

2205436 - Power Electronics and Drives

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Submission date: 31-Mar-2026 04:43PM (UTC+0100)

Submission ID: 278895175

File name: Assignment_Report_2_.docx (224.04K)

Word count: 2694

Character count: 15930



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Power Electronics and Drives –
ACDA6004

Drives & Rectifiers

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Section 1 – Motor Drive System Specification

1.1 Background

A motor drive system is an integrated arrangement of components used to control the operation of an electric motor. It typically includes a power supply, power electronic converters, and a control unit that together regulate the motor's performance. The primary function of the system is to manage key parameters such as speed, torque, and direction by adjusting the electrical energy delivered to the motor. This is achieved through control techniques such as pulse-width modulation (PWM), which varies the voltage and current supplied to the motor.

The control unit may also use feedback from sensors, such as encoders or Hall-effect sensors, to monitor motor performance and make real-time adjustments. This closed-loop control improves accuracy, efficiency, and reliability. Motor drive systems are essential in a wide range of applications, from industrial automation to household appliances, where precise motor control is required.

The motor drive system ensures that the motor operates efficiently and responds to changing load or operational conditions, making it a critical part of modern electromechanical systems.

1.2 Analysis of Requirements

	Motor A	Motor B	Motor C	Motor D	Motor E
Power	500kW	80kW	10kW	5kW	1kW
Phases	3	3	3	3	1
Voltage	400	400	400	400	230
Required to be reversible?	Yes	Yes	No	Yes	No
Variable speed required?	Yes	Yes	Yes	No	No
Quantity installed	5	10	23	17	127
Example application	Rolling Mill	Gantry Crane	Conveyor	Cutting Machine	Pumps / Fans

Table 1: Motor Analysis

Shown in Table 1 is a variety of motors and their requirements. Using the information provided, motors A and B can be grouped together as they have similar requirements – in this case, both are required to be reversible and have variable speed. The remaining motors do not need to be grouped. Grouping the motors in this way makes the system more cost-effective and optimised.

Motors A and B share key features: they both operate on a 3-phase, 400 V supply, as well as the previously mentioned criteria. These requirements necessitate variable frequency drives

(VFDs) with bidirectional control capabilities. Grouping these motors allows the use of similar high-power, flexible drives that can efficiently manage the precise speed and direction demands of heavy industrial applications such as rolling mills and gantry cranes.

Motor C, while also a 3-phase, 400 V motor requiring variable speed, does not need to be reversible. This difference allows it to be grouped separately, simplifying the control system by eliminating the reversing function and thus reducing complexity and cost.

Motor D requires reversibility but operates at a fixed speed. This allows it to be controlled using simpler and more cost-effective reversing starters or contactors, avoiding the expense and complexity of variable speed drives.

Motor E operates on single-phase 230 V power, with neither variable speed nor reversing requirements, and exists in large quantities. Grouping these motors separately reflects their fundamentally different electrical nature and simpler control needs, often found in applications such as pumps and fans.

By grouping motors based on these operational and electrical similarities, the system design maximises efficiency, reduces unnecessary expenditure on complex drives, and ensures maintainability and scalability across various applications.

1.3 Proposed Drive Technologies

Motors A and B are high-power motors that require both variable speed control and reversibility. Due to their demanding operational characteristics and applications such as rolling mills and gantry cranes, these motors are best served by variable frequency drives (VFDs) equipped with IGBT inverters and active front end (AFE) technology. The use of an AFE enables efficient handling of high-power loads by allowing bidirectional power flow, which is essential for regenerative braking. This capability improves energy efficiency by feeding power back into the grid during braking and reduces mechanical wear on braking components. Additionally, motors A and B can share a common DC bus, which simplifies the power architecture and reduces overall system complexity and cost. The combination of VFDs with AFE technology provides the precise speed and torque control required for heavy industrial processes, making it the optimal choice for these motors.

Motor C operates at variable speed but does not require reversing functionality. For this motor, a standard VFD with a diode rectifier is an appropriate choice. This set-up is simpler and more cost-effective than an AFE-equipped drive since regenerative braking is not needed for conveyor applications. The lower cost and adequate performance make standard VFDs ideal for controlling motor C's speed efficiently without unnecessary features.

Motor D requires the ability to reverse but operates at a fixed speed. For this motor, the use of a direct-on-line (DOL) starter combined with a reversing contactor or a soft starter is suitable. This approach eliminates the need for expensive VFDs, resulting in significant cost savings.

The reversing contactor handles direction changes electrically, ensuring simple and reliable operation.

