

Power Electronics & Drives - ACDA6004 - Ethan Longley.docx

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Submission date: 30-Mar-2026 08:33PM (UTC+0100)

Submission ID: 278832446

File name: Power_Electronics_Drives_-_ACDA6004_-_Ethan_Longley.docx (824.75K)

Word count: 3749

Character count: 23949



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Design and Analysis of Industrial Motor Drive Systems and Rectifier Technologies for Power Quality Optimisation

POWER ELECTRONICS & DRIVES (ACDA6004)

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Contents

Chapter 1 – Introduction.....	3
1.1 Background Research to Power Electronics and Drives	3
1.2 Aim and Scope of the Report.....	3
1.3 Report Structure	Error! Bookmark not defined.
Chapter 2 – Motor Drive System Design (Task 1).....	4
2.1 Overview of Industrial Motor Drive Requirements.....	4
2.2 Analysis of Factory Motor Systems	4
2.2.1 Motor Specification and Operational Requirements	4
2.2.2 Key Design Considerations	4
2.3 Selection of Drive Technologies	5
2.3.1 Variable Frequency Drives (VFDs)	5
2.3.2 Direct-On-Line (DOL) and Starter Methods.....	5
2.3.3 Use of Common DC Bus Systems	5
2.4 Proposed Drive System Architecture	6
2.4.1 Drive Selection for Each Motor Type.....	6
2.4.2 Control Strategy and System Integration	7
2.5 Protection, Monitoring and Practical Considerations	7
2.5.1 Protection Mechanisms	7
2.5.2 Data Acquisition and Diagnostics.....	7
2.5.3 Cost and Implementation Considerations.....	7
2.6 Discussion and Evaluation	8
2.7 Conclusion (Task 1).....	8
Chapter 3 – Rectifiers and Harmonic Analysis (Task 2)	9
3.1 Introduction to rectification in VFD Systems.....	9
3.2 Rectifier Technologies	9
3.2.1 Diode Rectifiers	9
3.2.2 Thyristor (SCR) Rectifiers	10
3.2.3 IGBT-Based Active Rectifiers.....	10
3.3 Comparison of Rectifier Technologies.....	10
3.3.1 Performance and Control Characteristics	10
3.3.2 Cost and Complexity	11
3.3.3 Suitability for Industrial Applications	11
3.4 Harmonic Generation in Power Electronic Systems.....	11
3.4.1 Sources of Harmonics	11
3.4.2 Impact on Power Quality and Power Factor	12

3.5 Harmonic Mitigation Techniques	12
3.5.1 Passive Filtering Methods	12
3.5.2 Active Filtering and Advanced Rectifiers.....	12
3.5.3 Design Considerations for Harmonic Reduction	12
3.6 Simulation and Results Analysis	13
3.6.1 Simulation Model Description.....	13
3.6.2 Results and Observations	13
3.6.3 Interpretation of Results	14
3.7 Discussion.....	Error! Bookmark not defined.
3.8 Conclusion (Task 2).....	Error! Bookmark not defined.
Chapter 4 – Overall Conclusions	15
4.1 Summary of Key Findings	Error! Bookmark not defined.
4.2 Engineering Recommendations	Error! Bookmark not defined.
References.....	16

Chapter 1 – Introduction

1.1 Background Research to Power Electronics and Drives

Power Electronics play a crucial role in modern industrial systems by allowing an efficient conversion, control and conditioning of electrical energy for a wide range of applications [1]. Motor drive systems, especially those based on induction motors, are extensively utilised due to their robustness, cost effectiveness and suitability for high-power industrial operations [2]. These systems are fundamental for achieving a better level of automation, process control and enhanced efficiency [3]. The increased demand for energy efficiency and cost reduction has led to a worldwide usage of variable frequency drives (VFDs), which allow accurate motor speed and torque control whilst significantly reducing energy consumption [4]. However, concerns regarding the power quality and harmonic distortion have driven advancements within power electronic converter technologies and control strategies [3]. As a result, modern industrial drive systems are increasingly designed to optimise their performance, reliability and efficiency in line with environmental requirements [4].

