

Assignment 1

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PSDE 6019

Major Project

Lecturer – R Davies

2018-2019

Project Definition, Research and Quality
Planning

Liesel Williams

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1. Executive Summary

Electronic Engineering modules taught at CSG require investigation into motor and generator characteristics and performance, a safe teaching aid for demonstration and experimentation purposes does not currently exist.

A bespoke AC/DC motor generator set designed specifically with all parameters available for view/manipulation and able to satisfy the curriculum requirements up to Level 6 will replace the outdated Feedback Ltd equipment currently in use.

The block diagram of the final solution (see Fig 16) gives a basic understanding of the system and specifically contains:

- Siemens 3kW DC motor controlled by 3-phase 4 quadrant Siemens DCM drive
- Siemens 3kW cage rotor motor controlled by 4 quadrant Siemens S series inverter drive
- Mechanical coupling via a belt drive system
- Motor speed measurement/feedback with incremental encoders
- All appropriate protection and line filtering
- Siemens 1500 PLC
- HMI 12" comfort panel
- All devices controlled through TIA portal via ProfiNET

The drives will not have any restrictions in their control allowing full flexibility for demonstrating four quadrant operation. Configuration of all parameters will be made available for access, modification and can be read or written to the particular drive.

Safety is built into the design by utilising failsafe's such as Safe Torque Off, interlock guards and emergency stops.

Currently the work undertaken has been focused on the physical, electrical and software design of the test rig and in particular selecting the correct specification PLC, drives and motors, including looking at various manufacturers for comparison purposes.

Four HMI screens were developed in order to allow the user to select manual or automatic control and when in automatic control to sequence the motor through a number of pre-programmed steps, record the pertinent data and produce a real time graph. (see Figs 1-4)

By inspecting Fig 21 the progress to date can be seen and looks forward to the completion stages in late April.

2. Introduction

This assignment aims to provide systematic understanding of project design and quality management techniques in the context of wider industrial engineering environments with regard to a range of constraints.

A critical understanding of project specification, design and management techniques, constraint limitations, standards and regulations in the initial stages of this complex individual project was necessary. One example of this in the project background section was the international standard for functional safety of machinery EN ISO 13849-1 that defines safety functions, avoidance systems for systematic failures; definition of performance levels etc.

A wide range of constraints including environmental and sustainability limits, ethical, safety and security risks; legal requirements such as IP rights, liability and commercial opportunities also featured in the project initial investigation and planning stages.

A functional design specification (FDS), which identified clearly the measurable performance and features of the final solution demonstrating an awareness of business, customer and user needs is essential in determining project success. A test procedure based on the FDS is necessary and used to prove the outcomes of the project have been satisfied. (Section 4)

A valuable project management technique utilised in this work is the recording of achievement and weekly project activity in the form of a logbook. This provides valuable evidence of authenticity, measurable progress, problems encountered and resource needs.

This valuable information informs the project plan, which was developed using a well-established project management software product namely Microsoft Project. (Section 6)

3. Project Background, Problem Definition and Constraints

The project is required to provide an AC/DC motor generator set for teaching Electrical and Electronic Engineering modules at Level 3, 4, 5 and 6, which require investigation into motor and generator characteristics and performance.

A safe teaching aid to demonstrate performance characteristics would enhance the learning experience for students at all levels.

Currently there is some outdated Feedback Ltd equipment (together with single phase Parker SSD and AB drives) for carrying out manual experiments on various motors however, a major drawback is that each machine requires wiring and coupling arrangements to be set up individually before running the experiment. This is not only a drain on teaching staff time but also causes safety issues such as inadequate guarding, trailing leads, exposed conductors etc.

This AC/DC motor generator test rig will be a bespoke design which will be built specifically to meet the educational needs of students attending Cole Sir Gar. No test rig of this nature exists on the current market to solve this need. Control engineering apparatus for educational purposes can be purchased from a company called TQ (Tecquipment Academia) but these do not include 4 quadrant motor drives and they are not industry standard equipment such as the drives and PLC to be fitted in this bespoke design. (Tecquipment Academia, 2018)

Ethical Engineering - Fundamentals of engineering ethics within this project include sustainable technology, safe and reliable solutions in case of misuse and alternative solution consideration.

Environment and Sustainability - Environmental considerations include energy reduction i.e. limiting the kW rating of the machines to a minimum to conserve power consumption. This factor depends on achievement of full 4 quadrant functionality at the lowest possible power rating. The drives will also run in economic power mode, automatically adjusting consumption and they have inbuilt technology for hibernation along with a profile on PROFINET called PROFInergy, which allows power consumption management without the need for hard-wired systems.

One of the features of the test rig is that it can demonstrate regenerative braking thus furthering the students understanding of modern energy efficiency technology.

Under EU legislation the Energy Savings Opportunity Scheme ESOS requires efficient use of energy in commercial ventures to be examined. Modern motor drives have energy efficient technology built in

Health and Safety – Under the HASAW act 1974 risk assessments are mandatory on all new equipment, a comprehensive risk assessment will be carried out covering supervision, training, testing, operation and access to the test rig.

Under the Provision and Use of Work Equipment Regulations 1998, appropriate and sufficient guarding and failsafe options are included in the design. The motor enclosure guarding is clear Plexiglas and the enclosure door will have an 'energise to open' safety interlock installed. There will be two safety stops on the test rig to deactivate operation. The panel enclosure will also have a safety lock isolator and interlock guard on the clear Plexiglas door preventing access to 415V inside the panel.

Using the appropriate CU and PM integrated safety functions to EN ISO 13849-1 PLd, IEC 61508 SIL2 and EN954-1 Cat.3.Ple/SIL3 are achievable. (ISO, 2015)

Security, Risk and Liability – Appropriate controls and supervision identified from the risk assessment and from college policy will ensure secure and safe operation, risk limitation and assign liability arising from contravention of safe operating procedures put in place to safeguard all users and ensure damage limitation.

Intellectual Property – Divided into Industrial Property and Copyright, the former includes patents, trademarks and industrial designs. The project design and build utilises commercially available components i.e. PLC, HMI, motors and drives. An industrial design is primarily of an aesthetic nature and so technical features are not protected under an industrial design registration.

The system is to be used for educational purposes for teaching AC and DC motors, drives, PLCs, instrumentation and integrated systems.

CoP and Standards – In the electro technical industry the International Electrotechnical Commission (IEC) is the leading standards organisation with countries globally having their own national versions of IEC standards. Updates to Standards and Directives for control panels in line with advancing technology has led to a revised version of IEC 60204-1 (Electrical Equipment of Machines) 2016 and new EU Directives have been transported into national legislation by the end of 2016. Utilising modern industrial drives compliance is built in.

Engineering Management – Project management techniques utilised in the planning and implementation phases ensuring systems are integrated, regulations are upheld, schedules monitored, procurement management and closeout are achieved effectively.

4. Functional Design Specification and Test Plan

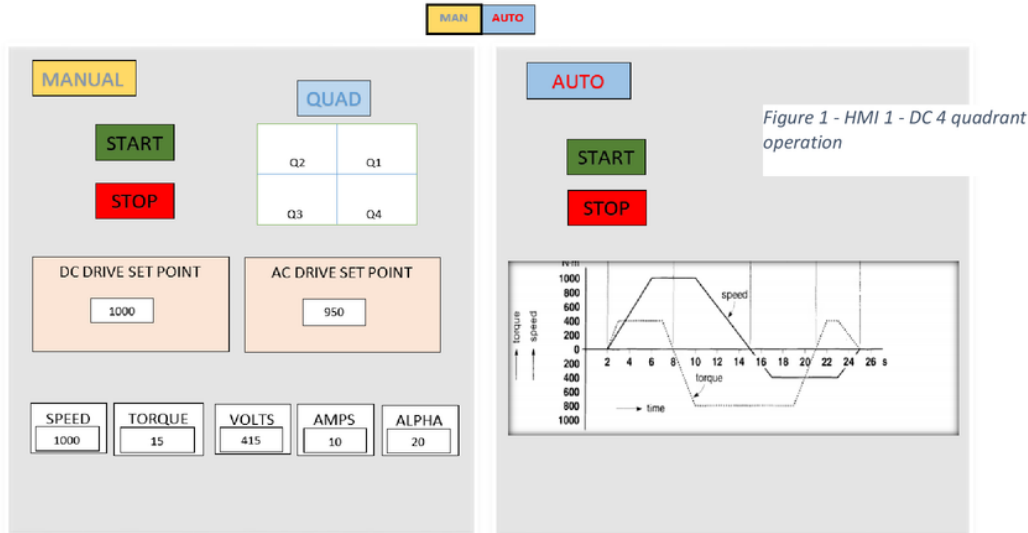
4.1 FDS

The project outcomes and measurable performance parameters and features are:

1. Functional operation for teaching
 - a. Level 3; load testing a DC motor using a constant firing angle, Speed control of an AC induction motor using an inverter.
 - b. Level 4; demonstration of integration methods between drives, PLC and HMI
 - c. Level 5; performance characteristics of a DC motor under a range of loads and regions of operation, performance characteristics of AC induction motor under various loads and regions of operation, control loop tuning.
 - d. Level 6; control strategies for DC controlled rectification and 4 quadrant operation, control strategies for induction motor speed control and 4 quadrant operation, energy saving features.
2. Four HMI screens to control specific sequences and demonstrate DC 4 quadrant operation, AC 4 quadrant operation, DC speed control via field weakening and AC speed control above base speed via inverter fed drive. Mimic screens are shown below with manual and automatic control options and a tracer graph on screen in real time. PLC program will sequence this operation in automatic mode. Data to be uploaded to webserver allowing graphical analysis.
3. Motor model verification and comparison with Matlab Simulink for DC and AC systems

