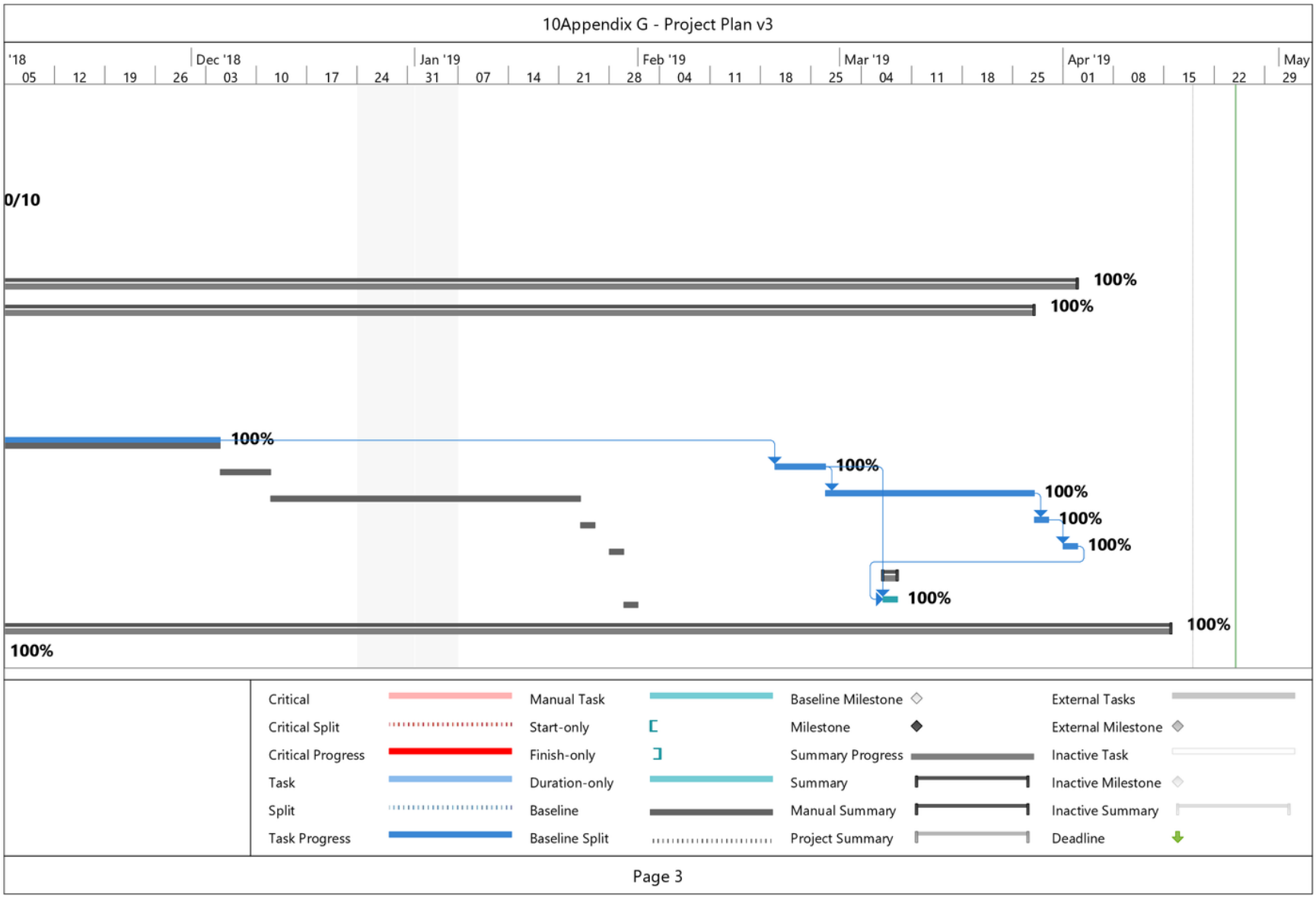
Critical	Manual Task	Baseline Milestone	External Tasks
Critical Split	Start-only	Milestone	External Milestone
Critical Progress	Finish-only	Summary Progress	Inactive Task
Task	Duration-only	Summary	Inactive Milestone
Split	Baseline	Manual Summary	Inactive Summary
Task Progress	Baseline Split	Project Summary	Deadline

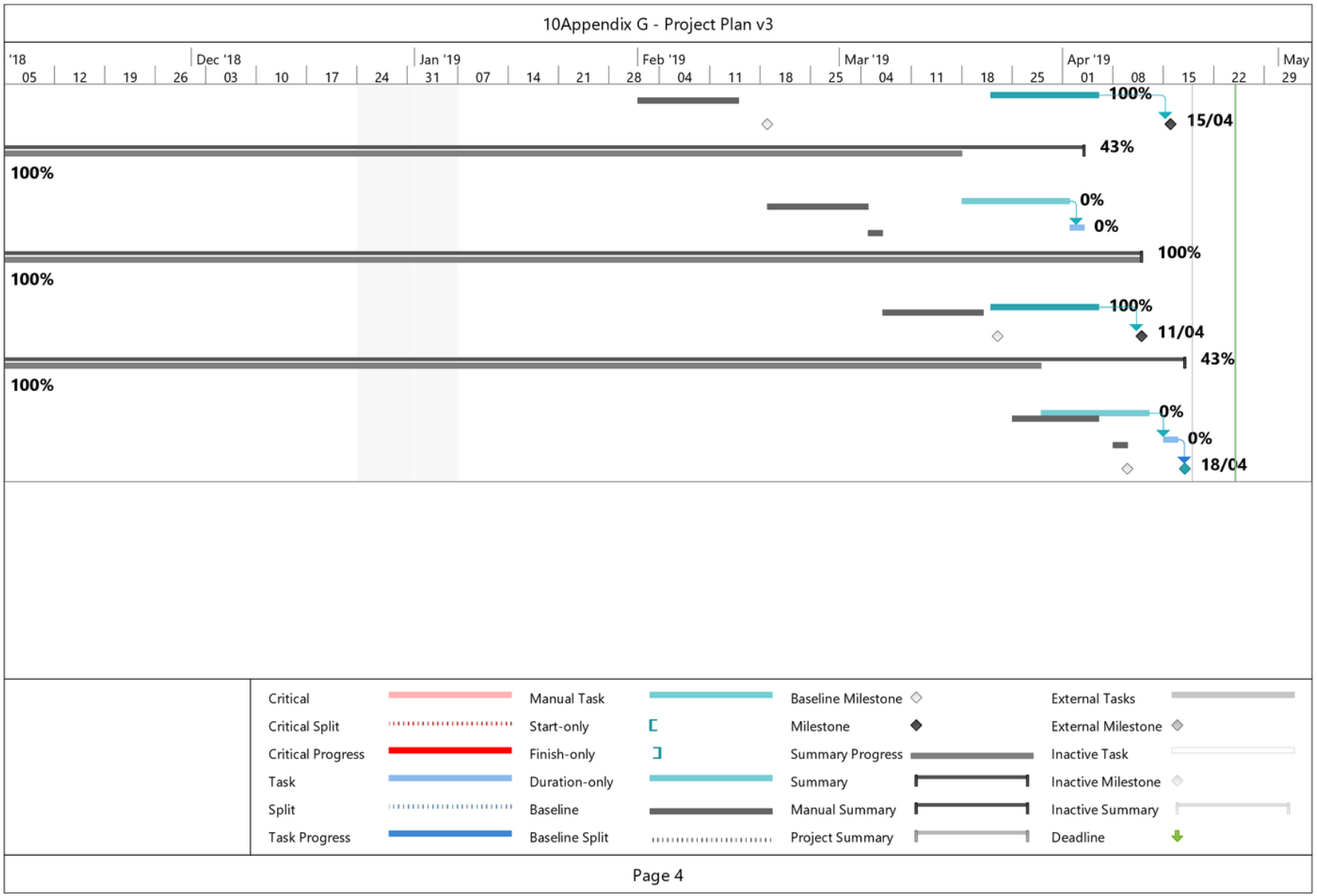
10Appendix G - Project Plan v3

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
23		Sequence DC motor	11 days	Fri 22/03/19	Fri 05/04/19	
24		Test DC motor	6 days	Mon 08/04/1	Mon 15/04/19	23
25		**HMI 2**	**108 days**	**Mon 22/10/1**	**Wed 03/04/19**	
26		HMI design FW	10 days	Mon 22/10/1	Fri 02/11/18	11
27		Sequence FW	11 days	Mon 18/03/1	Mon 01/04/19	
28		Test FW	2 days	Tue 02/04/1	Wed 03/04/19	27
29		**HMI 3**	**114 days**	**Mon 22/10/1**	**Thu 11/04/19**	
30		HMI design AC motor	10 days	Mon 22/10/1	Fri 02/11/18	11
31		Sequence AC motor	11 days	Fri 22/03/19	Fri 05/04/19	
32		Test AC motor	6 days	Tue 02/04/1	Thu 11/04/19	31
33		**HMI 4**	**118 days**	**Mon 22/10/1**	**Thu 18/04/19**	
34		HMI design VSI	10 days	Mon 22/10/1	Fri 02/11/18	11
35		Sequence VSI	11 days	Fri 29/03/19	Fri 12/04/19	
36		Test VSI	2 days	Mon 15/04/1	Tue 16/04/19	35
37		Finish	0 days	Thu 18/04/1	Thu 18/04/19	36