1.2 Aim and Scope of the Report

This report analyses motor drive system selection for industrial applications and evaluates rectifier technologies in the context of harmonic generation and power quality. The study will focus on engineering justification of suitable drive solutions for different motor requirements, alongside a comparative assessment of diode, thyristor and IGBT-based rectifiers. Simulation based evaluation is also used to analyse harmonic distortion and assess the performance of various rectification approaches.

Chapter 2 – Motor Drive System Design (Task 1)

2.1 Overview of Industrial Motor Drive Requirements

Industrial motor drive systems operate under varying load conditions, influencing drive selection. Constant torque loads include conveyors, while variable torque loads are typical in pumps and fans [5]. Effective control of speed and torque is essential for efficiency and reliability. Variable frequency drives (VFDs) enable precise speed control and energy savings, particularly in variable torque applications [6]. Simpler methods such as direct-on-line (DOL) starters are used where speed control is unnecessary, offering cost-effective solutions [1].

2.2 Analysis of Factory Motor Systems

2.2.1 Motor Specification and Operational Requirements

The factory incorporates a range of induction motors with varying power ratings and operational requirements, as summarised in Table 1. Motor A represents a high-powered application (500kW) requiring both reversible operation and variable speed control, indicating a demanding industrial process such as a rolling mill. Motors B and D also require reversible operation, suggesting applications involving bidirectional motion, such as cranes or positioning systems. Variable speed operation is required for motors A, B and C highlighting the need for flexible control to optimise performance and efficiency. In contrast, motor E is a low-power single phase motor with no requirement for speed control or reversing, making it suitable for simpler applications such as pumps or fans. These varying requirements necessitate careful selection of appropriate drive technologies [7-8].

Table 1 - Motor Requirements Summary

Motor	Power	Phases	Voltage	Reversible	Variable Speed	Application
A	500kW	3	400v	Yes	Yes	Rolling Mill
B	80kW	3	400v	Yes	Yes	Gantry Crane
C	10kW	3	400v	Yes	Yes	Conveyor
D	5kW	3	400v	Yes	Yes	Cutting Machine
E	1kW	1	230v	No	No	Pumps / Fans

2.2.2 Key Design Considerations

Several critical engineering factors must be considered to select an appropriate motor drive system. Control flexibility is essential, particularly where variable speed is required, making VFDs more suitable than fixed speed solutions. However, this must be balanced against cost, as simpler methods such as DOL starters offer lower initial investment but reduced functionality. Reliability and maintenance requirements are also significant, particularly in large-scale installations where downtime must be minimised. Additionally, protection mechanisms, including overcurrent and thermal protection are necessary to ensure safe operation. Scalability is also important due to the high number of motors installed, while modern systems increasingly incorporate data monitoring and diagnostic systems [8].

2.3 Selection of Drive Technologies

2.3.1 Variable Frequency Drives (VFDs)

Variable frequency drives (VFDs) provide precise control of motor speed and torque by converting AC to DC and back to AC at variable frequency [9]. This enables efficient operation and reduces mechanical stress during startup and stopping [10]. VFDs are widely used in applications requiring flexibility and improved energy efficiency.