Motor E consists of numerous small, single-phase units primarily used for pumps and fans. Due to the large quantity of these motors and their generally simple operational requirements, basic starters are preferred. This choice prioritises cost-effectiveness, as complex control systems are typically unnecessary for these applications.

1.4 System Level Design Considerations

The implementation of a common DC bus in the motor drive system offers significant benefits in terms of energy efficiency and system integration. One of the primary advantages is the reduction of energy waste. By sharing the DC bus among multiple motors, regenerative energy produced during braking—such as when cranes decelerate—can be effectively captured and reused by other drives on the same bus. This energy sharing not only improves overall system efficiency but also reduces the demand on the power supply, leading to cost savings and decreased environmental impact.

To ensure safe and reliable operation, the common DC bus is equipped with comprehensive protection mechanisms. Overcurrent protection prevents damage to electrical components by detecting and interrupting excessive current flow. Thermal protection safeguards the system against overheating by monitoring temperature levels and initiating shutdowns or alarms when thresholds are exceeded. Earth fault detection is also critical, identifying leakage currents to ground that could pose safety hazards or damage equipment.

The control system for the common DC bus is typically integrated via a programmable logic controller (PLC), which facilitates centralised management and coordination of all connected drives. Communication protocols such as Modbus or Profibus enable seamless data exchange between the PLC and individual drives, supporting efficient control and monitoring.

Central monitoring capabilities allow real-time tracking of key parameters, including energy usage, fault logs, and system status. This data collection is crucial for predictive maintenance strategies, enabling early detection of potential issues and minimising downtime through timely interventions.

1.5 Discussion

The selected approach balances cost and performance by applying variable frequency drives (VFDs) only where speed control and energy savings justify their higher cost, while using simpler fixed-speed drives for less critical loads. Although VFDs improve efficiency and process control, deploying them across all motors would not be cost-effective. Instead, selective use ensures optimal resource allocation. Standardisation further enhances the system by simplifying maintenance, reducing spare parts inventory, and improving reliability. Using consistent components and control strategies also streamlines integration and troubleshooting, making the overall system more scalable, cost-effective, and easier to manage in industrial applications.

1.6 Conclusion

In conclusion, the proposed system demonstrates that different motors require tailored drive solutions based on their operational demands. High-power motors such as A and B benefit from advanced drive technologies, including VFDs with active front ends, which provide precise control, reversibility, and improved energy efficiency through regenerative capability. In contrast, lower-power or less complex motors, such as C, D, and E, can be effectively operated using simpler and more cost-efficient solutions without compromising functionality. By integrating these varied technologies within a single system, overall performance, efficiency, and reliability are enhanced. This coordinated approach ensures optimal resource utilisation while maintaining a cost-effective and scalable industrial drive system.

Section 2 – Rectifiers and Harmonics in VFDs

2.1 Types of Rectifiers

2.1.1 Diode Rectifier

A rectifier diode works by allowing electric current to flow in only one direction, converting alternating current (AC) into direct current (DC). Its operation is based on the behaviour of a p–n junction, formed by joining p-type and n-type semiconductor materials.

When the diode is forward biased (positive voltage applied to the p-side and negative to the n-side), the depletion region at the junction narrows. This allows charge carriers—holes from the p-side and electrons from the n-side—to move across the junction, enabling current to flow easily. When the diode is reverse biased (positive voltage applied to the n-side), the depletion region widens, creating a barrier that largely prevents current flow.

Rectifier diodes are widely used in power conversion due to their low cost and simple design, making them suitable for basic applications such as standard AC–DC conversion. However, they are uncontrolled devices, meaning they cannot regulate or adjust the output voltage since conduction occurs automatically when forward biased. As a result, they offer no flexibility in control compared to more advanced semiconductor devices. Additionally, diode rectifiers draw non-sinusoidal current from the supply, leading to the generation of harmonic distortion. These harmonics can negatively impact power quality and may require additional filtering in industrial systems.

2.1.2 Thyristor (SCR) Rectifier

A thyristor, also known as a silicon-controlled rectifier (SCR), is a semiconductor device used in variable frequency drives (VFDs) to control the conversion of AC to DC. Its operation is based on a four-layer p–n–p–n structure and requires a gate signal to begin conduction.

When a forward voltage is applied across the thyristor, it remains in a non-conducting state until a gate pulse is applied. Once triggered, the device conducts and continues to do so until

the current falls below a certain holding level. By controlling the timing of the gate pulse (known as the firing angle), the point at which the thyristor turns on during each AC cycle can be adjusted. This allows control over the average output voltage, making thyristors suitable for applications where variable DC voltage is required.