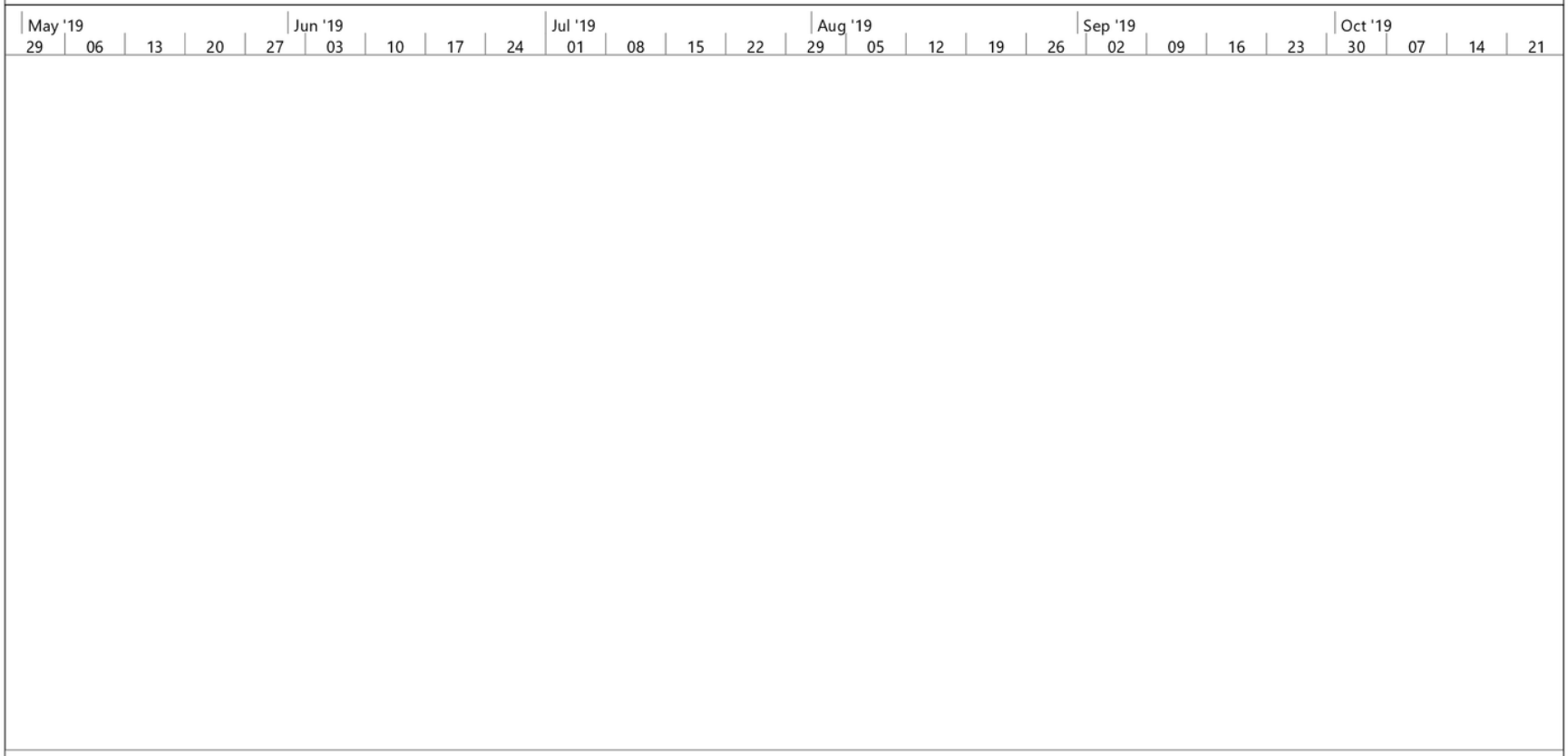


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Critical Progress	Finish-only	Summary Progress	Inactive Task
Task	Duration-only	Summary	Inactive Milestone
Split	Baseline	Manual Summary	Inactive Summary
Task Progress	Baseline Split	Project Summary	Deadline

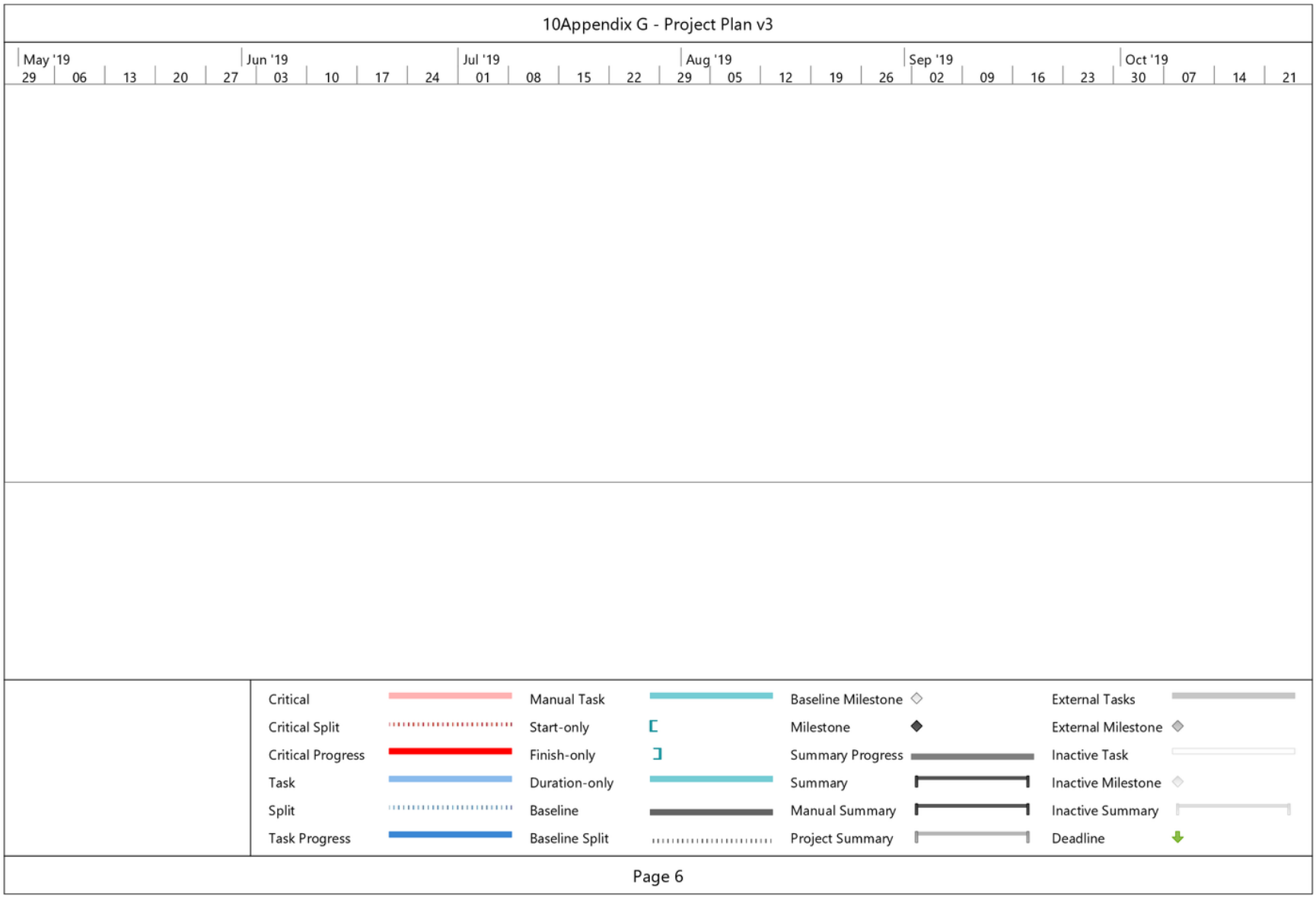

10Appendix G - Project Plan v3
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External Tasks
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Inactive Task
Inactive Milestone
Inactive Summary
Deadline


10Appendix G - Project Plan v3
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Project Summary
External Tasks
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Inactive Summary
Deadline

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Critical	Manual Task	Baseline Milestone	External Tasks
Critical Split	Start-only	Milestone	External Milestone
Critical Progress	Finish-only	Summary Progress	Inactive Task
Task	Duration-only	Summary	Inactive Milestone
Split	Baseline	Manual Summary	Inactive Summary
Task Progress	Baseline Split	Project Summary	Deadline


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May '19
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Baseline Split
Baseline Milestone
Milestone
Summary Progress
Summary
Manual Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Deadline

Appendix H - Costing Spredasheet

Main parts breakdown for AC/DC Siemens Motor test rig.

Item.	Materials / Labour Description.	Unit	Cost £.	Total £.
1	Siemens Stormrichter 6RA8013-6DV62-0AA0	1	1513.48	1513.48
2	Siemens DC Shunt Motor 1GA51060AD766VEO-Z	1	2500	2500
3	SINAMICS S120 CU 6SL3040-1MA01-0AA0	1	637.24	637.24
4	SINAMICS S120 Smart Line Module 6SL3130-6AE15-0AB1	1	1421.71	1421.71
5	SINAMICS S120 Single MOMO 9A 6SL3120-1TE21-0AD0	1	827.66	827.66
6	Siemens AC Induction motor 1LE1004-1B52-3AA4-Z-G01	1	1267.55	1267.55
7	HMI TP1200 Comfort Panel 6AV2124-0MC01-0AX0	1	2275.01	2275.01
8	Siemens S7-1500 6ES7511-1FK02-0AB0	1	850.05	850.05
9	Ethernet Switch 6GK5008-0BA00-1AB2	1	108.99	108.99
10	Torque Transducer TQ514	1	2345.57	2345.57
	Total for main parts			13747.26
	Note: Other supplier costs include other parts for test rig, construction, programming, CE mark and delivery			
	Grand total			27314.00

Installation of 32Amp 3Phase & Neutral Mains Supply in G8 Electronics' Laboratory.