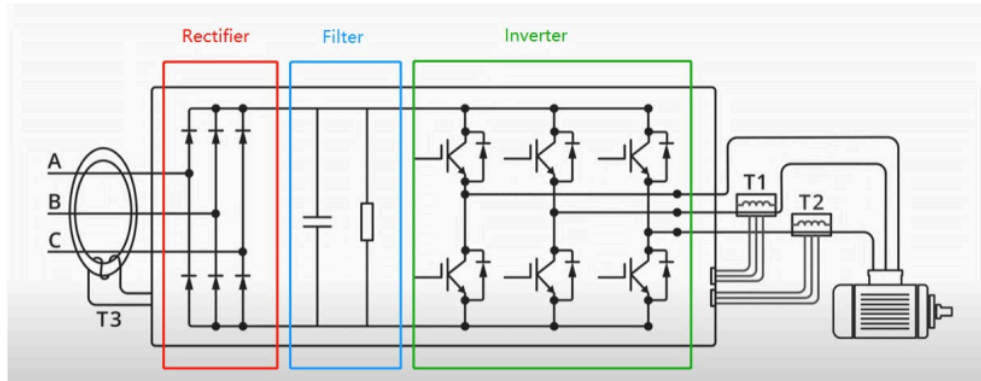


Figure 1 - VFD Circuit [9]

2.3.2 Direct-On-Line (DOL) and Starter Methods

Direct-on-line (DOL) starters apply full voltage to the motor, resulting in high inrush current and mechanical stress. Soft starters reduce these effects by gradually increasing voltage. These methods are suitable where constant speed operation is sufficient [11-12].

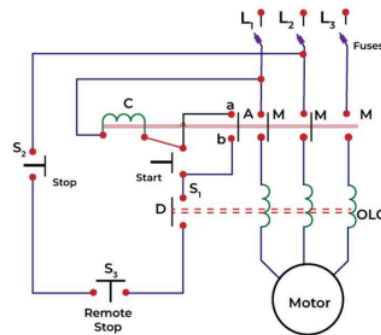


Figure 2 - DOL Circuit [12]

2.3.3 Use of Common DC Bus Systems

Energy can be effectively distributed among connected motor systems thanks to common DC bus systems, which use a shared DC link between several drives. In these setups, other drives running on the same DC bus can utilise the regenerative energy generated by braking motors, increasing system efficiency and lowering energy losses. This method works especially well in large-scale industrial applications that use reversible or high-power motors, including crane systems and rolling mills (e.g.,

Motors A and B). Common DC bus topologies therefore provide improved system performance and energy usage [13].

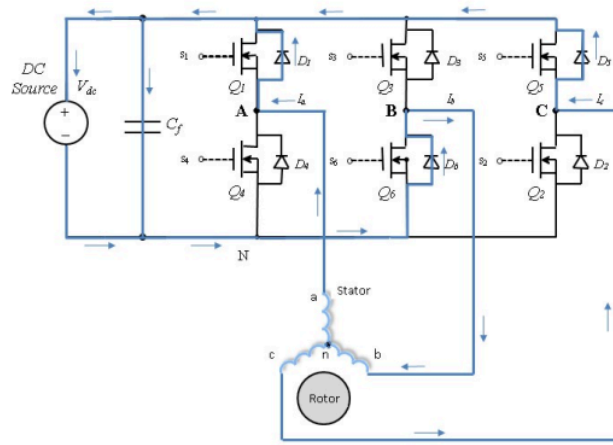


Figure 3 - Common DC Bus System Architecture [14]

2.4 Proposed Drive System Architecture

2.4.1 Drive Selection for Each Motor Type

Each motor's drive technology selection is determined by its operational and application needs. A high-power variable frequency drive (VFD) is the best option for Motor A (500 kW), which is utilised in a rolling mill and needs both reversible operation and variable speed. In this instance, integrating a common DC bus system is beneficial since it increases overall efficiency and permits energy recovery while braking. Like this, Motor B (80 kW), which operates in a gantry crane application, needs accurate speed and bidirectional control, which a VFD successfully accomplishes.

A smaller VFD is a suitable and economical option since Motor C (10 kW), which is used in a conveyor system, requires variable speed control but not reversing. A direct-on-line (DOL) starter with a reversing contactor can be used to operate Motor D (5 kW), which needs reversing but not variable speed. If better control and less mechanical stress are required, a low-power VFD might be taken into consideration. Lastly, a DOL starter is the most practical and affordable option because Motor E (1 kW), which is used in pumps or fans, does not require speed control or reversing.

