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Abstract

This report looks and compares different motor drives and rectifier designs in different industrial settings. Drives were selected based on several factors including, the operating requirements, cost, control, and system usability along with standardisation. Rectifiers were analysed using proteus, where single phase, 3-phase 6 pulse and 3-phase 12 pulse rectifiers all got analysed against each other. Results proved that having a higher pulse reduces harmonic distortion and noise whilst also improves the overall quality of the waveforms.

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Introduction

In the first part of this report, a detailed comparison of available motor drive technologies is provided to determine the most suitable drive for each motor in a factory refit scenario. Each motor was carefully considered, and a justification was given for the selected technology. In the second part, an overview of how diodes, thyristors, and IGBTs are used for rectification is provided, before analysing simulation results from five different circuits where harmonic distortion and power quality are examined.

Motor drives Technologies

When choosing a motor system to use, it's very important to understand and consider the characteristics of each technology against the requirements of the application. The main technologies used are Direct-on-line (DOL) starters, Star-Delta starters, electronic soft starters and variable frequency drives (VFD).

Direct-On-Line Starters

Direct-on-line starters are the cheapest and simplest option of a starting induction motor, which connects the motor directly to the voltage supply. Because of this, a large inrush of current is produced, typically six to eight times its full load current which can cause disturbances to the supply and mechanical shock. Since DOL don't offer any speed control and only limited protection, they can only be safely used in small motors with basic on and off cycles [1].

Star-Delta Starters

Star-delta starters offer a reduced starting current by starting up by connecting windings in a star configuration and then switching to a delta configuration when at full speed. This reduces the inrush current to approximately a third of the current a DOL will produce. When the configuration from star to delta occurs, it causes a torque transient, which can cause added mechanical stress. Similarly to DOL, no variable speed control is provided. There also needs to be six accessible motor terminals which limit the usability [2].

Electronic Soft starters

Electronic soft starters have a smooth, gradual ramp-up of voltage during starting due to the use of thyristors, which eliminates mechanical shock and reduces the inrush current. Once at full speed, the soft starter allows itself to be bypassed, which results in no speed control available. Reversibility can be achieved with the use of an additional reversing contractor connected. Built-in protection functions, including overload, phase loss, and thermistor monitoring, are typically included [3].

Variable frequency drives

Variable frequency drives offer the greatest flexibility of all, allowing you to convert AC to DC and then back into a variable frequency AC which allows the use of precise speed control. When working with variable torque loads, the speed reduction of 20% can help save up to 50% of the power consumption due to affinity laws. Regenerative braking, which returns energy to the DC bus instead of losing it as heat, is made possible by active front end variations. Multiple drives can share a single rectifier and directly interchange energy between motors thanks to a

common DC bus. Cost and possible harmonic distortion, which calls for proper filtering, are the main drawbacks [4].

Motor Selection

Motor A 500kW Rolling Mill

Motor A is composed of five 500kW induction motors driving rolling mills, which require variable speed and need to be reversible. Because of this it demands a four-quadrant operation, motoring and braking in both directions. Because of this a standard VFD is not suitable due to the high torque and inertia demands of the rolling mill. Because of this, the ABB ACS880 motor was chosen, which allows power flow in both directions. When the mill slows down or reverses, the energy is fed into the DC bus instead of wasting the energy through energy resistors. This provides a significant amount of saved energy over five 500KW motors. All the drives will share a common DC bus, which links multiple inverters into a single rectifier. This reduces the component count and allows energy regenerated by one motor to be used directly by another motor. The ACS880 supports PROFINET fieldbus communication, enabling real-time monitoring of speed, current, and power via the factory SCADA system, supporting predictive maintenance [5].

Motor B 80kW Gantry Crane

Motor B consists of ten 80kW induction motors for gantry cranes, also requiring a variable speed and complete reversibility. A smooth and controlled acceleration and deceleration is vital for everyone's safety as it can prevent load swings and protect workers below. For these reasons, the ABB ACS880 was chosen again. When a crane is lowering its load, the motor is getting driven by gravity rather than driving the load itself. This is known as overhauling, and without regeneration, the energy would be wasted as heat from braking resistors. The ABB ACS880 recovers the energy back to the common DC bus, allowing it to be consumed by other motors that are accelerating. Standardising the same motor across multiple applications provides benefits including using the same spare parts, reduced cost in training and maintenance and a consistent software interface [5].