Item.	Materials / Labour Description.	Unit	Cost £.	Total £.
1	1 Metre 4mm. Sq. single core pvc cable in phase & earth colours	5	0.3	1.5
2	3 Phase 5 pin 32 amp Industrial Wall mounted angled socket.	1	8.17	8.17
3	32 Amp 3 Pole Non fused Rotary Lockable Isolator.	1	19.83	19.83
4	Sundries plugs / Screws / Fittings	1	3	3
5	Labour, Include, Testing, Voltage Insulation & Earth Continuity etc.	3.5	38.77	135.695
6	***Grand Total.***			**168.195**

Risk Report

safe:machine

Risk Assessment

The risk assessment method used is a Hazard Rating Number system, a quantative risk assessment method. It was developed originally by Chris Steel, and was introduced in an article in Safety, Health and Practitioner magazine in 1990. It has been adapted since, and updated. Any risk assessment method is dependent upon identifying the hazard and determining the control measure, the numbers provide guidance to prioritising the assessments.

This method works by identifying the hazard, then assessing the hazard against Likelihood of Occurrence, how likely is it that the hazard will lead to an injury? Consideration must be given to how easy it is to avoid the hazard. Choose from one of the options, from Almost impossible, to Certain. Then determine what the Frequency of Exposure is, many hazards are going to be there always, so the Frequency is likely to be Constant. Variations can include access into electrical enclosures, which is probably going to be not Constant, it can be assumed to be Monthly for most. The next Variable is Degree of Possible Harm, i.e. what could happen, from a scratch or bruise, to a fatality. Then finally, the Number of People at Risk at any one time, usually one for most hazards.

The numbers are multiplied together to give a Hazard Rating Number, which equates to a Degree of Risk from Negligible to Unacceptable. The principle is that if possible the hazard should be designed out, if not possible, safeguards built in and finally any residual risk controlled with warnings and training.

A control measure is determined from the assessment, and a re-assessment carried out. Adequate risk reduction should be demonstrated. If sufficient risk reduction is not achieved, further controls should be added until the hazard is deemed tolerable.

Risk assessment is very subjective, and different people have very different ideas, which is why the numbers are used as guidelines, not intended to be an absolute.

EN ISO 12100: 2010 Safety of machinery - General principles for design. Risk assessment and risk reduction, is a useful standard and one anyone carrying out risk assessment should have access to.

It is the responsibility of the person carrying out the assessment to ensure that the assessments are adequate, if duplicating or amending existing risk assessments.

Key

Liklihood of Occurrence (LO)		Frequency of Exposure (FE)		Degree of Possible Harm (DPH)		Number of Persons at Risk (PE)	
0.033	Almost Impossible, possible in extreme circumstances	0.1	Infrequently	0.1	Scratch/bruise	1	1-2 persons
0.5	Highly Unlikely, though conceivable	0.2	Annually	0.5	Laceration/mild ill health	2	3-7 persons
1	Unlikely, but could occur	1	Monthly	1	Break minor bone/illness (temporary)	4	8-15 persons
2	Possible, but unusual	1.5	Weekly	2	Break major bone/illness (permanent)	8	16-50 persons
5	Even Chance, could happen	2.5	Daily	4	Loss of 1 limb/eye, serious illness (temporary)	12	51+ persons
8	Probable, not surprised	4	Hourly	8	Loss of 2 limbs/eyes, serious illness (permanent)		
10	Likely, to be expected	5	Constantly	15	Fatality		
15	Certain, no doubt						

Degree of Risk

Negligible	Very Low	Low	Significant	High	Very High	Extreme	Unacceptable
0-1	>1-5	>5-10	>10-50	>50-100	>100-500	>500-1000	>1000

Risk Report

safe:machine

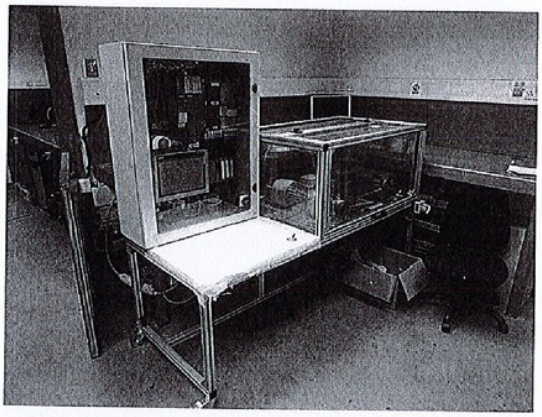
Name	Techniques Services Ltd	**Address**	
Contact	Andy Billington		Ordinal Street Trafford Park Manchester M17 1GB
Telephone	07535 056439		
Email	andy.billington@techniqueservices.com		

Project

Number	Name	Engineers
1433	Motor Test Rig	Derek Coulson

Machine

Name	Motor Test Rig	**Serial Number**	507610
Type	Motor Test Rig	**Manufacturer**	Techniques Services Ltd
Power Supply	400V AC 3~	**Model**	-
Location	Ordinal Street,	**Building**	Trafford Park
Area	Manchester, M17 1GB		



Checklist: Machinery Directive: CE Marking

Checklist	EHSR 1
Section	8 1.2.1 Safety and reliability of control systems
Regulation	Control systems must be designed and constructed in such a way as to prevent hazardous situations from arising. Above all, they must be designed and constructed in such a way that: - they can withstand the intended operating stresses and external influences, - a fault in the hardware or the software of the control system does not lead to hazardous situations, - errors in the control system logic do not lead to hazardous situations, - reasonably foreseeable human error during operation does not lead to hazardous situations.

Risk Assessment

Identifier 0080101

Total Weight 205.4 [206kg]

Risk Report

safe:machine

Initial Hazard

Injury due to the potential failure of the Safety Related Control System as a result that there is no validation information that the E stops and interlock meet the correct Performance Level under EN 13849.

It appears that all controls are through HMI, which means the HMI must be a device that can be validated, or additional controls added.

L.O	1 **F.O**	5 **N.P.E**	1 **D.P.H**	4 **HRN**	Significant (20)

Control Measure

Ensure that the supplier provides a validation report to EN 13849, demonstrating the safety related control system meets the required Performance Levels. (PLr). (We believe a minimum of PL c for the E stops, PL d for the interlock); Request the SISTEMA or Pascal file, if available.

L.O	0.033 **F.O**	5 **N.P.E**	1 **D.P.H**	4 **HRN**	Negligible (0.66)

Notes

Without detailed drawings, it can not be determined with any degree of certainty as to the integrity of the safety circuit on this machine. The safety circuit should be checked in detail when the drawings are made available.

SISTEMA and Pascal are the two main commercial software packages used to produce validation reports.Having the files makes it possible for SAICA to update safety related control systems and update the reports easily in the future. Without the files, the validation has to be done from scratch. ✓

Introduced	**Completed By**	**Completed On**
25/02/2019 17:39:55		

Checklist EHSR 1

Section 11 1.2.4.1 Stopping - Normal stop

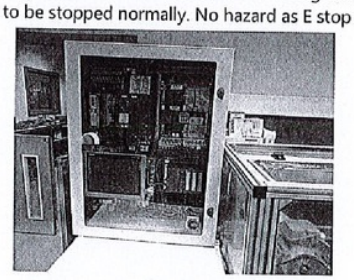
Regulation Machinery must be fitted with a control device whereby the machinery can be brought safely to a complete stop.

Risk Assessment

Identifier 0110101

Initial Hazard

Non-compliance due to the machine controls being through HMI, not switches. Potential of HMI failure could lead to machine not being able to be stopped normally. No hazard as E stop or isolator can be operated to stop the machine. ?



IMG_7592.JPG

Buttons added although not needed due to 'E' stop buttons.

L.O	0.5 **F.O**	5 **N.P.E**	1 **D.P.H**	0.5 **HRN**	Very Low (1.25)

Control Measure

Ensure that either the HMI has data that can be validated as part of the safety related control system, or add Start, Stop and Reset controls, coloured in accordance with EN 60204-1, section 10.

L.O	0.033 **F.O**	5 **N.P.E**	1 **D.P.H**	0.5 **HRN**	Negligible (0.0825)

Risk Report

safe:machine

Introduced	Completed By	Completed On
25/02/2019 18:17:39		

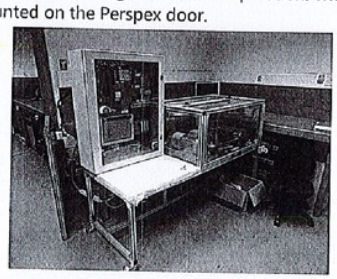
Checklist EHSR 1
Section 13 1.2.4.3 Stopping - Emergency stop
Regulation The emergency stop function must be available and operational at all times, regardless of the operating mode.

Risk Assessment

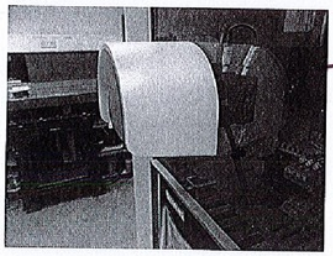
Identifier 0130301

Initial Hazard

Injury due to the inability to bring the machine to a safe stop in an emergency situation as a result of the E-Stop shrouds being of the incorrect type, and too large for ease of operation. The stops cannot be operated by the palm of a hand.
One is mounted on the Perspex door.