The recommended drive configurations are summarised in Table 2.

Table 2 - Recommended Drive Selection

Motor	Requirment	Selected Drive	Justification
A	High power, reversible, variable speed	High-power VFD + DC bus	Efficiency + energy recoevery
B	Reversible, Variable Speed	VFD	Precise control
C	Variable Speed	Small VFD	Energy saving
D	Reversible, Fixed Speed	DOL + reversing / VFD	Cost vs Control
E	Fixed Speed	DOL	Simple and Low cost

2.4.2 Control Strategy and System Integration

Programmable logic controllers (PLCs) are used to coordinate motor drive operation, enabling control of speed, direction and sequencing. Communication protocols such as Modbus and Ethernet/IP allow real-time data exchange between drives and control systems. This integration supports automation, improves efficiency and enables condition monitoring and predictive maintenance in line with modern Industry 4.0 requirements [15].

2.5 Protection, Monitoring and Practical Considerations

2.5.1 Protection Mechanisms

For motor drive systems to operate safely and dependably, appropriate protection mechanisms are necessary. While overvoltage prevention protects equipment from brief voltage spikes, overcurrent protection is necessary to stop excessive current flow that could harm electrical components [16]. Short-circuit protection is essential for isolating fault conditions and avoiding system damage, while thermal protection is required to prevent motors and drives from overheating [17].

2.5.2 Data Acquisition and Diagnostics

Modern motor drive systems incorporate sensors to monitor parameters such as current, temperature and vibration. This enables condition monitoring and predictive maintenance, allowing faults to be detected early. As a result, downtime is reduced and system reliability is improved [18].

2.5.3 Cost and Implementation Considerations

The selection of motor drive systems must balance initial investment costs against long-term operational benefits. While advanced solutions such as variable frequency drives involve higher upfront costs, they can provide reduced energy consumption and lower lifecycle costs over time. Maintenance requirements and system reliability also influence overall cost, as increased downtime can significantly impact production efficiency and profitability [19]. Therefore, cost-effective solutions must consider both cost and operational performance.

2.6 Discussion and Evaluation

Drive selection requires balancing performance, control and cost. VFDs provide superior efficiency and precise speed control, making them suitable for high-power applications such as Motor A. In contrast, DOL starters are simpler and more cost-effective but lack flexibility and introduce high inrush currents. Although VFDs have higher initial costs, their energy savings and reduced mechanical stress justify their use in demanding applications.

2.7 Conclusion (Task 1)

The operational needs and features of each motor have been taken into consideration while choosing motor drive systems. Because of their better control capabilities, energy efficiency, and lower mechanical stress. Variable frequency drives (VFDs) were found to be the best option for high-power and variable speed applications, such as Motors A, B, and C. For low-power, fixed-speed applications, like Motor E, where cost-effectiveness is a top concern, more straightforward techniques, such direct-on-line (DOL) starters, were considered suitable. A balance between cost and performance was considered for intermediate scenarios, such Motor D. All things considered, the chosen drive configurations offer a productive, dependable, and financially feasible solution.

Chapter 3 – Rectifiers and Harmonic Analysis (Task 2)

3.1 Introduction to rectification in VFD Systems

Rectification is a key stage in VFD systems, converting AC to DC before inversion to controlled AC output as shown in Figure 4. The rectifier significantly affects efficiency, power quality and harmonic distortion. Therefore, selecting an appropriate rectifier is essential for reliable and efficient operation [20–21].