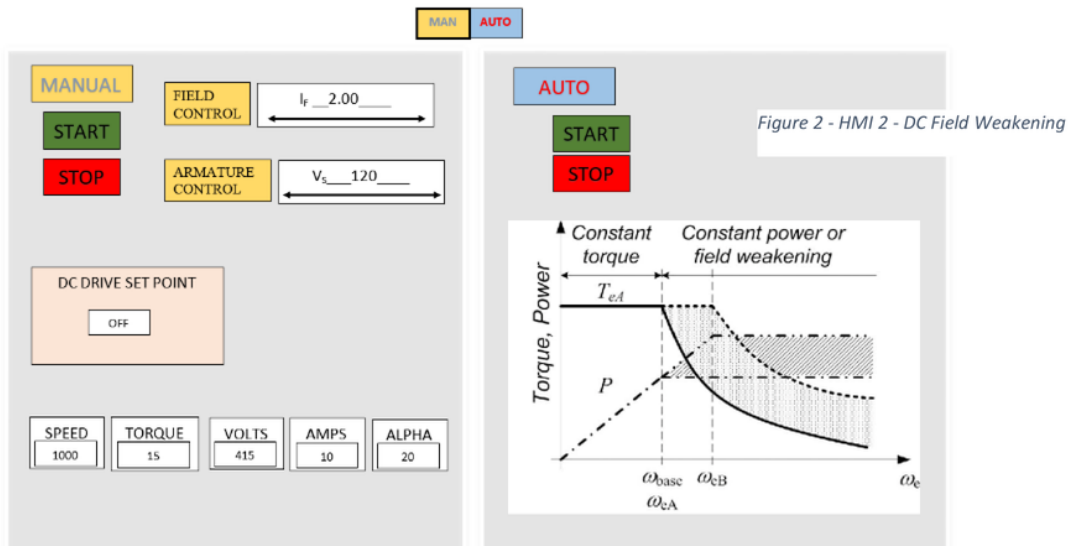
Point 2 above is the focus of the operational FDS and the four HMI screen mimics are shown overleaf, detailing the sequencing of their operation for test.

DC DRIVE 4 QUADRANT OPERATION



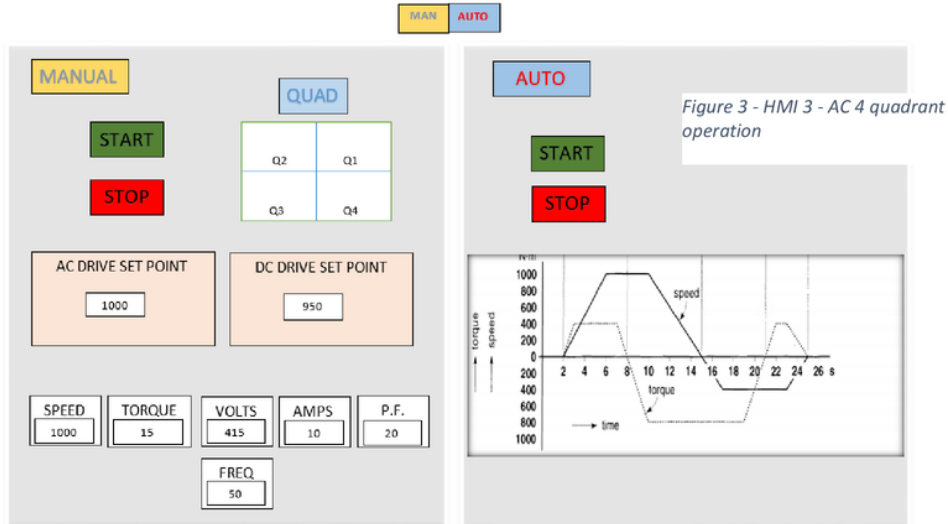
Ramp speed to 1000 rpm and after few seconds delay reverse the applied torque to show quadrant 2, when direction of rotation reverses we are in quadrant 3, then reverse the torque once more and observe quadrant 4. Torque disturbances can be provided by AC motor. Monitor V_a , I_a , N , α and T_m and make these parameters available for download to webserver.

DC DRIVE FIELD WEAKENING OPERATION



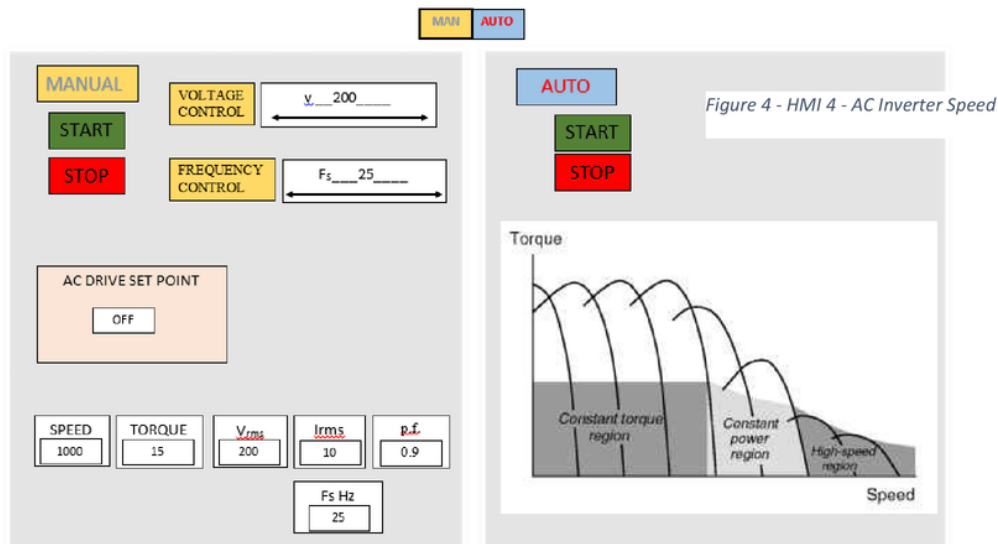
Gradually ramp-up speed from zero by armature voltage control to rated base speed and max reference voltage. Delay 5 seconds. Further increase demand in speed by reducing the field current slowly i.e. field weakening. In this zone, monitor constant power. Below base speed monitor constant maximum torque available. Monitor V_s , I_s , N , α and T_m and make these parameters available for download to webserver. 5 second delay then automatically ramp-down the speed to zero.

AC DRIVE 4 QUADRANT OPERATION



Ramp speed to 1000 rpm and after few seconds delay reverse the applied torque to show quadrant 2, when direction of rotation reverses we are in quadrant 3, then reverse the torque once more and observe quadrant 4. Torque disturbances could be provided by the DC motor. Monitor Vdc, Is, N and Tem and make these parameters available for download to webserver.

AC DRIVE INVERTER SPEED



Gradually ramp-up the speed from zero to base speed by increasing the frequency up to 50Hz via the VFD. In this zone, a constant V/f ratio is automatically maintained. Delay 5 seconds. Ramp-up speed further by increasing frequency at constant rated voltage and constant power with reduced torque. Monitor Vs, I, N, f_s and T_m and make these parameters available for download to webserver. Delay 5 seconds then automatically ramp-down the speed to zero.

4.2 Testing Plan

For each of the four HMI screens testing will be recorded on a simple chart:

- DC drive 4 quadrant operation – HMI 1
- DC drive field weakening for speed control above base speed – HMI 2
- AC drive 4 quadrant operation – HMI 3
- VFD operation above base speed – HMI 4

HMI 1 - DC drive 4 quadrant operation									
Manual					Auto				
Quad	Va (V)	Ia (A)	N (rpm)	Tm (Nm)	Quad				
1					1	2	3	4	
2					Tracer Graph (Y/N)				
3					Data Upload				
4					Va	Ia	N	α	Tm

Figure 5 – HMI 1 and 2 DC motor test results tables

HMI 2 - DC drive field weakening										
Manual		Auto								
Nom Speed (rpm)	Max Speed (rpm)	Ramp Sequence					Tracer graph (Y/N)	Data Upload		
		Ramp Up	Delay	Ramp Up	Delay	Ramp Down		Vs	Is	N
								α	Tm	

In manual mode values can be noted, for auto mode simply insert a tick to signify compliance.

HMI 3 - AC drive 4 quadrant operation									
Manual					Auto				
Quad	Va (V)	Ia (A)	N (rpm)	Tm (Nm)	Quad				
1					1	2	3	4	
2					Tracer Graph (Y/N)				
3					Data Upload				
4					Vdc	Is	N	fs	Tm

Figure 6 - HMI 2 and 3 AC motor test results tables

HMI 4 - VFD operation above base speed												
Manual		Auto										
Nom Speed (rpm)	Max Speed (rpm)	Ramp Sequence					Tracer graph (Y/N)	Data Upload				
		Ramp Up	Delay	Ramp Up	Delay	Ramp Down		Vs	Is	N	fs	Tm

The AC tests follow the same format.

5. Literature Review

Through extensive research, three solutions to address the problem specified in the FDS, have been investigated and compared in order to justify the final solution.