IMG_7591.JPG



IMG_7595.JPG

Re-located and shroud removed.

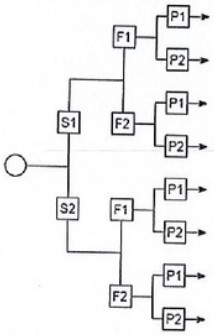
L.O	F.O	N.P.E	D.P.H	HRN	
	2	5	1	2	Significant (20)

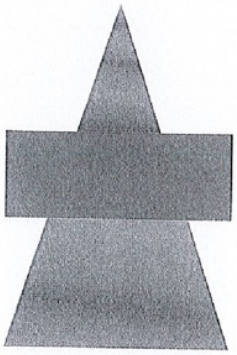
Control Measure

Shrouds should be replaced with smaller ones, or the E stops relocated so it is not an issue. See EN ISO 13850.
Ensure that the E stop on the panel door can withstand the force of operation without breaking the Perspex.

L.O	F.O	N.P.E	D.P.H	HRN	
	0.033	5	1	2	Negligible (0.33)

EN 13849: Emergency Stop





Severity: S2 - Serious

Frequency of Exposure: F1 - Rarely, infrequent

Possibility of Avoidance: P1 - Possible

Performance Level: c

Notes

Shroud Removed and 'E' Stop Relocated.

Notes

EN ISO 13850 - 4.5 Prevention of unintended actuation of an emergency stop device
The emergency stop device shall be designed to avoid unintended actuation.
So far as practicable, unintended actuation shall be prevented by location rather than the use of other application design measures.

The actuation of the emergency stop device shall not be impaired. To prevent unintended actuation of the emergency stop device some precautions can be taken, e.g.:
— locate the emergency stop device away from foreseeable heavily trafficked areas,
— select the type of emergency stop device,
— select appropriate size or shape of the emergency stop device, or
— mount the emergency stop device within a recessed surface of the surrounding control panel.
The use of a protective shroud around the emergency stop device should be avoided, except when necessary to prevent unintended actuation and other measures are not practicable.
A protective shroud shall not have any sharp corners or edges or rough surfaces which could lead to injury. Corners and edges shall be de-burred and surfaces shall be smooth to the touch.
For emergency stop devices intended to be actuated by hand the measures against unintended actuation shall not impede or hinder actuation with the palm of the hand, from any foreseeable position of the machine operator and others who could need to actuate them

Introduced	Completed By	Completed On
25/02/2019 18:19:06		

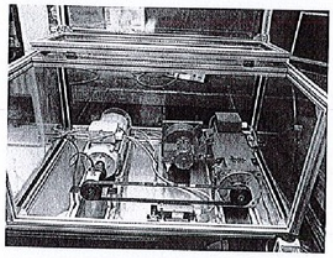
Checklist	EHSR 1
Section	23 1.3.7 Risks related to moving parts
Regulation	The moving parts of machinery must be designed and constructed in such a way as to prevent risks of contact which could lead to accidents or must, where risks persist, be fitted with guards or protective devices.

Risk Assessment

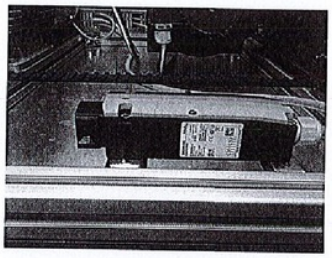
Identifier 0230101

Initial Hazard

Injury due to interlock being overridden, which allows access into the drive belt.



IMG_7618.JPG



IMG_7615.JPG

L.O	F.O	N.P.E	D.P.H	HRN	
	1	5	1	4	Significant (20)

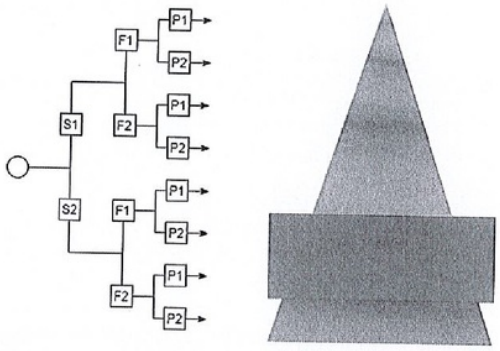
Control Measure

On delivery, the interlock must be secured with fixings that do not easily allow defeat, see EN ISO 14119. There must be a test report showing that the safety devices are tested and functional.

L.O	F.O	N.P.E	D.P.H	HRN	
0.033	5	1	4		Negligible (0.66)

Safety Acutator fixed with security Screws.

EN 13849: Guard interlock



Severity: S2 - Serious

Frequency of Exposure: F2 - Often to continuously

Possibility of Avoidance: P1 - Possible

Performance Level: d

Notes

Notes

EN ISO 14119 - 7.2 Additional measures to minimize defeat possibilities of interlocking devices
The interlocking devices shall be selected and/or installed such that defeating in a reasonably foreseeable manner is prevented.
In the following, possible measures against defeat in a reasonably foreseeable manner are mentioned.
For the requirements and applicability see Table 3.
a) Prevention of accessibility to the elements of the interlocking device
1) mounting out of reach (see Figure 11),
2) physical obstruction or shielding (see Figure 10),
3) mounting in hidden position;
b) Prevention of substitute actuation of the interlocking device by readily available objects
1) low level coding of actuators;
2) medium level coding of actuators;
3) high level coding of actuators;
c) Prevention of dismantling or de-positioning of the elements of the interlocking device by use of non-detachable fixing (e.g. welding, gluing, one-way screws, riveting)

NOTE 1 Use of non-detachable fixing can be an inappropriate solution in cases where a failure of the interlocking device during lifetime of the machinery can be expected and a fast change is necessary. In this case other measures, e.g. a), b) and d), should be used to provide the required level of risk reduction.

Introduced	Completed By	Completed On
25/02/2019 18:30:28		

Checklist EHSR 1

Section 29 1.4.2.1 Special requirements for guards - Fixed guards

Regulation Their fixing systems must remain attached to the guards or to the machinery when the guards are removed.

Risk Assessment

Identifier 0290201

Risk Report

safe:machine

Initial Hazard

Injury due to underguard fixings being missing in a number of places, guard fixings not secured to guard.



IMG_7620.JPG

all screws put back in ✓ ✓

L.O	1	**F.O**	1	**N.P.E**	1	**D.P.H**	4	**HRN**	Very Low (4)

Control Measure

Ensure all guard fixings are in place. If the guard is to be removed routinely, the fixings must be retained to the guard. If not to be removed, the guard does not need retained fixings, this must be documented.

L.O	0.033	**F.O**	1	**N.P.E**	1	**D.P.H**	4	**HRN**	Negligible (0.132)

Introduced	**Completed By**	**Completed On**
25/02/2019 18:36:23		

Checklist	EHSR 1
Section	33 1.5.1 Electricity Supply
Regulation	Where machinery has an electricity supply, it must be designed, constructed and equipped in such a way that all hazards of an electrical nature are or can be prevented. The safety objectives set out in directive 73/23/EEC shall apply to machinery. However, the obligations concerning conformity assessment and the placing on the market and/or putting into service of machinery with regard to electrical hazards are governed solely by this directive.

Risk Assessment

Identifier 0330105

Risk Report

safe:machine

Initial Hazard

Confusion and or injury due to the fact that the nameplate for electrical equipment is not present or does not contain relevant information.



IMG_7596.JPG

L.O	0.5 F.O	5 N.P.E	1 D.P.H	2 HRN	Very Low (5)

Control Measure

Ensure that a nameplate has been fitted to the machine detailing the following information :

* Supplier name; Teco
* Serial number; 507610
* Rated voltage; 400
* Number of phases; 3
* Frequency; 50
* Full load current; 32a
* Short circuit interrupting capacity of the over-current devices;
* Reference to the electrical drawings.

in accordance with EN60204-1:2018, clause 16.4

L.O	0.033 F.O	5 N.P.E	1 D.P.H	2 HRN	Negligible (0.33)

Introduced	Completed By	Completed On
25/02/2019 18:42:42		

Risk Assessment

Identifier 0330102

New cable →

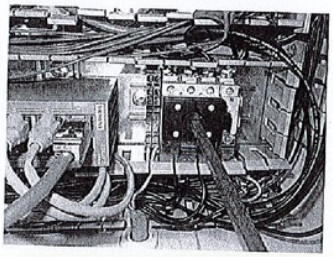
Coleg Sirgar AC/DC Test Rig			
Manufacturer	Technique Services 11-15 Ordinal St, Trafford Park. Manchester M17 1GB		
Serial/Drawing No.	507610		
400V AC 3 PH 50Hz Full Load Current 45A SCCR 5kVA			
CE	03/2019	Weight 206kg	85dB

Risk Report

safe:machine

Initial Hazard

Electric shock due to confusion as a result of the main incoming earth terminal not being clearly identified. No direct link to the backplate.



IMG_7605.JPG

New earth stud next to isolator installed

L.O	0.5 F.O	1 N.P.E	1 D.P.H	15 HRN	Low (7.5)

Control Measure

For each incoming supply ensure that a terminal is provided close to the associated phase conductor terminals for the main incoming earth.

The terminal must be suitable to enable the connection of the incoming earth and should be marked with the letters PE. Ensure that there is a direct link to the backplate from the opposite side of the PE termination, as short as possible for EMC compliance. Consider adding an earth cable to the enclosure from the second spare earth terminal.

EN60204-1:2018, clause 5.2.