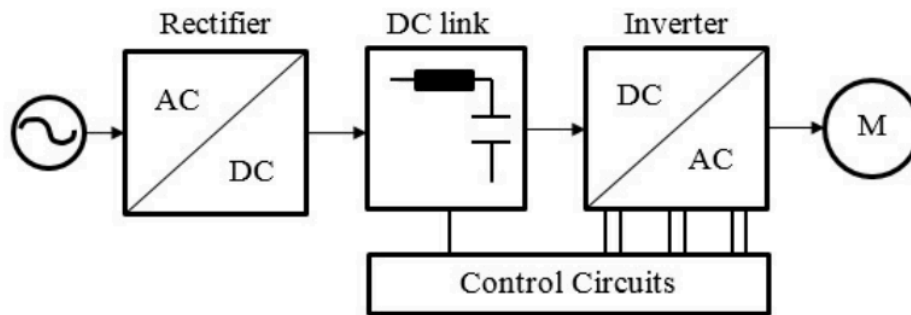


Figure 4 - Block Diagram of VFD [22]

3.2 Rectifier Technologies

3.2.1 Diode Rectifiers

Diode rectifiers (shown in Figure 5) are commonly used within electronic systems due to their simplicity, low cost and high reliability. Diode rectifiers can convert AC to DC whilst implemented as a three-phase bridge, without the need for control [23]. Diode rectifiers lack controllability as the output voltage is determined by the input characteristics. Big limitation of this is the harmonic distortion within the input current due to its non-linear operation, which can negatively impact power quality and efficiency. Despite this, diode rectifiers are suitable and cost-effective options [24].

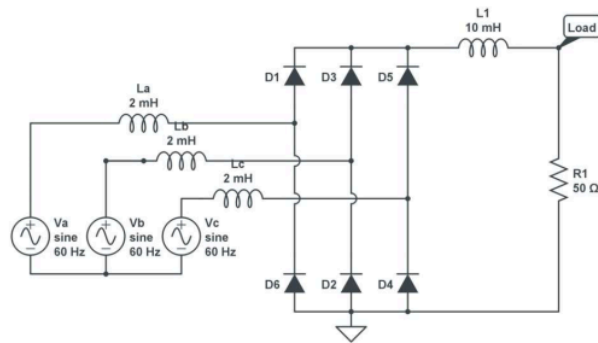


Figure 5 - Three Phase Six Pulse Rectifier [25]

3.2.2 Thyristor (SCR) Rectifiers

Thyristor (SCR) rectifiers provide controlled rectification through firing angle adjustment, allowing regulation of DC output voltage. However, this introduces increased harmonic distortion and reduced power factor compared to diode rectifiers. Despite greater complexity, SCR rectifiers are suitable for applications requiring adjustable output [26–27].

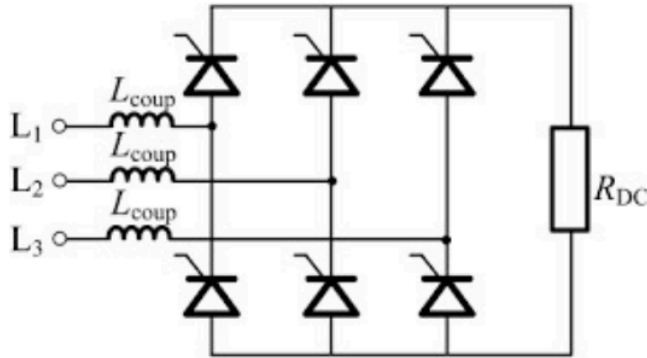


Figure 6 - Three-Phase Thyristor Rectifier [28]

3.2.3 IGBT-Based Active Rectifiers

IGBT-based active rectifiers are used as an advanced rectification solution which offers full control of the voltage and current through high frequency switching devices. Unlike the diode and thyristor rectifiers, active rectifiers utilise the pulse-width modulation (PWM) to regulate the DC output and form the waveform of the input current, which results in significantly reduced harmonic distortion and an improved power factor. These systems also support bidirectional power flow, allowing for regenerative operation where the energy can be returned to the supply during braking conditions. This makes them suitable for high-performance industrial applications which require efficient energy management. Although they are more complex and costly than traditional rectifiers, the IGBT-based systems provide better power quality, more flexibility and overall system performance [29].