For inverter-fed induction motor drives in steady state operation the importance of achieving full flux is considered.

Hughes states that “Three simple relationships need to be borne in mind in order to simplify understanding of the inverter-fed characteristics. Firstly, we established that for an induction motor, the torque developed depends on the strength of the rotating flux density wave, and on the slip of the rotor. Secondly, the strength of the flux wave depends directly on the supply voltage to the stator windings, and inversely on the supply frequency. And thirdly, the absolute speed of the flux wave depends directly on the supply frequency” (2013, pp. 207-208)

It is the case that the voltage supplied by the inverter varies in direct proportion to the frequency, thus the flux wave will have constant amplitude. The inverter cannot supply voltages above its maximum voltage range meaning full flux is not maintained beyond base speed and performance is adversely affected.

Typical torque-speed curves, showing the constant torque region, below base speed and constant

voltage region above. In this region we observe the amplitude of the flux wave reduces inversely with frequency, the peak torque reduces inversely with the square of frequency and the torque-speed curve becomes less steep.

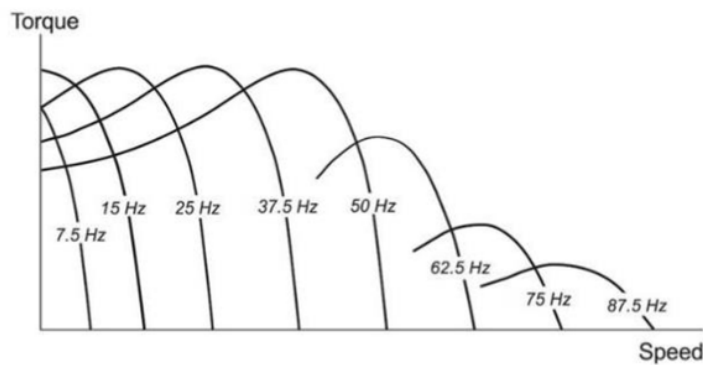


Figure 7 - AC drive torque-speed curves

MATLAB RESEARCH

MECHANICAL COUPLING OF TWO MOTOR DRIVES – variable and bi-directional load to motor shaft.

Coupling of AC4 model (DTC 3-phase induction motor drive) to DC2 model (single-phase dual-converter). Each drive can operate either as a motor or as a generator.

Diagram of two interconnected drives (Exp1 AC4 Speed Reg, DC2 Torque Reg, vice versa for Exp2)

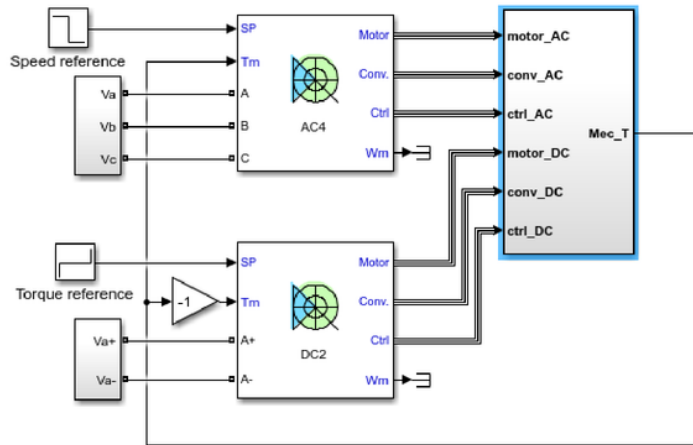


Figure 8 - Mechanical Coupling of two motor drives

Discrete
5e-06 s.
powergui

Mechanical Coupling of Two Motor Drives I

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

?

According to (MathWorks, 1994-2019) the output from mechanical shaft model represents torque transmitted from AC4 motor to DC2 generator. It is directly connected to Tm of AC4 and inverted and connected to Tm of DC2.

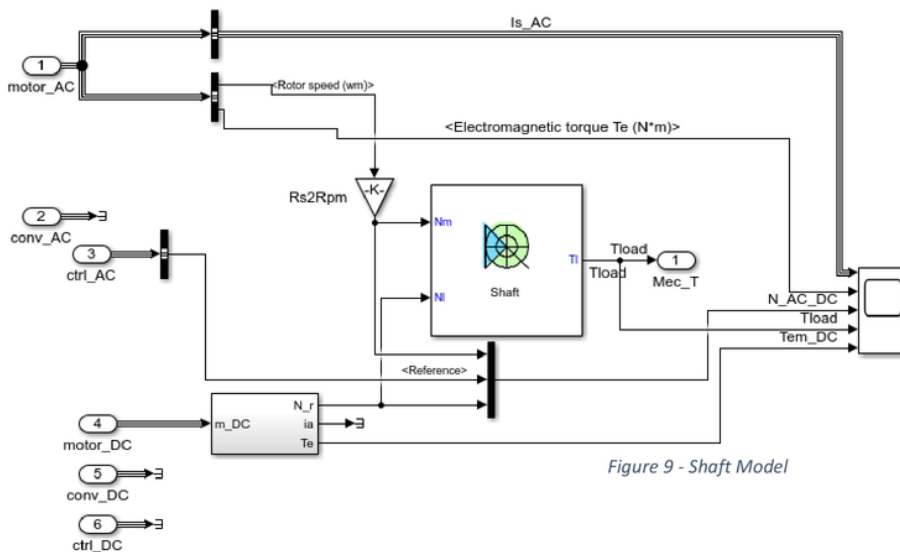


Figure 9 - Shaft Model

Exp1 - Speed regulated AC4 with Torque regulated DC2

AC4 motor drive response

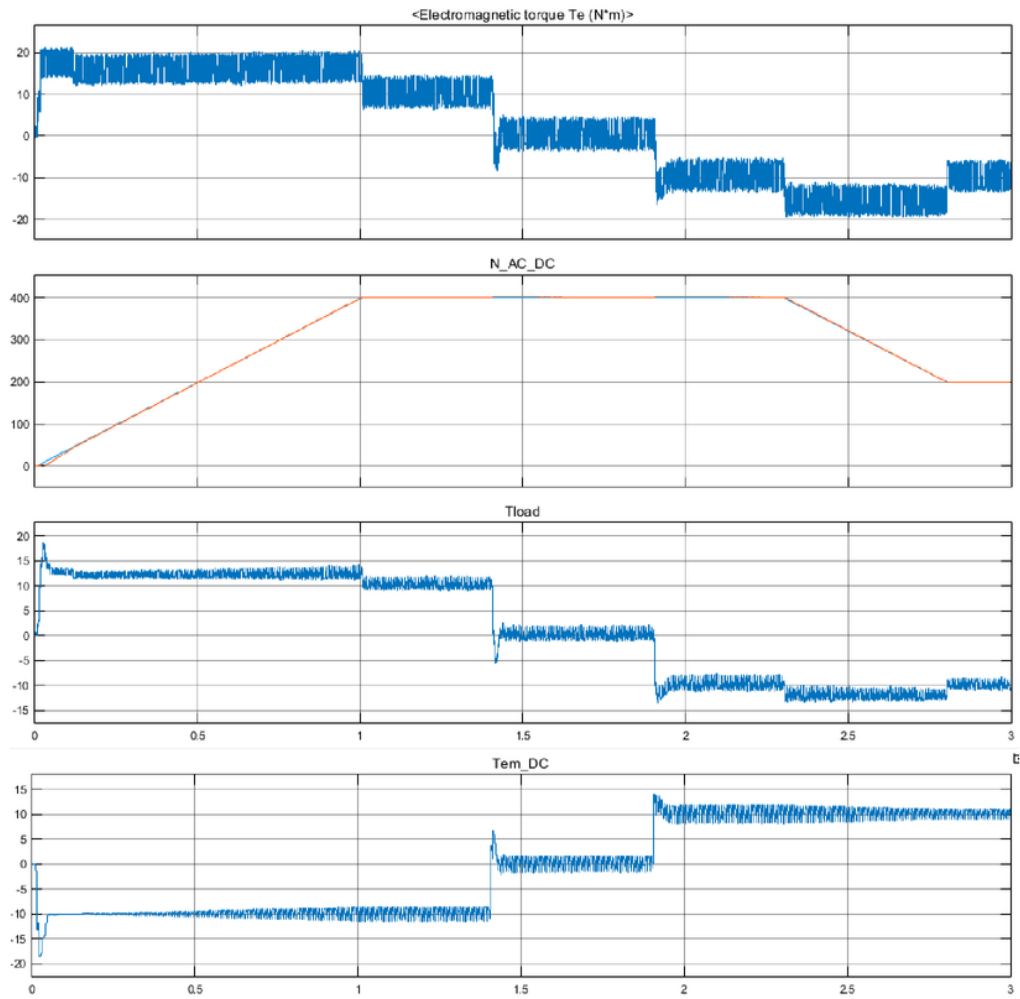


Figure 10 - AC motor drive response

AC4 motor drive <u>startup</u> at nearly full load then load disturbance torques are applied.					
0-1	1	1.4	1.9	2.3	2.8
+400rpm/s to AC4	400rpm steady AC4 <u>T_e</u> drops to 10Nm	0Nm on DC2	+10Nm on DC2	-400rpm/s to AC4	+200 rpm
AC4 motor speed follows ramp	AC4 = motor DC2 = generator	AC4 <u>T_e</u> drops to 0 to maintain speed	AC4 = generator DC2 = motor	AC4 motor speed follows ramp	<u>T_e</u> stable at - 10Nm