Thyristors were commonly used in older VFD designs before the widespread adoption of modern IGBT-based drives. While they provide controllable output voltage, they have several drawbacks. In particular, they generate more harmonic distortion than diode rectifiers due to the delayed switching, which further distorts the input current waveform. This can negatively affect power quality and often necessitates additional filtering or mitigation techniques.

2.1.3 IGBT (Active Front End)

An IGBT-based active front end (AFE) is an advanced power conversion system used in modern variable frequency drives (VFDs), offering full control over the AC–DC conversion process. Its working principle is based on high-frequency switching of IGBTs using pulse-width modulation (PWM) to actively shape the input current and regulate the DC bus voltage. This allows the converter to draw a near-sinusoidal current from the supply while maintaining precise voltage control.

Unlike diode or thyristor rectifiers, IGBTs are fully controllable devices, enabling accurate regulation of both voltage and current. This results in a near-unity power factor (approximately 1), improving overall power quality and reducing reactive power demand. Additionally, AFE systems allow bidirectional power flow, meaning regenerative energy produced during braking can be fed back into the supply. Despite these advantages, IGBT-based AFEs are the most expensive option due to their complexity and advanced control requirements.

A simplified comparison of the three types of rectifiers is shown below in Table 2.

Feature	Diode	SCR	IGBT
Cost	Low	Medium	High
Control	None	Partial	Full
Harmonics	Medium	High	Low
Power Factor	Poor	Poor	Excellent
Regeneration	No	Limited	Yes

Citation Needed

Table 2: Rectifier Comparison

2.2 Harmonic Generation

Harmonics in variable frequency drives (VFDs) are caused by the non-linear current drawn by power electronic converters. In diode and thyristor rectifiers, current is drawn in pulses rather than as a smooth sinusoidal waveform, producing harmonic frequencies that are multiples of the supply frequency. Thyristor-based drives generate higher harmonic distortion due to delayed firing angles, which further distort the waveform. In contrast, IGBT-based

active front end drives use pulse-width modulation to shape the input current, significantly reducing harmonics. Excessive harmonics can lead to overheating, increased losses, and poor power quality, requiring mitigation methods such as filters or advanced drive designs.

2.3 Effects of Harmonics

Harmonics increase losses by causing excessive heating in conductors, transformers, and motors, which can shorten insulation life. Efficiency is reduced because additional energy is wasted as heat rather than delivered as useful output. Harmonics also degrade power factor, leading to higher demand charges and poor system utilisation. Over time, these effects can damage equipment, causing overheating, vibration, and premature failure of sensitive components. Mitigation methods such as filters, proper system design, and adherence to harmonic standards help control these issues and improve overall power quality and reliability in practice.

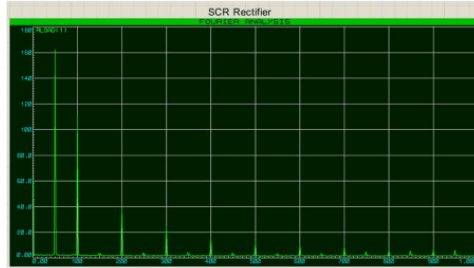
2.4 Harmonic Reduction Methods

Harmonic reduction methods are used to improve power quality and protect electrical systems. Line reactors are inductive components that limit harmonic currents and smooth waveform distortion. Passive filters, made of capacitors and inductors, are tuned to absorb specific harmonic frequencies. Active filters use power electronics to inject counteracting currents, effectively cancelling harmonics in real time. Multi-pulse rectifiers, such as 6-pulse or 12-pulse designs, reduce harmonics by phase-shifting and combining outputs. Active front end (IGBT) converters provide advanced control, drawing near-sinusoidal current with low distortion. Together, these methods enhance efficiency, reduce heating, and extend equipment lifespan.

2.5 Power Factor Explanation

Power factor is a measure of how effectively electrical power is used, defined as the ratio of real power (kW) to apparent power (kVA). A low power factor occurs when reactive power, caused by inductive loads like motors and transformers, reduces system efficiency. This leads to higher current, increased losses, and possible penalties from suppliers. Power factor correction improves this by reducing reactive power. Common methods include installing capacitor banks, using synchronous condensers, or employing active power factor correction devices. These techniques supply reactive power locally, improving efficiency, reducing losses, stabilising voltage, and lowering electricity costs in industrial and commercial systems.