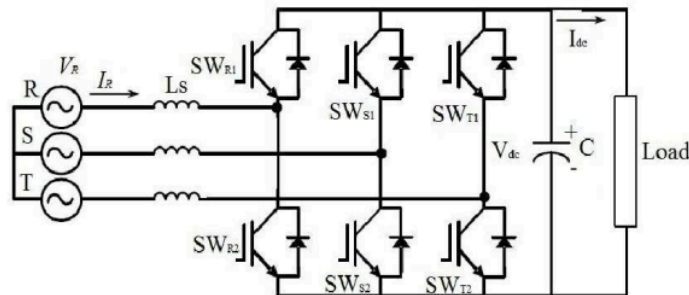


Figure 7 - IGBT-based Rectifier Circuit [30]

3.3 Comparison of Rectifier Technologies

3.3.1 Performance and Control Characteristics

Rectifier technologies can differ when it comes to controllability and efficiency. Diode rectifiers offer no control over the output voltage, whereas the thyristor rectifiers allow adjustable output through

firing angle control even with its reduced efficiency. IGBT-based rectifiers, however, provide full control of voltage and current, allowing for high efficiency and low harmonic distortion [23, 27, 29].

3.3.2 Cost and Complexity

The cost and complexity of rectifier technologies vary. Diode rectifiers are the simplest and most cost effective due to their passive operation and minimal control requirements [23]. Thyristor rectifiers have additional complexity through firing angle control, while IGBT-based active rectifiers are the most expensive as they require advanced control systems and switching devices [27, 29].

3.3.3 Suitability for Industrial Applications

The suitability of rectifier technologies depends on the requirements of the application. Diode rectifiers are appropriate for low-cost systems where control is not important, whilst thyristor rectifiers are suitable for applications which need an adjustable output voltage. IGBT-based active rectifiers are mostly used in high performance systems where low harmonics, efficiency and regenerative capability is essential [31].

A comparison of rectifier technologies can be seen in Table 3.

Table 3 - Comparison of Rectifier Technologies

Feature	Diode Rectifier	Thyristor (SCR) Rectifier	IGBT Active Rectifier
Control	None	Partial (Firing Angle)	Full (PWM Control)
Efficiency	Moderate	Low (Due to delays)	High
Harmonics	High	High	Low
Power Factor	Poor	Poor	Near Unity
Cost	Low	Medium	High
Complexity	Low	Medium	High
Applications	Simple Loads	Controlled DC Systems	High-Performance Drives

3.4 Harmonic Generation in Power Electronic Systems

3.4.1 Sources of Harmonics

Harmonics are generated by switching devices and non-linear loads. Rectifiers and inverters work by rapidly switching semiconductor devices, causing changes from pure sinusoidal waveforms in the input current. This behaviour results in the creation of harmonic frequencies that are integer multiples of the fundamental supply frequency [32]. As well as this, loads such as diode and thyristor rectifiers draw current in distinct pulses rather than continuously, further contributing to the distortion of the waveform. These harmonics can propagate through the electrical system, leading to a reduction in power quality [33].