Motor C 10kW conveyor

Motor C is composed of twenty-three 10 kW induction motors driving conveyor systems, which require variable speed control but do not require it to be reversible. Since four quadrants also isn't needed for this application, the ABB ACS580 drive is chosen here since it provides a much more cost-effective option compared to the ABB ACS880 previously used. Across installing all 23 motors, there will be massive savings by using this cheaper motor. The ACS580 provides precise speed control, which allows the conveyors to run at reduced speeds during low-demand periods. Through using the Affinity law, a slight reduction in conveyor speed produces a disproportionately large reduction in overall energy consumption of the motors, which could deliver massive savings over the course of their lifetime. The ACS580 includes a built-in EMC filter, electronic overload protection, and PROFINET fieldbus communication for integration with the factory SCADA system [6].

Motor D 5kW cutting machine

Motor D consists of seventeen 5kW induction motors that will be driving cutting machines, which require reversibility but does not require variable speed. A full VFD would be an unnecessary justification for this motor, as precise speed control is not required when running, which will help save a lot of money across the seventeen motors. Because of this, the motor chosen for this application is the ABB PSTX Soft Starter. The PSTX gradually ramps up the voltage that's applied during startup, allowing a smooth buildup of torque as opposed to a high load in one go. The smooth buildup will protect the sensitive cutting tools and mechanical coupling from the stress that a hard start would provide. A reversing contactor arrangement in front of the soft starter provides reversibility. Additionally, the PSTX eliminates the need for additional protection relay hardware by including overload, phase loss, and thermistor protection [7].

Motor E 1kW Pumps/Fans

Motor E is composed of 127 single-phase, 230V, 1kW induction motors that will power pumps and fans. These don't require the use of variable speed or reversibility. Because of the simplicity, a Direct-On-Line (DOL) starter is the most appropriate due to its low cost and simplistic design. The inrush current of 1kW at start-up will be low and not cause issues. There is no need to use a more complex and expensive motor with a soft starter or a VFD, as the extra features will not be used. With 127 units installed, the savings of a simple motor will be massive. Because of the number of units installed, standardisation of a single starter product is necessary. The use of common spare parts, consistent design and a familiar interface will significantly reduce the maintenance time and allow replacements to be carried out efficiently. Each starter includes a thermal overload relay providing basic but adequate motor protection for this application [8][9].

Part 2

Principles Of Rectification, Phases, and Pulse Numbers

In a drive with a variable frequency, the rectifier converts the incoming AC supply into DC, which then gets fed into an inverter that will produce a variable frequency AC output for the motor's speed control. The quality of the DC conversion has a direct impact on the quality of harmonic distortion and power quality across the network. A single-phase rectifier produces two pulses per cycle, resulting in a high-ripple DC output. A three-phase rectifier will naturally produce a smoother output since the three supplies are evenly spaced out by 120 degrees. While a six pulse bridge will produce six pulses per cycle, a twelve pulse rectifier further improves the quality of the rippling by combining two, six pulse rectifiers and applying them at a 30 degree offset. The increase in pulses along with the slight offset significantly reduces the rippling and harmonic distortion, which will improve the overall quality of power [10].

Comparison Of Diodes, Thyristors and IGBT's

The three main semiconductors used for rectifiers in drives are diodes, thyristors (SCRs), and IGBTs; each of these offers different levels of performance, control and cost.

The simplest semiconductor for a rectifier is a diode, which automatically conducts whenever a forward bias is applied, even without any extra control signals. This makes them passive, robust and inexpensive, but lacks more complex abilities such as regulating the output voltage. Diodes are commonly used in a standard six-pulse rectifier, where cost is a bigger priority than output voltage control.

Thyristors, also known as SCRs, add a level of control by needing a gate trigger signal to start conducting. The output voltage can be controlled by varying the gate signal's firing angle. But once an SCR is turned on, it can't be turned off by a gate. Instead, it will keep conducting until the current naturally drops to zero. This limits the ability to control and switch frequencies compared to IGBTs.

IGBTs give you full control over switching, and you can turn them on and off with a high-frequency gate signal. This allows for very precise control of the output, a huge decrease in harmonic distortion, and, most importantly, bi-directional power flow, which lets energy flow back to the supply network during regenerative braking [10].

Harmonic Noise

The main power supply works at a fundamental frequency of 50Hz. Harmonics are extra frequencies that are whole-number multiples of the fundamental frequency. For example, the 3rd harmonic is at 150Hz, and the 5th is at 250Hz. In a perfect system, there would only be the fundamental frequency. However, non-linear loads such as rectifiers add harmonic frequencies that alter the shape of the supply waveform. Harmonics are caused by rectifiers because they pull current from the supply in pulses instead of a smooth, continuous sinusoidal waveform. When a semiconductor device switches, it rapidly draws a lot of current from the supply. These current pulses have harmonic frequency components that are put back into the supply network. This changes the voltage waveform and affects other devices that are connected to the same supply [11].