L.O	0.033 F.O	1 N.P.E	1 D.P.H	15 HRN	Negligible (0.495)

Introduced	Completed By	Completed On
25/02/2019 18:40:05		

Risk Assessment

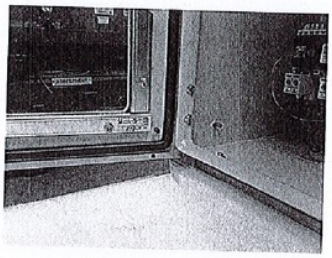
Identifier 0330101

Risk Report

safe:machine

Initial Hazard

Electric shock in the event of a single fault failure due to no earth strap on the enclosure door having electrical components mounted on it.



IMG_7612.JPG

all earth Bonding completed ✓

L.O	0.5 F.O	1 N.P.E	1 D.P.H	15 HRN	Low (7.5)

Control Measure

Use a copper conductor to guarantee the continuity of the protective bonding circuit to the door. Otherwise use fastenings or hinges with low resistance in accordance with EN60204-1:2006, clause 8.2.3 & 18.

L.O	0.033 F.O	1 N.P.E	1 D.P.H	15 HRN	Negligible (0.495)

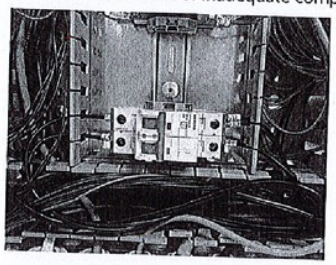
Introduced	Completed By	Completed On
25/02/2019 18:40:05		

Risk Assessment

Identifier 0330103

Initial Hazard

Injury due to confusion as a result of inadequate component identification within the electrical enclosure.



IMG_7606.JPG

all items identified both on unit and backplate ✓

L.O	0.5 F.O	1 N.P.E	1 D.P.H	15 HRN	Low (7.5)

Control Measure

Ensure that all items of controlgear are placed and oriented so that they can be identified without moving them or the wiring in accordance with EN60204-1:2018, clause 11.2.1

L.O	0.033 F.O	1 N.P.E	1 D.P.H	15 HRN	Negligible (0.495)

Notes

Markings should not be fixed to the covers of trunking as they may be removed, lost or swapped with other covers.

Introduced	Completed By	Completed On

Risk Report

safe:machine

25/02/2019 18:42:42

Risk Assessment

Identifier 0330104

Initial Hazard

Injury due to the fact that there are no electrical test results available for the equipment.

L.O	0.5	**F.O**	5	**N.P.E**	1	**D.P.H**	15 **HRN** Significant (37.5)

Control Measure

Ensure that electrical test results are available in accordance with EN60204-1:2006, clause 18

Where there is no dedicated product standard for the machine, the verifications shall always include the items a), b) and f) and may include one or more of the items c) to e):

a) verification that the electrical equipment complies with its technical documentation;
b) in case of protection against indirect contact by automatic disconnection, conditions for protection by automatic disconnection shall be verified according to 18.2;
c) insulation resistance test (see 18.3);
d) voltage test (see 18.4);
e) protection against residual voltage (see 18.5);
f) functional tests (see 18.6).

ESC

Awaiting Report from ESC?

ESC

L.O	0.033	**F.O**	0.1	**N.P.E**	1	**D.P.H**	15 **HRN** Negligible (0.0495)

Introduced	**Completed By**	**Completed On**
25/02/2019 18:42:42		

Checklist	EHSR 1
Section	40 1.5.8 Noise
Regulation	Machinery must be designed and constructed in such a way that risks resulting from the emission of air-borne noise are reduced to the lowest level, taking into account the technical progress and the availability of means of reducing noise, in particular at source.

Risk Assessment

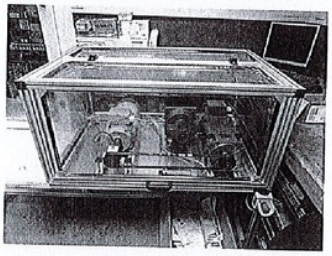
Identifier 0400101

Risk Report

safe:machine

Initial Hazard

Injury due to the fact that the noise levels have not been recorded for the machinery.



IMG_7593.JPG

Noise meter?

85dB @ 1m away Running @ Max Speed.

L.O	1 F.O	5 N.P.E	1 D.P.H	2 HRN	Low (10)

Control Measure

Ensure that the noise levels are recorded and any control measures put in place to control noise levels.

L.O	0.033 F.O	5 N.P.E	1 D.P.H	2 HRN	Negligible (0.33)

Introduced	Completed By	Completed On
25/02/2019 18:49:22		

Checklist EHSR 1

Section 42 1.5.10 Radiation

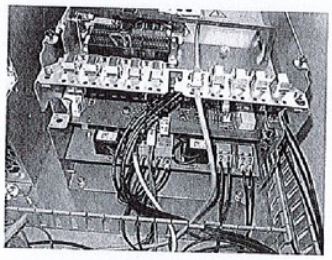
Regulation Undesirable radiation emissions from the machinery must be eliminated or be reduced to levels that do not have adverse effects on persons.

Risk Assessment

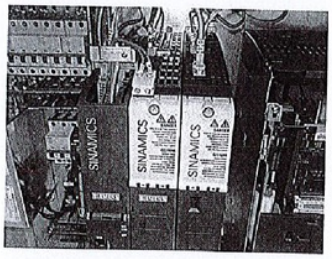
Identifier 0420101

Initial Hazard

Hazard due to equipment not being EMC compliant. Screened cables terminated at plastic glands incoming into panel, not at drive brackets.



IMG_7607.JPG



IMG_7610.JPG

L.O	1 F.O	5 N.P.E	1 D.P.H	2 HRN	Low (10)

Control Measure

All drives should be installed according to the suppliers EMC instructions, using filters, correct brackets, ferrites and screened cables.

L.O	0.033 F.O	5 N.P.E	1 D.P.H	2 HRN	Negligible (0.33)

Bonding Completed Motor cables Bonded @ the drives

Risk Report

safe:machine

Notes

Any issues are likely to result in process or product failure rather than safety issues.

Introduced	Completed By	Completed On
25/02/2019 18:50:17		

Checklist	EHSR 1
Section	58 1.7.3 Marking of machinery
Regulation	All machinery must be marked visibly, legibly and indelibly with the following minimum particulars: - the business name and full address of the manufacturer and, where applicable, his authorised representative, - designation of the machinery, - the CE Marking, - designation of series or type, - serial number, if any, - the year of construction, that is the year in which the manufacturing process is completed.

Risk Assessment

Identifier 0580101

Initial Hazard

Confusion due to the fact that the nameplate may not contain the correct information.



New label made.

IMG_7596.JPG

L.O	F.O	N.P.E	D.P.H	HRN	
0.5	5	1	1	Very Low (2.5)	

Control Measure

Ensure that the nameplate contains the following information:

Name and address of the manufacturer; ✓
CE marking; ✓
Designation of series or type; ✓
Serial number, if any; ✓
Year of construction. ✓

L.O	F.O	N.P.E	D.P.H	HRN	
0.033	5	1	1	Negligible (0.165)	

Notes

Electrical information should also be provided. ✓

Introduced	Completed By	Completed On
25/02/2019 18:55:09		

Risk Report

safe:machine

Checklist	EHSR 1
Section	61 1.7.4.2 Contents of the instructions
Regulation	The instructions must contain all relevant information as listed in EHSR 1.7.4.2

Risk Assessment

Identifier 0610101

Initial Hazard

Injury due to the fact that the instructions may not contain the correct information.

L.O	2 **F.O**	5 **N.P.E**	1 **D.P.H**	2 **HRN**	Significant (20)

Control Measure

Ensure an instruction manual is available which must contain, where applicable, at least the following information:

Instructions must be identified as Original Instructions.

L.O	0.033 **F.O**	5 **N.P.E**	1 **D.P.H**	2 **HRN**	Negligible (0.33)

Notes

EHSR 1.7.4.2. Contents of the instructions (Machinery Directive)
Each instruction manual must contain, where applicable, at least the following information:
(a) the business name and full address of the manufacturer and of his authorised representative;
(b) the designation of the machinery as marked on the machinery itself, except for the serial number (see section 1.7.3);
(c) the EC declaration of conformity, or a document setting out the contents of the EC declaration of conformity, showing the particulars of the machinery, not necessarily including the serial number and the signature;
(d) a general description of the machinery;
(e) the drawings, diagrams, descriptions and explanations necessary for the use, maintenance and repair of the machinery and for checking its correct functioning;
(f) a description of the workstation(s) likely to be occupied by operators;
(g) a description of the intended use of the machinery;
(h) warnings concerning ways in which the machinery must not be used that experience has shown might occur;
(i) assembly, installation and connection instructions, including drawings, diagrams and the means of attachment and the designation of the chassis or installation on which the machinery is to be mounted;
(j) instructions relating to installation and assembly for reducing noise or vibration;
(k) instructions for the putting into service and use of the machinery and, if necessary, instructions for the training of operators;
(l) information about the residual risks that remain despite the inherent safe design measures, safeguarding and complementary protective measures adopted;
(m) instructions on the protective measures to be taken by the user, including, where appropriate, the personal protective equipment to be provided;
(n) the essential characteristics of tools which may be fitted to the machinery;
(o) the conditions in which the machinery meets the requirement of stability during use, transportation, assembly, dismantling when out of service, testing or foreseeable breakdowns;
(p) instructions with a view to ensuring that transport, handling and storage operations can be made safely, giving the mass of the machinery and of its various parts where these are regularly to be transported separately;
(q) the operating method to be followed in the event of accident or breakdown; if a blockage is likely to occur, the operating method to be followed so as to enable the equipment to be safely unblocked;
(r) the description of the adjustment and maintenance operations that should be carried out by the user and the preventive maintenance measures that should be observed;
(s) instructions designed to enable adjustment and maintenance to be carried out safely, including the protective measures that should be taken during these operations;
(t) the specifications of the spare parts to be used, when these affect the health and safety of operators;
(u) the following information on airborne noise emissions:
— the A-weighted emission sound pressure level at workstations, where this exceeds 70 dB(A); where this level does not exceed 70 dB (A), this fact must be indicated,
— the peak C-weighted instantaneous sound pressure value at workstations, where this exceeds 63 Pa (130 dB in relation to 20 μPa),
— the A-weighted sound power level emitted by the machinery, where the A-weighted emission sound pressure level at workstations exceeds 80 dB(A).
These values must be either those actually measured for the machinery in question or those established on the basis of measurements