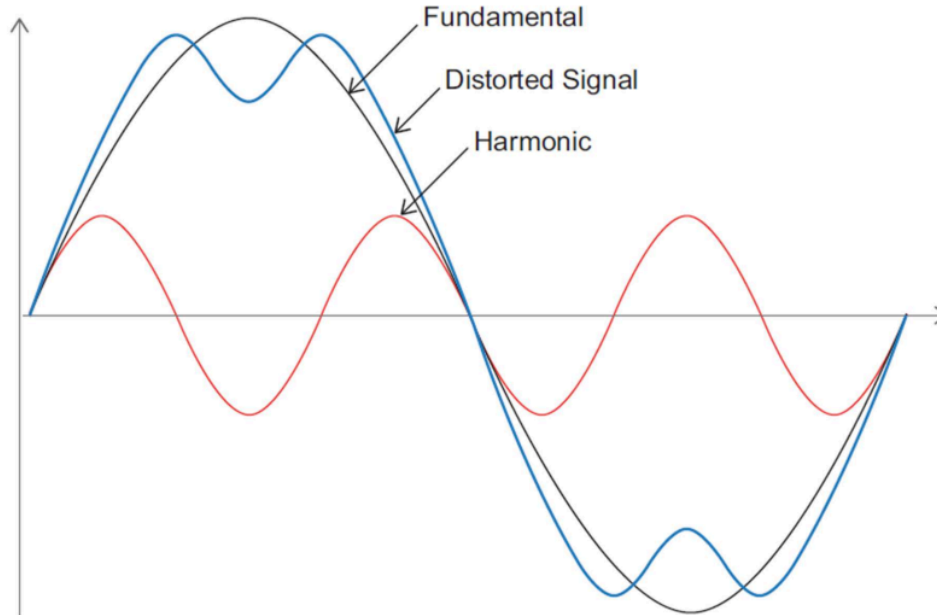


Figure 8 - Harmonic Distortion in Current Waveform [34]

3.4.2 Impact on Power Quality and Power Factor

Harmonics increase losses in electrical systems, causing overheating in transformers, cables and motors. This reduces efficiency and shortens equipment lifespan. They also degrade power factor by introducing distortion power, reducing effective power utilisation. Therefore, harmonic reduction is essential for efficient and reliable operation [35–36].

3.5 Harmonic Mitigation Techniques

3.5.1 Passive Filtering Methods

Passive filters use LC components to reduce harmonic distortion by providing low impedance paths for unwanted frequencies. They are simple and cost-effective but are limited to fixed frequencies and are less effective under varying load conditions [37].

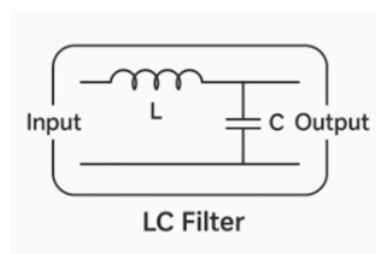


Figure 9 - LC Filter [38]

3.5.2 Active Filtering and Advanced Rectifiers

Active filtering methods, such as active front-end rectifiers, dynamically reduce harmonic distortion. IGBT-based systems use PWM to shape current waveforms, improving power factor and reducing

confirm that the implemented rectifier reduces harmonic distortion whilst maintaining a stable DC output.