Exp2 - Torque Regulated AC4 with Speed Regulated DC2

DC2 motor drive response

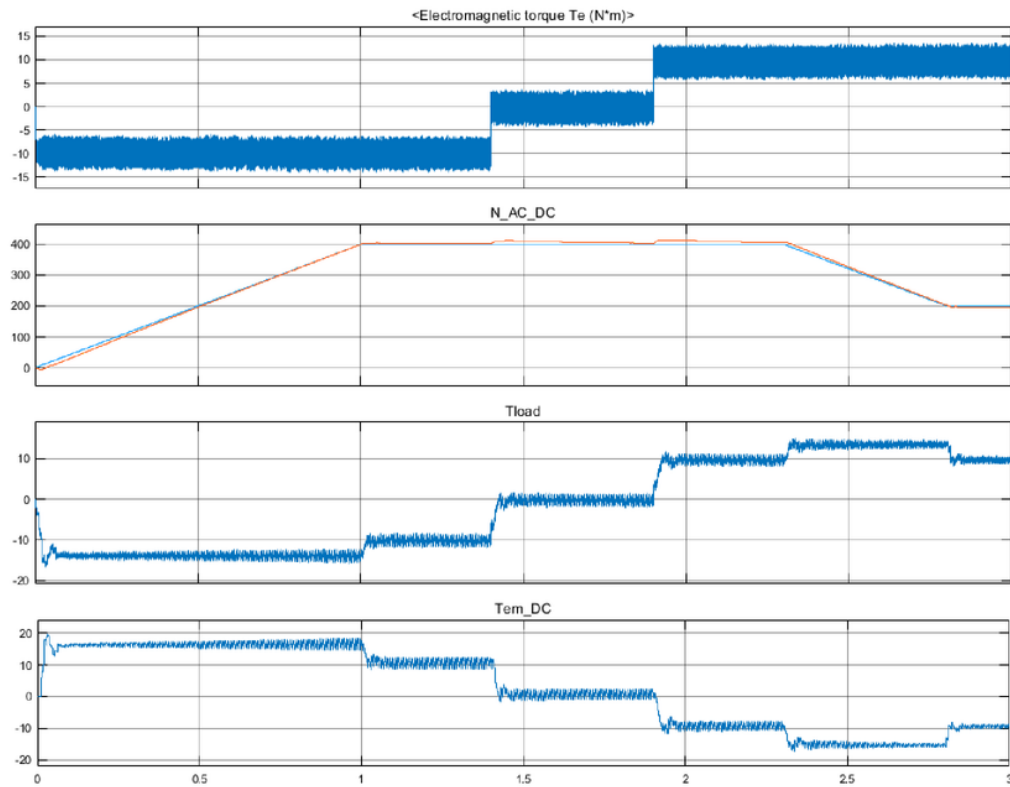


Figure 11 - DC motor drive response

DC2 motor drive <u>startup at nearly full load</u> then load disturbance torques are applied.					
0-1	1	1.4	1.9	2.3	2.8
+400rpm/s to DC2	400rpm steady DC2 Tem drops to 10Nm	0Nm on AC4	+10Nm on AC4 -10Nm on DC2	-400rpm/s to DC2	+200 rpm
DC2 motor speed follows ramp	AC4 = generator DC2 = motor	DC2 Tem drops to 0 to maintain speed	AC4 = motor DC2 = generator	DC2 motor speed follows ramp	Tem stable at - 10Nm

Conclusion – AC4 drive better speed regulation, load disturbances rejected more efficiently because of the fast dynamics of the AC4 electric torque. AC4 has DTC based on hysteresis comparators and high frequency switching. Torque ripple is higher. DC2 relies on naturally commutated thyristor converters.

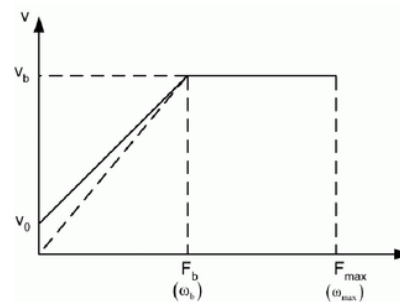
Simulate an AC motor drive

In the Electric Drives Library AC1-4 models are based on cage rotor induction motor, AC5 a wound rotor synchronous motor and AC6 a permanent magnet synchronous motor. Feed is variable AC voltage and frequency from an inverter (VSI) fed from uncontrolled diode rectifier and a capacitor (capacitive DC bus). Bidirectional power flow is not provided as the DC bus comes from a diode rectifier, so dynamic braking via a series braking resistor is used. (MathWorks, 1994-2019)

VSI utilises hysteresis modulation and space vector PWM. The former is a feedback current control method consisting of three hysteresis comparators, one for each phase (used in AC3 and AC5). The latter utilises a reference voltage space vector, V_s , sampled at fixed frequency and constructed through timing of nonzero inverter space vectors V_1 - V_6 and zero space vectors V_0 and V_7 . The six active vectors are an angle of 60 degrees apart, the two zero vectors are at the origin.

Maintaining the V/f ratio in the constant torque region avoids magnetic saturation.

Figure 12 - V/f ratio regions



AC1 open loop V/f control, AC2 closed loop V/f and slip regulation, AC3 indirect field-oriented control, AC4 DTC drive.

Discrete,
 $T_s = 1e-006$ s.