A.B. 11 ?

taken for technically comparable machinery which is representative of the machinery to be produced.
In the case of very large machinery, instead of the A-weighted sound power level, the A-weighted emission sound pressure levels at specified positions around the machinery may be indicated.
Where the harmonised standards are not applied, sound levels must be measured using the most appropriate method for the machinery. Whenever sound emission values are indicated the uncertainties surrounding these values must be specified. The operating conditions of the machinery during measurement and the measuring methods used must be described.
Where the workstation(s) are undefined or cannot be defined, A-weighted sound pressure levels must be measured at a distance of 1 metre from the surface of the machinery and at a height of 1,6 metres from the floor or access platform. The position and value of the maximum sound pressure must be indicated.
Where specific Community Directives lay down other requirements for the measurement of sound pressure levels or sound power levels, those Directives must be applied and the corresponding provisions of this section shall not apply;
(v) where machinery is likely to emit non-ionising radiation which may cause harm to persons, in particular persons with active or non-active implantable medical devices, information concerning the radiation emitted for the operator and exposed persons.

Introduced	Completed By	Completed On
25/02/2019 17:32:49		

Appendix I2 - Coleg Sir Gâr Risk Assessment

Curriculum Area / Non Teaching Area _E & C_____ Dept ___Engineering_____ Location __Gr_____

What is being risk assessed (room/process/equipment/activity/individual)? __G8_ACDC Motor Generator Set___ Reference _____

Page Number ____1_____

Member of Staff Undertaken the Risk Assessment __L. Williams _____ Date Undertaken _25/04/19_____

Hazard	Person(s) at Risk	Existing Controls	Risk Rating (see matrix)			High Med Low	Any additional control measures required.
			Likelihood	Severity	Risk Score		
Electrical equipment – Fixed 3 phase Electric shock	Staff Learners All unscheduled pedestrian traffic in area whilst process in operation, i.e. visitors, cleaning staff.	Only trained & authorised persons to operate equipment. Pre-use checks No unescorted / unauthorised visitors permitted.	2	5	10	M	**Essential** Electrical panel must be locked to prevent access to live terminals. On-going training of operators. Award H&S Unit scheduled for delivery and first completion.
Physical harm		Routine maintenance & checks of equipment Electrical panel key is kept by staff so no access to live terminals is possible	2	5	10	M	Continued vigilance by staff for inappropriate/dangerous behaviour/practice.
Tripping hazard (cables)		Perspex guarding around motors prevents access by students. Automatic cut-off system already existing in machine. Trunking/cable ties etc. utilised whenever possible Good housekeeping disciplines	2	2	4	L	Safeguard limits to be programmed to prevent damage resulting from excessive load torques. Electrical 3 phase isolator to be locked off by staff member when not in use.

Coleg Sir Gâr Risk Assessment

Curriculum Area / Non Teaching Area _E & C_____ Dept ___Engineering_____ Location __Gr_____

What is being risk assessed (room/process/equipment/activity/individual)? ___ G8 ACDC Motor Generator Set_____ Reference _____

Page Number ____2_____

Member of Staff Undertaken the Risk Assessment __L. Williams _____ Date Undertaken _25/04/19_____

Hazard	Person(s) at Risk	Existing Controls	Risk Rating (see matrix)			High Med Low	Any additional control measures required.
			Likelihood	Severity	Risk Score		
Erratic, spontaneous, unpredictable or non-prescribed behaviour of learners within a potentially hazardous working environment (for example, acts of malicious damage, immature or negligent behaviour, horseplay etc.). Increased risk due to age group and inherent levels of maturity – cross reference to young people and schools provision RA. Compartmentalised nature of some resources, combined with inherently hazardous equipment /processes, increase existing	All learners, staff, visitors, cleaners	All students provided with H&S Induction training and measures of good engineering practice prior to commencement of first activities with OCN unit completed ASAP prior to workshop exposure, combined with vocational PEO H&S unit targeted for first completion. Close supervision of students, particularly during early stages of exposure to working environment, limited by class size and ergonomics of the resource area. Engineering workplace code of conduct repeatedly reinforced where appropriate during all sessions, particularly practical elements. Application of zero tolerance to deviations from standard engineering good practice and management of the concern note and formal disciplinary processes. No unescorted / unauthorised visitors permitted.	3 3 3	2 2 2	6 6 6	M M M	**Essential** On-going training of operators. Award H&S Unit scheduled for delivery and first completion. Continued vigilance by staff for inappropriate/dangerous behaviour/practice. Individual RAs to be completed for identified learners with potential for behavioural issues (Risk Register). Communicate Engineering's written '*Code of conduct'* for to supplement the provisions of the college student handbook – acceptance to be signed for.

identified hazards when self discipline of learners breaks down and standard procedures training not applied.					

Person completing the risk assessment _L. Williams____ Signature _____ Date ___25/05/19_____ Review Date _____May 2019_____	Curriculum Area Head / College Manager __A. Twells_____ Signature _____ Date _____

Recommendations for additional control measures identified	Are additional control measures to be implemented? (Y/N). If they are not to be implemented please state reasons below.	Additional control measures to be implemented. Action to be Taken and by whom?	Date Action completed.	Signature
Continued training and on- going monitoring of learners. X-Ref general behaviour RA	Y	Continued training and on- going monitoring of learners	On going	
Safeguards to be programmed to prevent deliberate or accidental misuse.	Y	Project update required	On-going	
Code of conduct to be introduced as part of standardised induction unit.	Y	Induction process – course leaders	On going	

Risk Rating Score Method

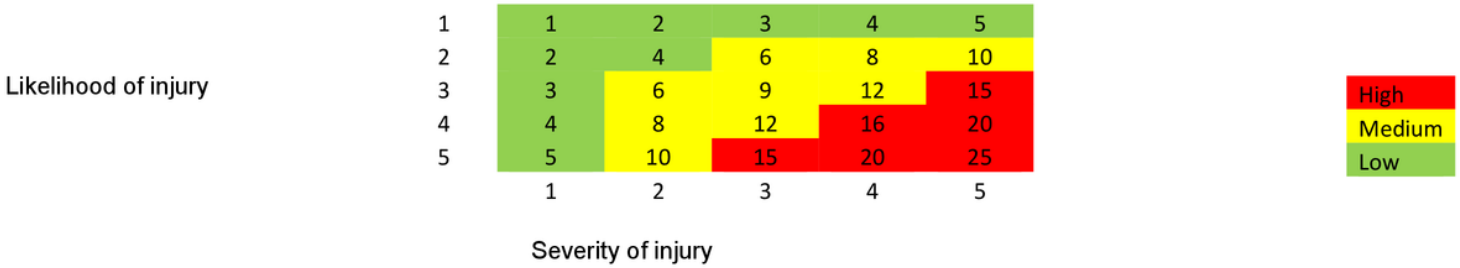
This example is known as a 5 x 5 matrix where values are given to the likelihood and the severity of each hazard identified. These are then **multiplied** to determine the hazard's overall risk rating, whilst taking into account the controls in place.

LIKELIHOOD	SCORE	SEVERITY OF INJURY	RISK
Very unlikely (difficult to see how this can occur)	1	**Very minor Injury** (no treatment or absence from work)	1
Unlikely (not expected to happen, but can't be ruled out)	2	**Minor Injury** (requiring first aid treatment / possible absence of up to 3 days)	2
Likely (could happen at some stage)	3	**Injury** (requiring over 3 days absence)	3
Very likely (may occur on a regular basis)	4	**Severe Injury** (Major injury as described under RIDDOR / long term absence / health effect)	4
Certain (no doubt about it)	5	**Fatality**	5

Level of Risk Identified

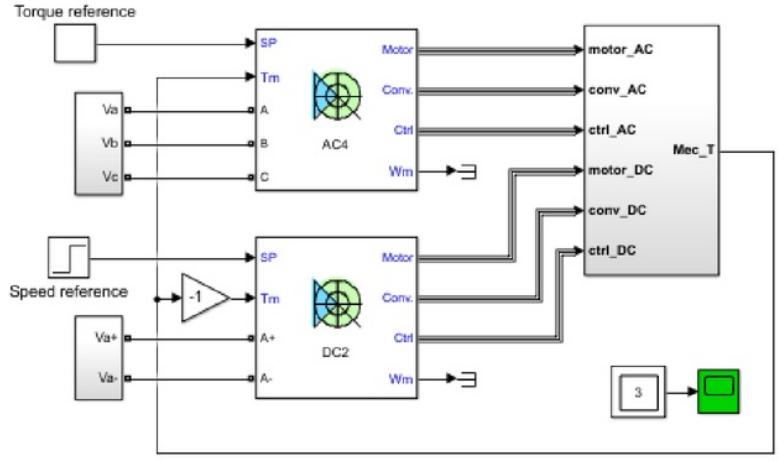
Please refer to the matrix below in determining whether or not the existing controls implemented are classified as High, Medium or Low.