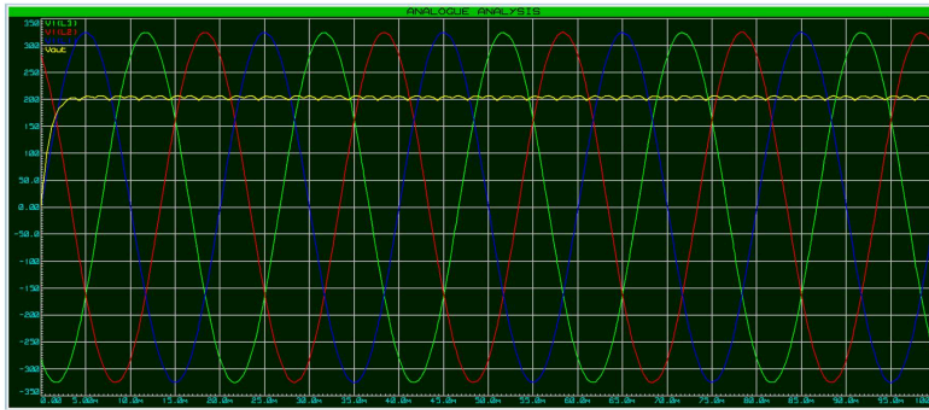


Figure 11 - Output Voltage Waveform

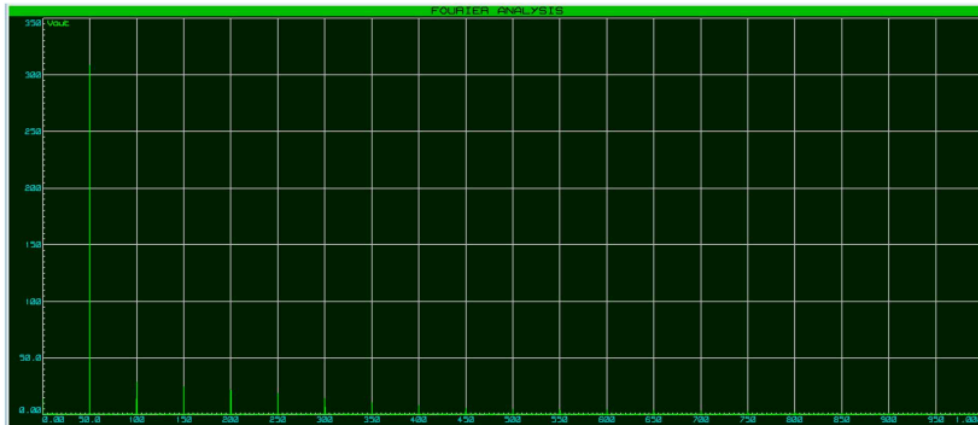


Figure 12 - Fourier Analysis of Output Voltage

3.7 Conclusion (Task 2)

The results above show that the 12-pulse rectifier provides a better performance compared to conventional diode and thyristor rectifiers. The reduction of harmonic content and the smoother DC output show an improvement in power quality, which aligns with the theoretical expectations of harmonic cancellation through phase-shifted rectifier operation. Whilst the diode rectifiers are simpler and thyristor rectifiers offer more control, the 12-pulse configuration achieves more balance between efficiency and harmonic reduction, making it the most suitable for high-performance applications.

Chapter 4 – Overall Conclusions

The study has shown that variable frequency drives, which offer increased efficiency, flexibility, and decreased mechanical stress, are the best option for industrial motor control. Furthermore, sophisticated rectification methods greatly lower harmonic distortion and enhance power quality, especially 12-pulse and IGBT-based rectifiers. VFD-based drive designs with suitable harmonic abatement techniques are advised for high-performance industrial applications. To further maximise performance and dependability, future upgrades might make use of active front-end converters and improved monitoring systems.

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FINAL GRADE

GENERAL COMMENTS

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

GRADING FORM: SMU GENERIC_SMOSEY

ETHAN LONGLEY

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ENGAGEMENT WITH LITERATURE*including reading, referencing, academic conventions and academic honesty*

Exceptional engagement with an extensive range of relevant and credible literature. Engagement with a range of mostly relevant and credible sources but with some reliance on information gained through class contact. Referencing conventions evident though not always applied accurately or consistently. Sources used are informed by the latest research.

10.65

KNOWLEDGE & UNDERSTANDING*Knowledge of the basic underlying concepts and principles of a subject.*

Excellent coherent and detailed knowledge and systematic understanding of the principles and theories of current research and scholarship.

21

Clear awareness of challenges to established views and the limitations of the knowledge base.

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Excellent critical thinking, analysis, synthesis and evaluation. Ability to investigate contradictory or incomplete information and make strong, persuasive, arguments and sophisticated judgements. Some evidence of independent thought and ability to 'see beyond the question', suggesting a grasp of the broader field and wider concepts.

24.15

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Can identify problems and propose appropriate solutions in complex and unpredictable contexts. Evidence of some innovation and creativity.

6.8

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for

employment requiring the exercise of some personal responsibility within a structured and managed environment.



Can communicate professionally confidently and consistently in a suitable format. Work is coherent, very fluent and is presented professionally. Demonstrates excellent graduate employment skills and an appetite for further development.

7.4