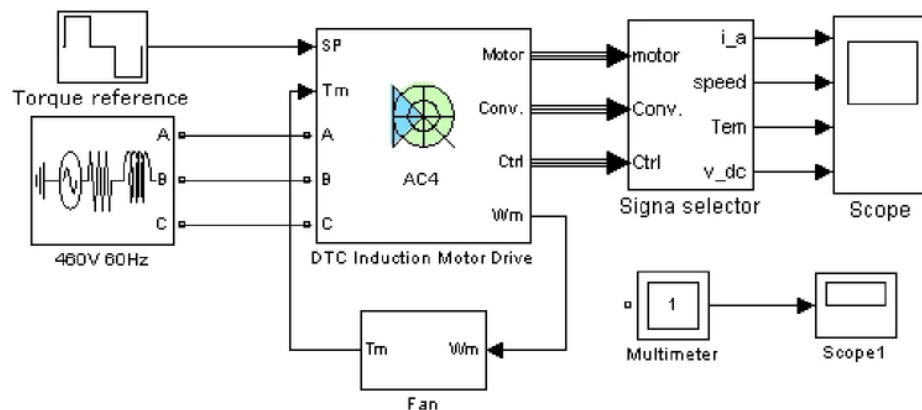


Figure 23 - AC4 DTC drive

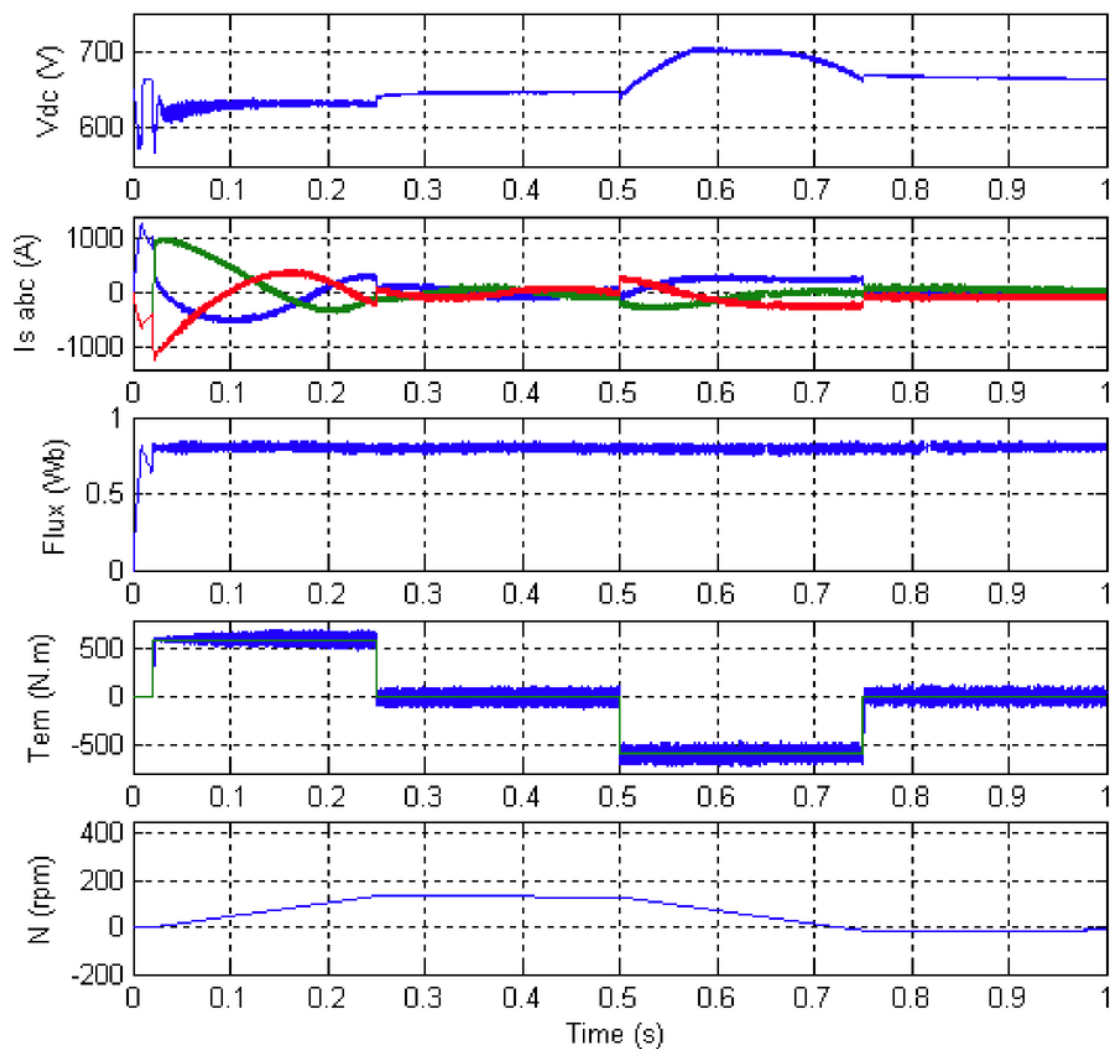


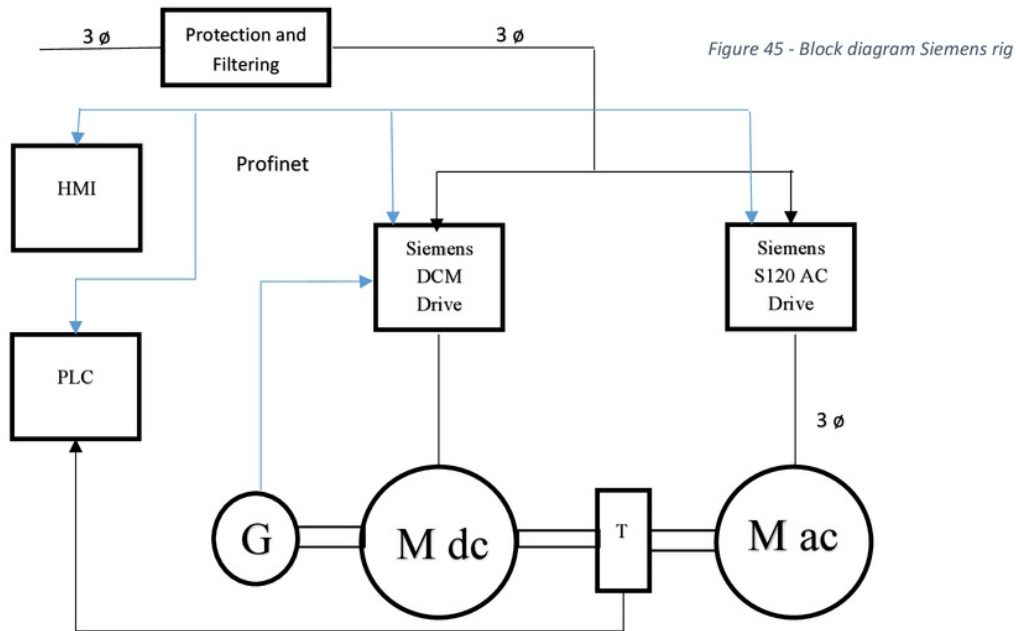
Figure 34 - AC4 DTC response

We can observe the motors very fast torque response			
0.02 - 0.25s	0.25 - 0.5s	0.5 - 0.75s	0.75 - 1s
600Nm Tem by AC induction motor	Tem to 0Nm N (rpm) decrease due to fan load	-600Nm braking, power back to DC bus limited by braking chopper to 700V	Tem to 0Nm, N (rpm) -10 to 0
Flux 0.8Wb, flux and torque oscillations dictated by DTC controller settings, hysteresis and switching frequency limit.			

THREE SOLUTIONS

1. Siemens motor-generator set

A block diagram of the main system operation is shown, the communication link between the drives, PLC and HMI is ProfiNet. There will be a hinged enclosure for the motors and two safety switches which trigger a safety relay offering PLd level protection.



The network diagram as seen on the TIA portal software, one major advantage of this system is that it uses a single software package for full control.

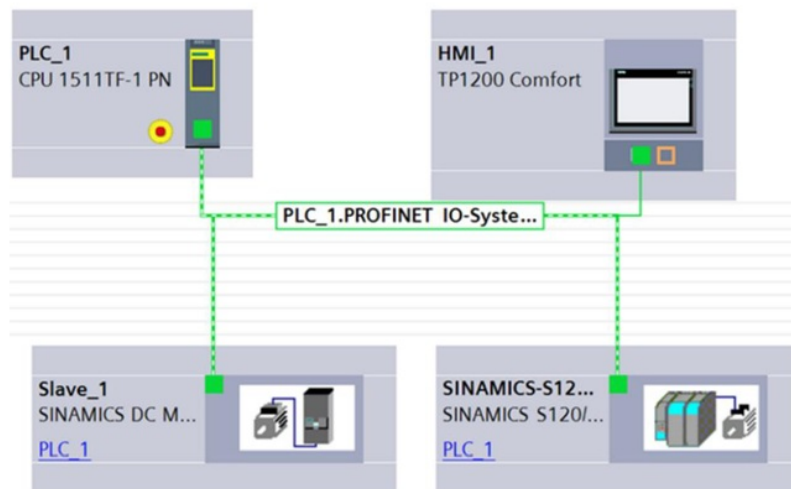


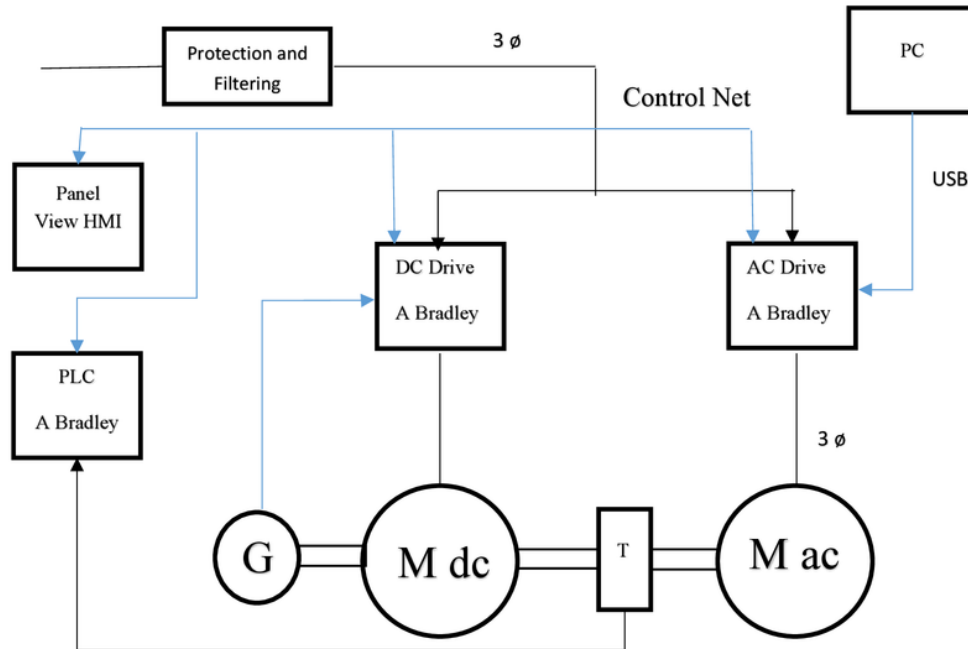
Figure 16 - TIA portal Network view

This table lists the main components for comparison purposes.

Item	Manufacturer	Ratings	Part number	Price
DC Drive	Siemens DCM	400V 3AC 13A	6RA8 013-6DV62-0AA0	£1513.48
DC Motor	Refurbished	0.69 - 3 kW	1GA5106-0AD76-6VE0	£2500.00
AC Drive SINAMICS S120	Siemens Single Motor Module	9.00A	6SL3 120-1TE21-0AD4	£637.24
AC Motor (with encoder)	Siemens	3 kW	1LE1004-1AB52-3AA4-Z-G01	£1267.55
HMI	Siemens	TP1200 Comfort 12" – Colour Touch	6AV2 124-0MC01-0AX0	£2275.00
1511F PLC	Siemens	CPU 1511F-1 PN	6ES7 511-1FK02-0AB0	£850.00
Ethernet Switch	Siemens	<u>ProfiNET</u>	6GK5-008-0BA00-1AB2	£108.00
Torque Transducer	Omega TQ514	12-15V, 350mA, 50NM	T22/50NM	£2345.57
				£11,496.84

2. Rockwell

An alternative solution is to use Allen Bradley drives which can be sourced in the UK through Routeco.com via the following website <https://ab.rockwellautomation.com/Drives>



Below is a list of the main parts for comparison.