2.6 Simulation



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Figure 1: SCR Rectifier Fourier Analysis

Shown in Figure 1 is a Fourier analysis of the SCR rectifier. The Fourier spectrum shows large peaks at low frequencies, indicating strong low-order harmonics. These harmonics cause the input current waveform to be highly distorted and far from a smooth sine wave. This distortion is due to the controlled switching of the SCR, where the firing angle delays current flow and creates irregular, discontinuous waveforms.

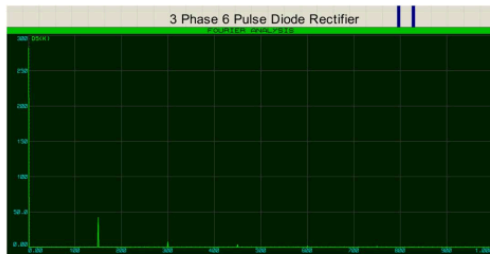


Figure 2: Fourier Analysis of 3-Phase 6-Pulse Rectifier

Figure 2 shows a 3-phase 6-pulse rectifier analysis. The harmonic content is more organised and reduced compared to the SCR case. The main harmonics appear at specific intervals (such as the 5th and 7th), and their magnitudes are smaller than those in Figure 1. As a result, the input current waveform is smoother, though still not perfectly sinusoidal.

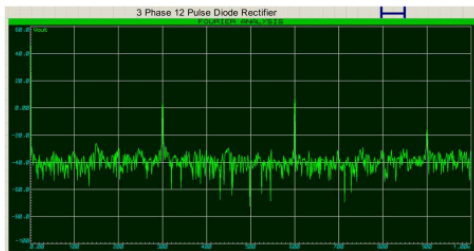


Figure 3: Fourier Analysis of 3-Phase 12-Pulse Rectifier

Shown in Figure 3 is a 3-phase 12-pulse rectifier analysis. The Fourier spectrum shows a significant reduction in low-order harmonics. Most of the remaining harmonics are at higher frequencies and have smaller amplitudes. This leads to a much smoother input current waveform that is closer to an ideal sine wave. This improvement occurs because the 12-pulse configuration cancels out several lower-order harmonics through phase shifting.

Looking at Total Harmonic Distortion (THD), Figure 1 has the highest THD due to the presence of strong and numerous harmonics. Figure 2 shows a reduction in THD, as the harmonic levels are lower and more controlled. Figure 3 has the lowest THD because many of the most significant low-order harmonics have been eliminated, leaving only smaller high-frequency components.

2.7 Conclusion

In conclusion, different power electronic devices offer trade-offs between cost, control, and power quality. Diodes are simple and inexpensive, but they produce significant harmonic distortion, resulting in “dirty” power and reduced efficiency. Silicon Controlled Rectifiers (SCRs) provide controllability over output, making them more flexible in applications, but they introduce even greater harmonics and lower power factor under certain conditions. Insulated Gate Bipolar Transistors (IGBTs) deliver the best overall performance, offering precise control, low harmonic distortion, and high efficiency. However, this comes at a higher cost and increased system complexity, making selection dependent on application requirements.

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Comment 1

You should add references when making bold statements like these

PAGE 9



Comment 2

Where are your circuits?



Comment 3

Why is the vertical axis here is in dB when all previous ones have been in either volts or amps - I am unable to tell as you have not included ANY circuits, or explained where in the circuit the measurement was taken.

PAGE 10



Comment 4

How does it do this? Why does it have this effect?



Comment 5

You should talk about the circuit types, not the figure numbers.

e.g. "The SCR rectifier showed the highest level of harmonic distortion, as shown in figure 1..."



Comment 6

You have not included ANY references. I cannot give any marks for engagement with literature as you have not shown any engagement.

GRADING FORM: SMU GENERIC_SMOSEY

JADE WILLIAMS

42.90

ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



No evidence of reading. Referencing conventions entirely absent.

0

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Knowledge is reasonably detailed, accurate with a good systematic understanding of the field of study.

18

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.



Largely descriptive work, with superficial use of critical evaluation. Weak development of arguments and judgements. Information accepted uncritically, uses generalised statements made with scant evidence and unsubstantiated opinions.

13.3

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



An adequate awareness and mostly appropriate application of well-established methods, materials, tools and/or techniques. Basic appreciation of the context of the application. Theoretical knowledge and understanding applied in practice, but not always making logical links between the two. Can identify problems and propose basic solutions in complex and unpredictable contexts without fully appreciating the complexity.

4.8

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 well, confidently and consistently in a suitable format. Work is coherent, fluent, well-structured and organised. Demonstrates very good graduate employment skills, with just occasional minor weakness.

6.8