Please note that any hazards described as High must be reduced.



Appendix J - Matlab mechanical coupling of two drives.

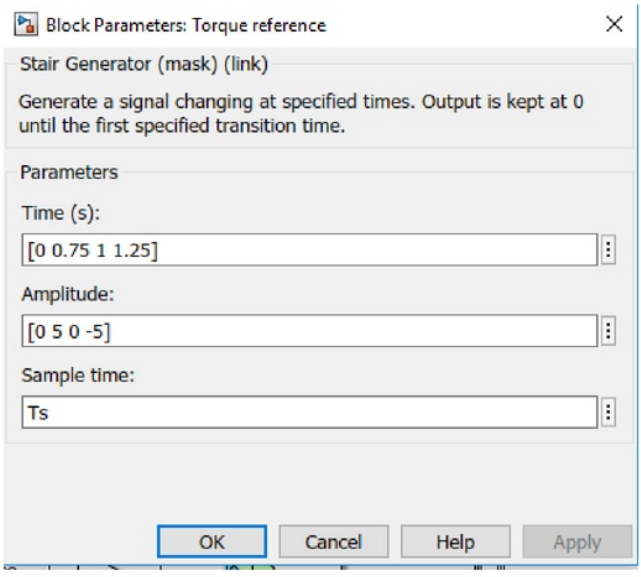
This model was revisited and shows how parameters can be easily altered. The torque speed set points have been modified to closer match those used on the rig.



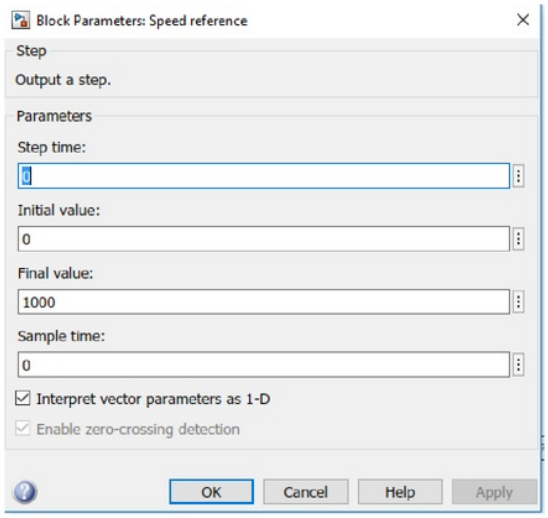
Mechanical Coupling of Two Motor Drives II

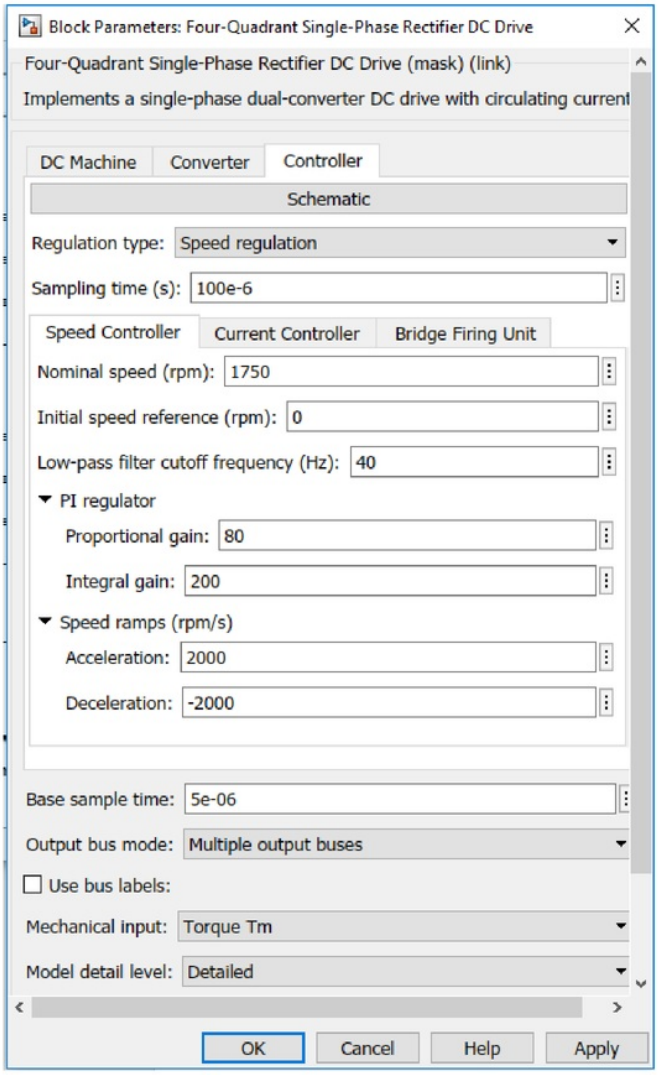
Louis-A. Dessaint , H. Fortin-Blanchette, C. Semaille (Ecole de technologie superieure, Montreal)