Figure 17 - Block diagram AB test rig

Item	Manufacturer	Ratings	Part number	Price
PowerFlex DC Drive	Rockwell	480 VAC, 3 PH, 14 Amps, 7.5 HP, IP20	20P41AD014RA0NN	£1860.00
DC Motor	Brook Crompton	3kW (4HP) x 1750RPM 180V DC Motor Mount IP22 - 132 Frame	MD132200M	£3203.00
AC Drive PowerFlex 525 AC	Rockwell	Embedded EtherNet/IP and Safety, 480 VAC, 3 Phase, 5 HP, 4 kW Normal Duty	20G1F3C302LNDNNNNN	£1650.00
AC Motor	CM107 -Open EE/PE/NP AC Motors	3 HP, 3600 RPM, Foot Mounted, Frame Size is 145T	CM107-DP00336ANHHC	£2023.45
HMI	2751P Panel View 5510 Graphic Terminal	(12" touch screen)	2715P-T12WD-B	£2944.01
PLC	Compact GuardLogix Dual Ethernet 2MB	Dual Ethernet w/DLR capability, 2MB standard + 1MB safety memory, 16 I/O Expansion, 32 Ethernet IP Nodes, 8 Axis CIP motion, Kinematics with Integrated Safety function.	1769-L33ERMSK	£2910.00
Ethernet Switch	ArmorStratix 5700,	4 copper 10/100 ports, 4 PoE 10/100 ports, 2 copper 10/100/1000 ports, Full FW, 1588 PTP, DLR	1783-ZMS4T4E2TGP	£2150.00
Torque Transducer	Omega TQ514	12-15V, 350mA, 50NM	T22/50NM	£2345.57
				£19,086.03

3. Parker with Siemens PLC and HMI

The third solution is to use Parker drives linked to motors using analogue signals. Each is controlled via a PLC with an Ethernet link to the HMI for operator control and interface. A block diagram is shown below.

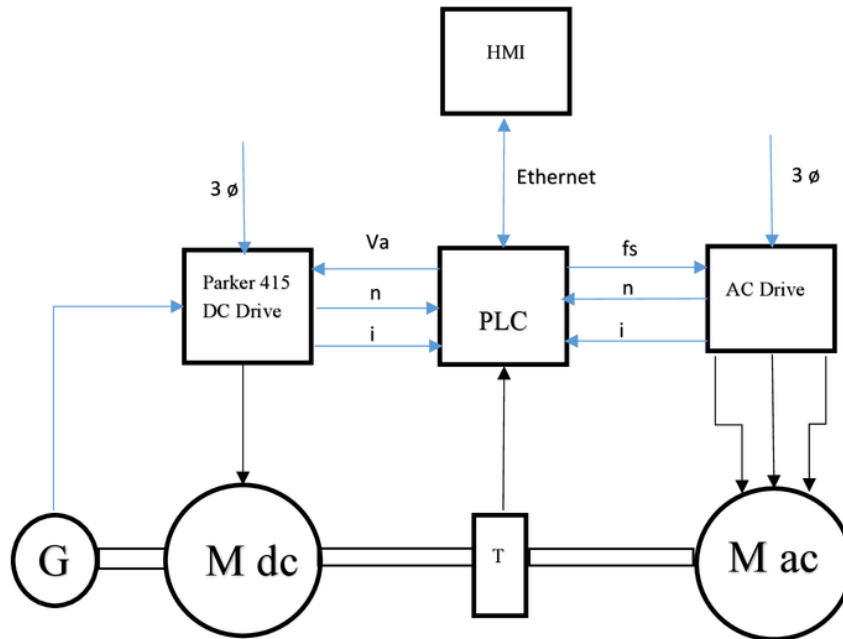


Figure 18 - Block diagram Parkers test rig

By feeding analogue values of armature voltage, actual speed and current between the DC drive and the PLC closed loop feedback control is achieved and the PLC can be programmed to sequence the operation of the motor for either speed control or to act as a brake for the AC motor. Similarly by feeding analogue values of frequency, speed and current between the AC drive and the PLC this motor could provide speed control and braking action.

Below is a list of the main parts which would be needed to construct the test rig.

Item	Manufacturer	Ratings	Part number	Price
DC Drive	Parker 514	110-500V, 32A	514C-32-00-00-00	£830.26
DC Motor	Brook Crompton	3kW (4HP) x 1750RPM 180V DC Motor Mount IP22 - 132 Frame	MD132200M	£3203.00
AC Drive	Parker SSD 890SD	4kW 400V AC Inverter Drive	890SD-532100B0-B00-1A0T0	£994.35
AC Motor	ABB	3kW, 3 phase, 4 pole 220-240V	3GAA102540-BSJ	£546.00
HMI	Parker SSD TS8015	15" Touch Screen	TS8015/00/00	£3748.64
PLC	Siemens	S7 -1200	6ES7214-1BG40-0XB0	£348.00
Ethernet Switch	Parker <u>LINKnet</u>	24Vdc 200mA, 100Mbit/s	AC890PX	£1250.00
Torque Transducer	Omega TQ514	12-15V, 350mA, 50NM	T22/50NM	£2345.57
				£13,265.18

	Siemens	Rockwell	Parkers
Overall Cost	Total cost of main parts = £11,496.84. Supplier quotation received for the design, build, test and commissioning = £27,510.00.	3 Total cost of main parts = £19,086.03. Including design, build, test and install costs makes overall = £35,099.19.	2 Total cost of main parts = £13,265.18. Including design, build, test and install costs makes overall = £29,279.14.
Connectivity	PROFINET industry standard for data communication over Industrial Ethernet.	3 Provides connection to open networks, including EtherNet/IP, ControlNet, and DeviceNet	1 Discrete and analogue signals between drives and PLC via A I/O and D I/O
User Control	Via TIA portal, allowing complete configuration and control of all the devices on the network.	3 Provides ability to develop custom C programs to integrate via external routines.	2 TIA portal for programming of Siemens PLC
Health and Safety	The Power Module has Safe Torque Off (STO) Failsafe Digital I/O F-DI and F-DO are also available. Options include a safe brake relay. (Siemens, AG 2018)	3 The Logix platform provides a single integrated control architecture for discrete, drives, motion, process and safety control.	2 Parker Drives have STO as a standard feature in accordance with EN 13849-1 (PLe) and EN62061 (SIL3)
Software	One software package TIA portal controls all accessories.	1 Runs on Windows 7 and Windows Server 2008 operating systems. Uses the same Studio 5000 environment and Logix control engine as other Logix platforms.	2 Siemens PLC software TIA portal
Score	15	8	9

3 = High 2 = Med 1 = Low

Final Solution Justification

Siemens

- Drives panel connected to two motors containing DC Drive, AC drive, PLC and 12" HMI linked via Ethernet conforming to standards IEC 60204-1 (Electrical Equipment of Machines) 2016 with full access to all drive parameters delivered by Technique Services.
- Three phase 415V supply voltage 3kW IEC squirrel cage induction motor with the following ratings: IP55, 4-pole, 50Hz, 240VD/415VY 3 AC. 3kW DC motor with following ratings: 5.9 – 8.7A, 725-2170 rpm, 0.69 – 3.05 kW, 4 Quadrant inverter drive, 4 Quadrant DCM drive PLC equivalent to Siemens 1500 for overall control and sequencing.
- The test rig mechanical design which consists of a standalone bench (2000x800x740mm) will be divided into 3 zones: Electrical panel, Motor enclosure and workbench space. Appropriate guarding and safety features are incorporated. An ETA panel STP81030 (800x1000x300mm) containing an AC and DC drive along with the PLC and door mounted HMI will sit in the left hand rear corner of the bench. The system operation will be from the HMI with dedicated screens for AC and DC drives.
- It is important to note that the drives will not have any restrictions in their control allowing full flexibility for demonstrating four quadrant operation. Configuration of all parameters will be made available for access, modification and can be read or written to the particular drive.

Supplier contractor is responsible for this part of the design and construction of test rig which will also be programmed with two basic operating screens and configuration of the telegrams for network communication between all devices. (Services, 2018)

Final solution has many advantages:

- Meets an exact specification in terms of size, power output, features, configuration, constraints, etc.
- Software for basic functionality will be supplied with rig which can then be expanded upon to perform various experiments.
- A high specification PLC via Ethernet communication, controls both drives, HMI and PC using one software platform. (The major deciding factor)
- Modern Industry standard equipment meets the needs of local employers.
- Motor and drive data available allowing Matlab Simscape modelling to predict performance.
- Data extraction and real time waveforms examined.
- Safety built into the design by utilising failsafe's, interlock guarding and emergency stops.
- Innovative control functions for ECO mode, hibernation, PROFlenergy etc.

A contingency plan in case delivery of the Siemens equipment was delayed was considered and took the form of the third alternative solution using Parkers Drives and a modern Siemens PLC. This contingency could be designed and implemented using CSG expertise and assembled by CSG technician.

6. Project Planning, Work breakdown and Management Techniques

As a key project deliverable the WBS below schedules the work into manageable chunks.

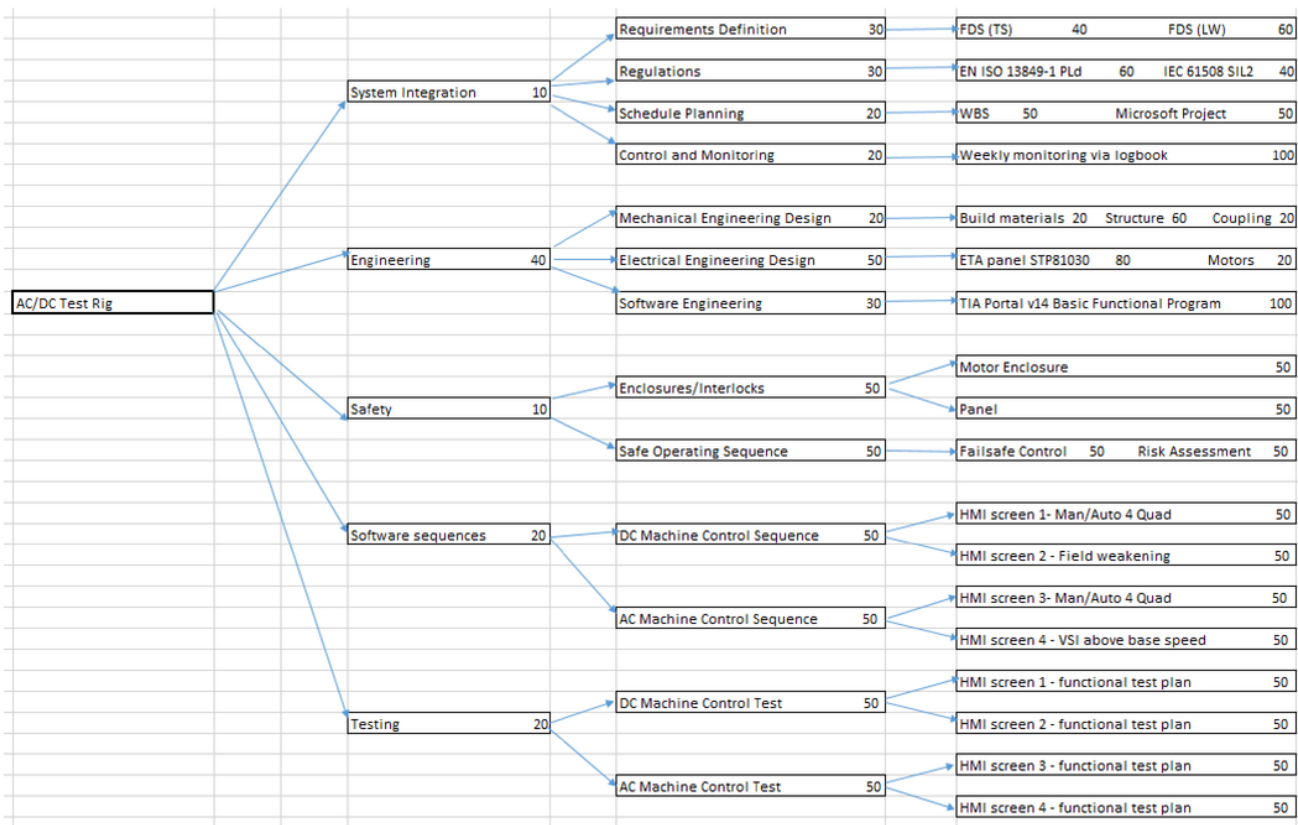


Figure 19 - Work Breakdown Structure

Figure 50 - Microsoft Project Gantt Chart

From this document a Microsoft Project plan was drawn up, see below.

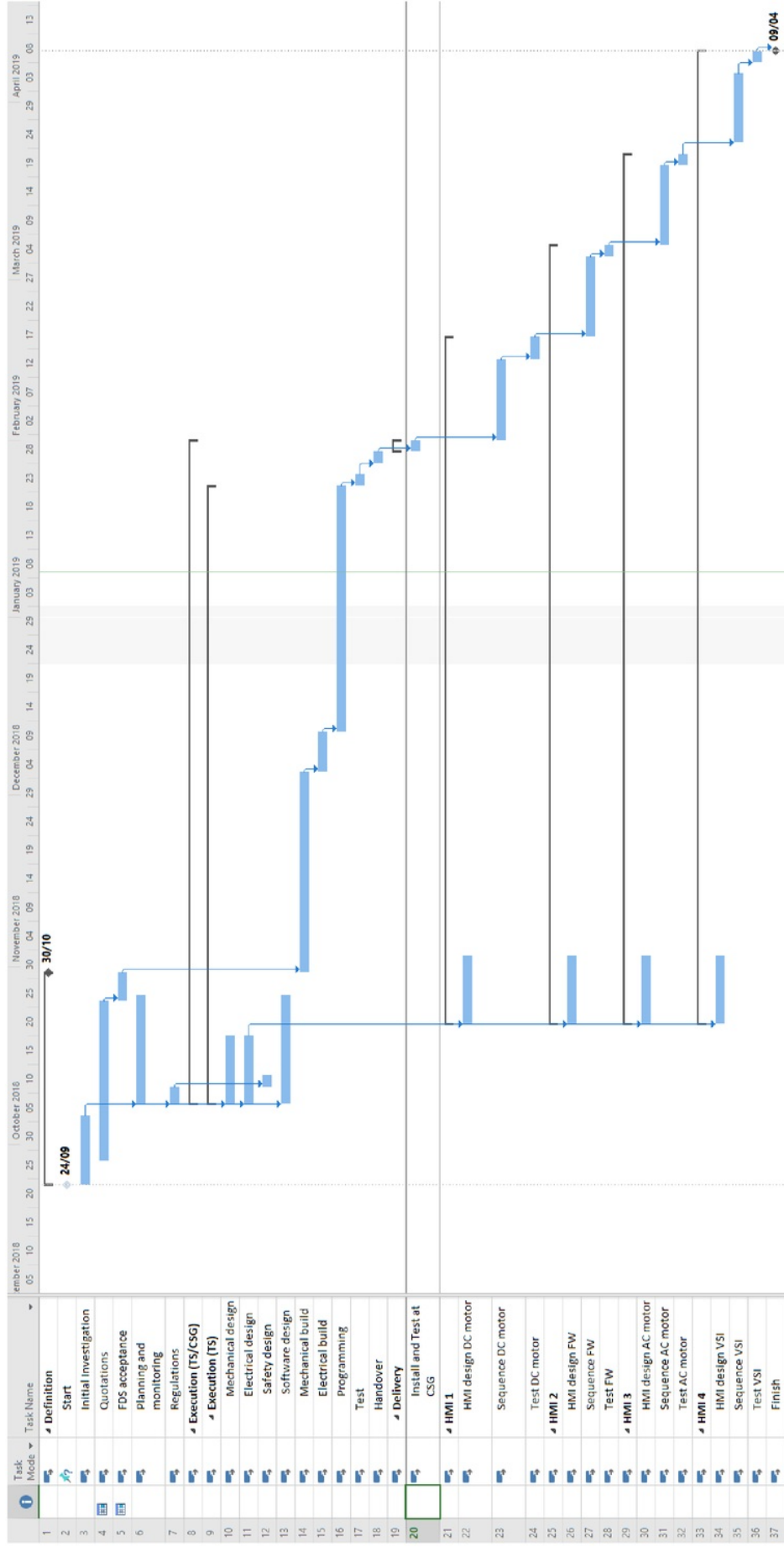
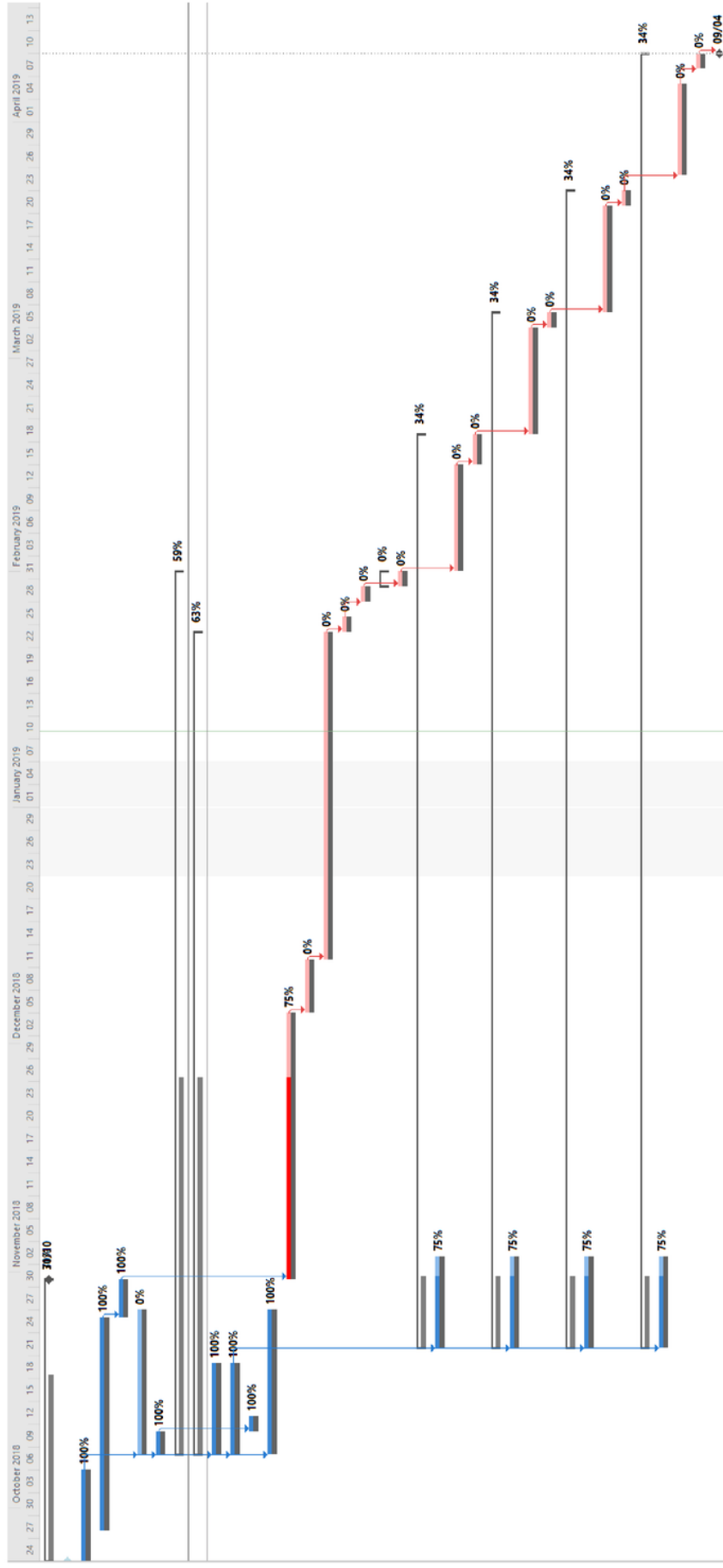


Figure 60 - Microsoft Project Gantt Chart

Figure 71 - Microsoft Project Progress Gantt Chart



7. Conclusions and Recommendations

The planning phase of this major project to design, build and test a bespoke industrial system for conducting experiments in an educational establishment was multi-faceted.