Torque reference changed to a step change from 0 to +5 to 0 to -5 Nm

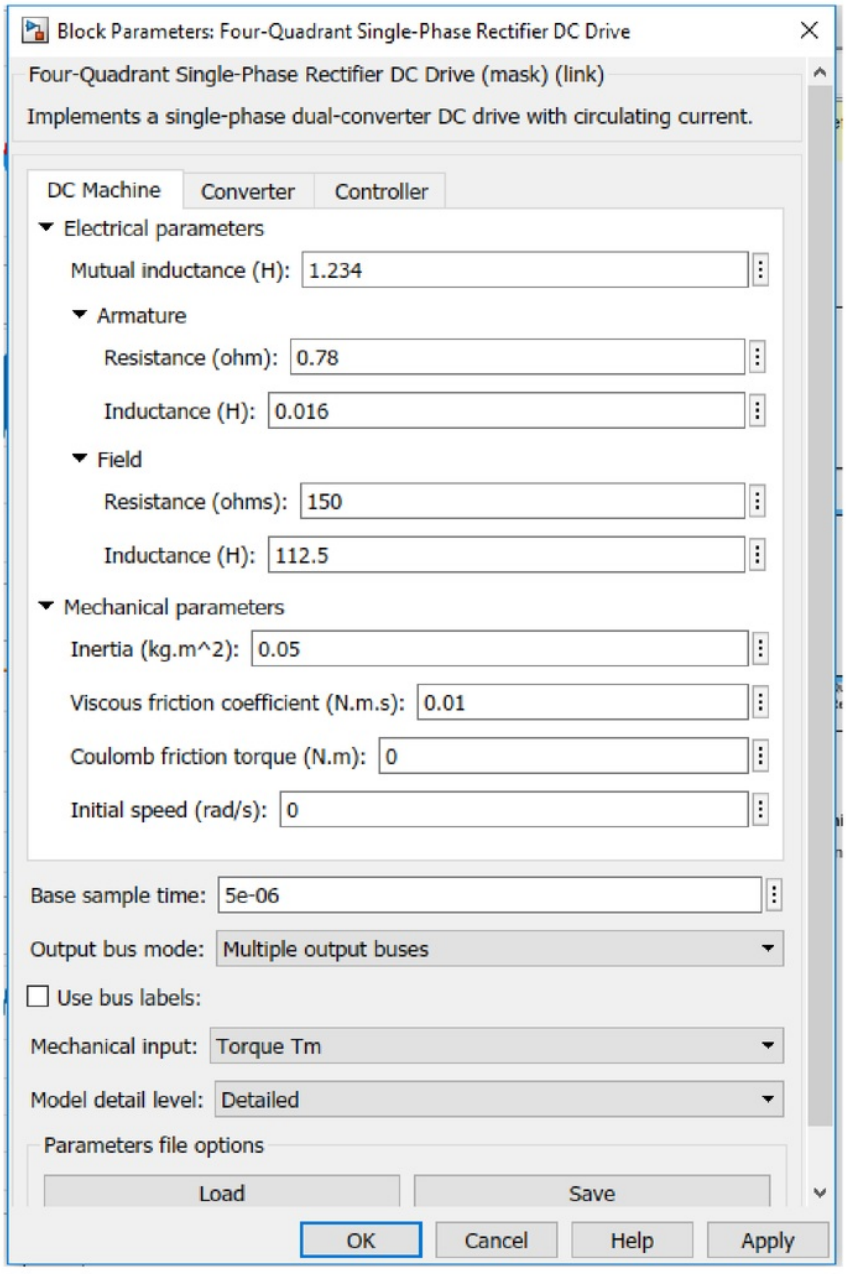


Speed reference changed to a ramp up to 1000 rpm at 2000rpm/s

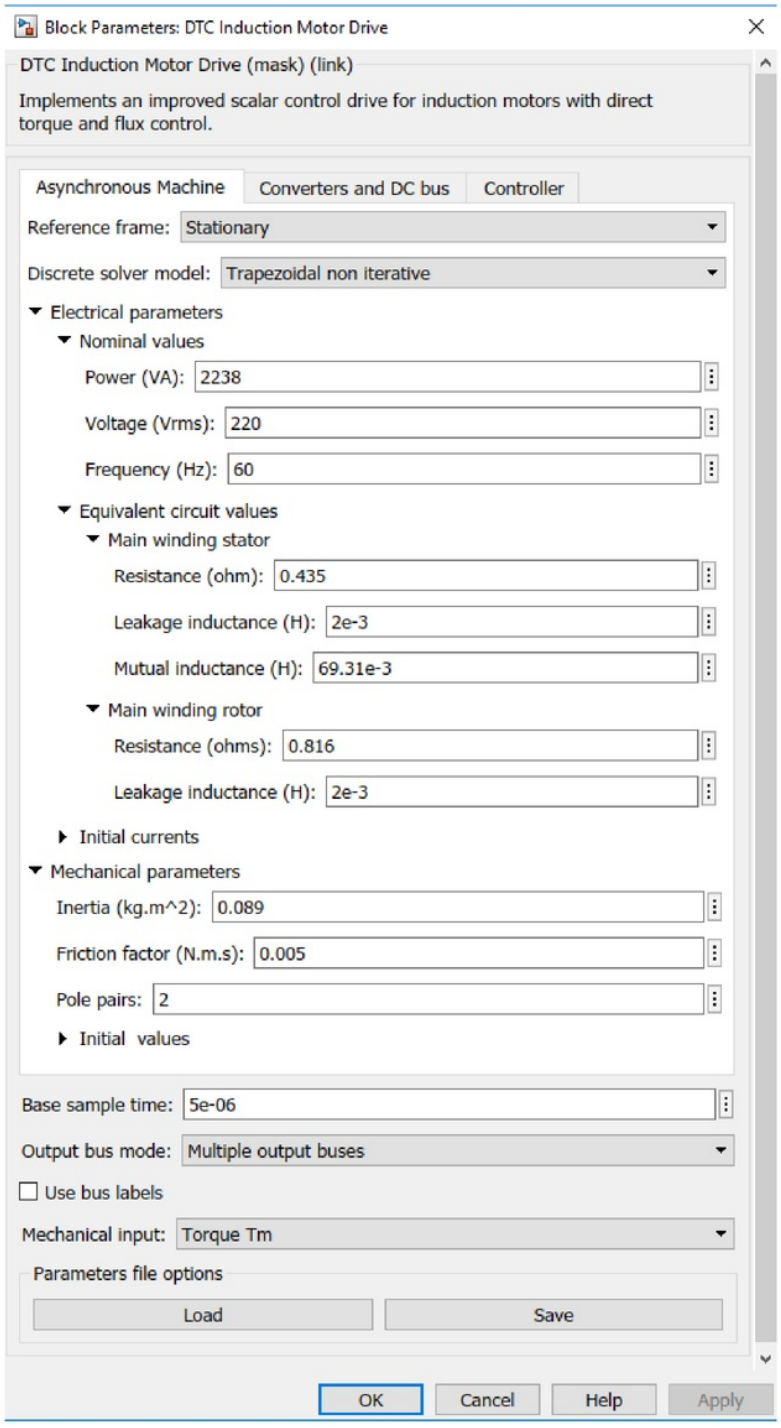




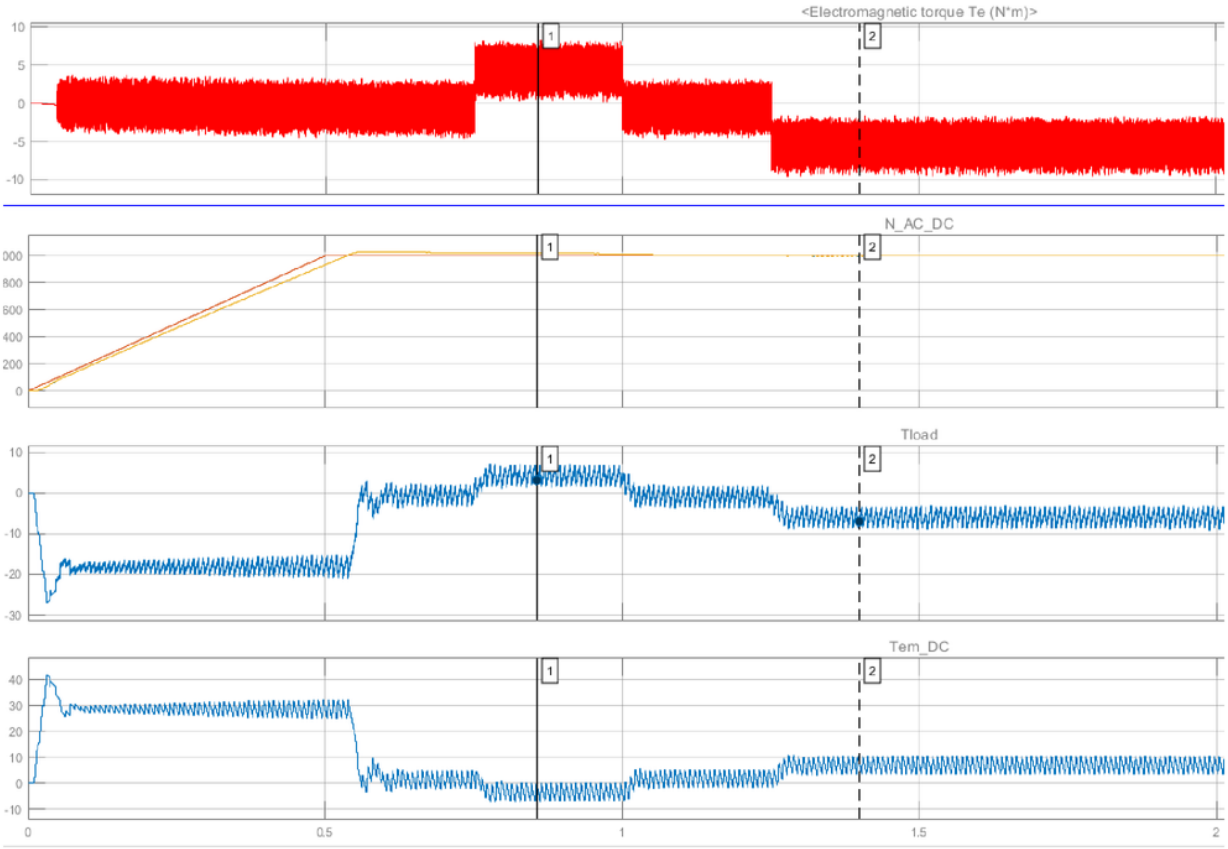
Access to change block parameters for DC Drive



Access to change block parameters for AC Drive



Results



Trace 1 shows the step change in torque applied to the AC machine, +5Nm at 0.75s, then 0Nm at 1s and -5Nm at 1.25s. Trace 2 shows the speed ramp applied to the DC machine which initially causes higher opposing torques to maintain the ramp which is 2000rpm/s. Trace 3 shows that the AC torque is positive at around +5Nm and therefore demonstrating quadrant 1 at cursor 1 and then -5Nm at cursor 2 demonstrating quadrant 2. Trace 4 shows the DC torque is equal and opposite thus demonstrating quadrant 2 at cursor 1 and quadrant 1 at cursor 2.

Project Assignment 2

GRADEMARK REPORT

FINAL GRADE

67 /100

GENERAL COMMENTS

Instructor

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GRADING FORM: NEW CSG-RUBRIC

LIESEL WILLIAMS	**67**

1. ENGAGEMENT WITH LITERATURE

Report contains good evidence of judicial usage of sources of technical literature employed in the design of the project solution particularly the vast amount of information presented in the drives manuals. The report contained extensive research particularly of technical literature relating to the project. Excellent evidence of reading from a wide range of credible sources from the large amount of information available for the drives which has

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involved much searching. However, Harvard method is not always applied correctly and some items in the citation list are duplicated in the bibliography. (7/10)

2. KNOWLEDGE AND UNDERSTANDING



There is very good evidence of advanced knowledge and critical understanding in the design of the project. This is seen in the mechanical, electrical and software aspects of the project. However, there is little explanation in the main report of the PLC program (though each section has been explained in the appendix), a clearer brief explanation could have been given in the main report. It is also to be noted that there is an error in the drawing for the modification made to the AC motor enable. A requirement was identified for a bespoke training aid to facilitate the teaching of motors. It was clear which parts of the final product were sub-contracted and how much was built locally. An opportunity exists to develop the rig as a sellable commodity. It would be a risk not to engage with IP and protect the design. (6.5/10)

6.5

3. COGNITIVE AND INTELLECTUAL



There is very good evidence of testing and analysis of results presented graphically to see relationships between parameters and theory accompanied by substantiating research. The appendix contains a wide range of information that includes safety and risks. Good analysis of outcomes. However, each

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item in the FDS should have been considered in this section and commented upon. No reference made to the actual cost in this section. The evaluation provided a good overview of the project and its success/issues. No consideration to the wider issues was provided. Conclusions briefly stated with some useful recommendation for further development of the project. However, these should probably be implemented as a priority. (19/30)

4. PRACTICAL APPLICATION



Most of the mechanical and electrical construction was carried out by a subcontractor while panel mods were made by the student. Most of the construction has been in the PLC program mods and HMI screen designs which are of a good standard with the extensive use of TIA portal and SINAMICS software tools. Final product is of a good quality which includes the HMI screens and their functional features. The PLC program code modifications are also well documented in the program.The final product had some quality issues, mainly due to the sub-contractor. Good evidence of use of testing with results recorded from the HMI screens and with the use of TIA Portal and SINAMICS software in on-line monitor mode. Spreadsheet and Gantt chart demonstrate good management of the design process. Log book is well organised and clearly records progress made and the changes that were necessary in the development of the design. The project was well managed throughout. (27.5/40)

27.5

5. TRANSFERABLE SKILLS



A good introduction and acknowledgements. However, summary only includes some of the report focusing too much on the outcome of the project. Well structured and presented with a good communication style. The report was very well written and presented in a professional manner. (7/10)

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