Initial investigation set out to determine the scope of the test rig and discover what, if any similar systems were available. In conjunction with drive specialists and with advice from Siemens representatives a design specification emerged which was realistic, affordable and achievable within the time frame allowed.

According to (Krishnan, 2015) a modern variable-speed system has four components (i) electric machines – ac or dc, (ii) power converter, (iii) controller – match motor and power converter to load requirements and (iv) load. There are many considerations in selecting a systems components from cost, efficiency, torque-speed profile, robustness, peak torque capability etc. and their significance varies for differing applications.

In general the load torque is a function of speed e.g. in a frictional system it is proportional to speed and in fans/pumps it is proportional to square of speed.

In general for a motor-load combination a torque equation can be written:

$$J \frac{d\omega_1}{dt} + B\omega_1 = T_m - \frac{N_1}{N_2} T_L$$

$$\frac{N_1}{N_2} = \text{gear teeth ratio i.e. for amplification of the torque to the load (direct drive =1)}$$

So to model the motor drive the load parameters of friction, inertia, torque-speed profile, gearing and backlash must be known. Profiles of common load types can be programmed for future experimental development.

Three main solutions came to the forefront and are outlined within section 6 of this report. The complexity and diversity of available technologies for motor drives proved a challenge in selecting the optimum system set up. The overarching success factors were prioritised (see page 25) and the final solution justified based on these.

Contingency planning is an important consideration for any project and this took the form of solution three which would allow the main specification outcomes to be achieved and measured performance recorded for comparison with theory and simulation. Solution three is the easiest to implement but does not provide full flexibility or meet the networking functionality requirements.

At this stage in the project development the supplier FDS is signed and work commenced well before Christmas. In tandem, design and development of the HMI screens for functional testing of both motors is on-going. Further work on background theory to predict performance and familiarisation with Siemens systems is also on-going.

Matlab simulation software called Simscape is highly configurable and as a desirable future development models could be constructed and tested including control loop tuning which would simulate experiments for the motor set and allow for accurate response prediction.

8. Citation List

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[Accessed 15 10 2018].

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9. Appendix



Project Proposal - AC/DC Test Rig

Course: BSc (Hons) Electrical and Electronic Engineering

Module: PSDE6019 Major Project

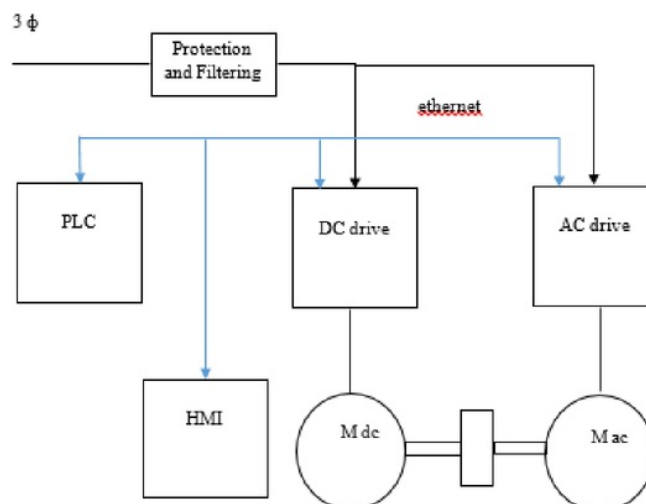
Student: Liesel Williams

Year: 2018/19

The project is based in Coleg Sir Gar, Graig Campus. The project is required to provide an AC/DC motor generator set for teaching. Electrical and Electronic Engineering modules at Levels 3 to 6, which require investigation of motor and generator characteristics and performance. A safe teaching aid to demonstrate performance characteristics would enhance the learning experience of students at all levels. Currently, the college has some old, outdated equipment produced by Feedback Ltd., for carrying out experiments on various motors and starters. However, a major drawback is that each machine requires wiring and coupling arrangements to be set up individually before running an experiment. This is not only a drain on teaching staff time but also causes safety issues such as inadequate guarding, trailing leads, exposed conductors etc. Presently, there is also no facility for testing a three-phase DC drives.

A totally enclosed test rig powered by a three-phase supply consisting of an AC induction motor mechanically coupled to a DC motor each is desirable with dedicated four quadrant drives for each motor, together with Ethernet links to a PLC and dedicated HMI screen. This would enable the user to control both types of motor safely while also providing a method of demonstrating characteristic graphs, four quadrant operation, load simulation and drive parameter selection and system integration for educational purposes. It could also provide the facility to select type of control loops and tuning methods for the control of speed, torque, tension and/or position.

Below is a block diagram of the proposed test rig.



Under the IEC 61508 Standard, new machinery supplied must achieve a SIL (Safety Integrity Level) between a 1 and 4 rating, this is a risk reduction measure where 4 gives greatest risk reduction and 1 the lowest. The SIL rating is provided by the SIF (Safety Instrumented Functions) implemented by SIS (Safety Instrumented Systems) intended to automatically achieve or maintain a safe state under a specific hazardous condition/event.

For the purposes of teaching, it would be advantageous to include, as part of the project, the use of Simulink to model the motors and drives, and to predict performance along with the effect of tuning the control loops. This would allow comparison of motor models with actual performance using data access either via a data logger, which will dump the data from the PLC and enable graphs to be produced from a spreadsheet, or by the addition of a 4 channel data logger as a necessary addition to the test rig. In order to tune the feedback loops the speed regulation of the drives need to be accessed and/or disabled.

The construction of the electrical system is to be carried out by Technique Services, a supplier of systems, but the main programming of the system will be within the scope of the project.

The following persons will have an input to the project:

Robert Davies (Coleg Sir Gar tutor)

Michael Hall (Coleg SirGar tutor)

Andrew Billington and Pawel Wieczorek (Technique Services)

The budget for the project is £29k and an order has already been placed with Technique for £27510.00 for the construction of the motor rig and control panel.

This gives a project spend of £1490.

The project must be completed by 05 April 2019.

Student (Liesel Williams)

Signature.....Date.....

College Manager (Adam Twells)

Signature.....Date.....

Tutor (Robert Davies)

Signature.....Date.....

Tutor (Michael Hall)

Signature.....Date.....

Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

71 /100

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GRADING FORM: NEW CSG-RUBRIC

LIESEL WILLIAMS

70.50

1. ENGAGEMENT WITH LITERATURE

Good research was evident from the report and was



primarily used to identify the options and determine the best approach. (6.5/10) Citation used throughout from a range of sources. However, bibliography is a duplication of the citation list. It should show the extent of background reading not referenced in the report. Some citations are missing from section 3.(3.5/5)

10

2. KNOWLEDGE AND UNDERSTANDING



A requirement was identified for a bespoke training aid to facilitate the teaching of motors, the project is intended to provide the solution. Good consideration given that sets the context of the project and its use in education and training. (8/10) It wasn't clear how much of the final product was to be sub-contracted and how much would be built locally. An opportunity may exist to develop the rig as a sellable commodity. It would be a risk not to engage with IP and protect the design. Good consideration given but no SIL assessment included. (9.5/15) Very good evidence presented. Sustainability was considered through the use of a programmed hibernation mode and the use of a power reduction technique within PROFINET. (4/5) Many aspects of health and safety considered, through the use of engineered risk reduction and appropriate assessments but no risk assessment included though one is mentioned and reference made to college policy. (2.5/5)

24

3. COGNITIVE AND INTELLECTUAL



Generally well explained but there are some issues that could be more clear. It wasn't clear if this would run several different motors in order for a comparison in performance to be made or if it was for a single motor type. (3.5/5) Detailed FDS described. Very good screens but there appears to be some confusion regarding the inclusion of Matlab modelling, is it in the specification or not. (7/10) A detailed test plan of how the 4 quadrants perform was included. (4/5) Good conclusions given with a clear way forward. (4/5)

18.5

4. PRACTICAL APPLICATION



Two good alternatives given and a ranking system use to grade the criteria; the highest score being the most suitable option. Very good analysis of choices and justification presented for final solution. (4/5) Very good use of management techniques including WBS and detailed Gantt chart with contingencies. (8/10)

12

5. TRANSFERABLE SKILLS



Too long, covers many aspects but not all contained in the report. (3.5/5) Very good quality, generally well written with clear diagrams and photos. However introduction does not really cover the aims and objectives of the project, it is too generic and reads like an introduction to the module. The word count of 3472 is within the limit 3600. Signatures are missing from the project proposal in the appendix. Font type and size are not

6

always consistent. (2.5/5)