Harmonic effects on power

Power factor is the ratio of real power (kW) to apparent power (kVA), representing how efficiently power is drawn from the supply and converted into useful work. A power factor of 1 indicates that all power drawn is doing useful work, whilst a lower power factor indicates that excess current is being unnecessarily drawn from the supply, which increases the losses and adds additional stress onto the network. Harmonics affect power factor in two main ways. Displacement power factor is the phase difference between the voltage and current waveforms, even without harmonics, a load can still have a poor power factor if these are out of sync. On top of this, harmonic distortion introduces an additional reduction known as distortion power factor, which pulls the true power factor down even further. Because of this, circuits with high harmonic content will draw more current from the supply than what is needed to do useful work, increasing losses and putting unnecessary stress on the supply network [12].

How to minimise harmonic distortion

The most efficient way to reduce harmonic distortion is by increasing the number of pulses of the rectifier. When switching from a single-phase to three-phase rectifiers with 6 or 12 pulses, it will significantly reduce the THD by producing a smoother DC output with less rippling. The use of IGBTs in an Active Front End configuration further reduces harmonic distortion through high-frequency switching and precise output control. Additional filtering, such as a DC choke, can also be added to further limit the harmonics [13].

Rectifier Circuit Simulations and Waveform Analysis

3-phase 12-pulse

The 12-pulse rectifier uses two six pulse bridges fed from Star-Delta and Star-Star transformers, offset by 30 degrees. This offset cancels the 5th and 7th order harmonics that would normally be present in a standard six pulse design [11]. The analogue analysis shows a consistently smooth DC output with minimal ripple, as the 120-degree phase spacing between the three supplies ensures the output voltage remains stable throughout each cycle. The Fourier analysis shows a high first peak that rapidly declines, with very little happening after reaching 5kHz.

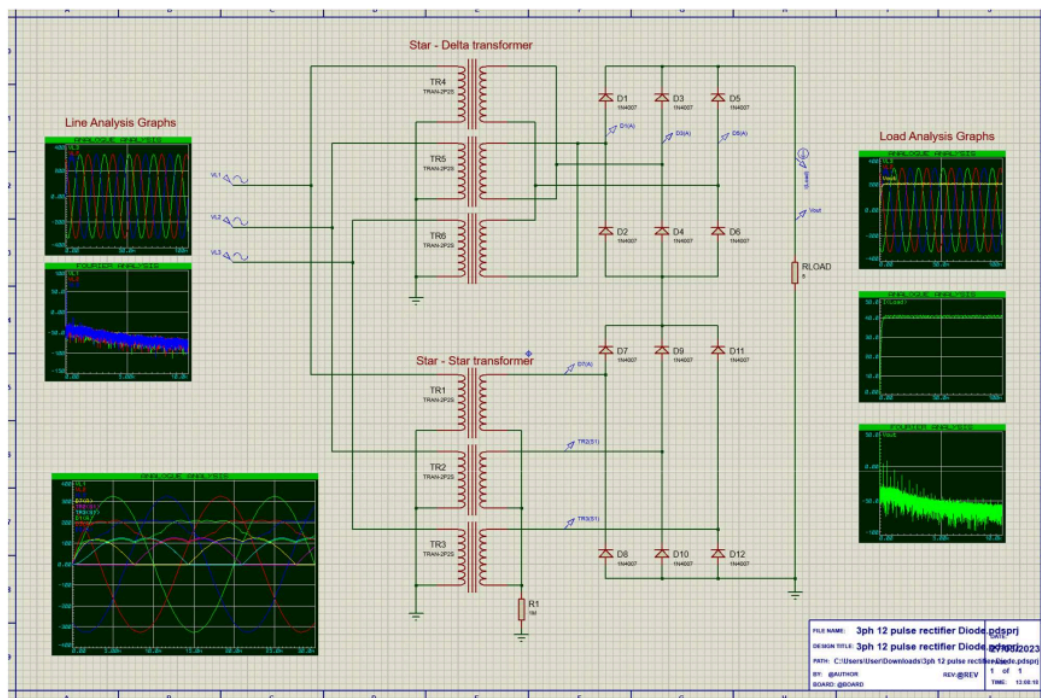


Figure 1 3 Phase 12 Pulse with graphs

3-phase 6-pulse

The six-pulse rectifier uses a single three-phase diode bridge, producing six pulses per cycle. Compared to the 12-pulse design, the analogue analysis shows a slightly less smooth DC output, since there are fewer pulses per cycle, and there are larger gaps between each voltage peak before filtering. The Fourier analysis shows distinct harmonic spikes, most notably the 5th and 7th order harmonics, which are clearly visible as prominent peaks [11]. Unlike the 12-pulse design, there is no phase-shifted transformer bank to cancel these harmonics, which results in bigger harmonics being supplied into the network.

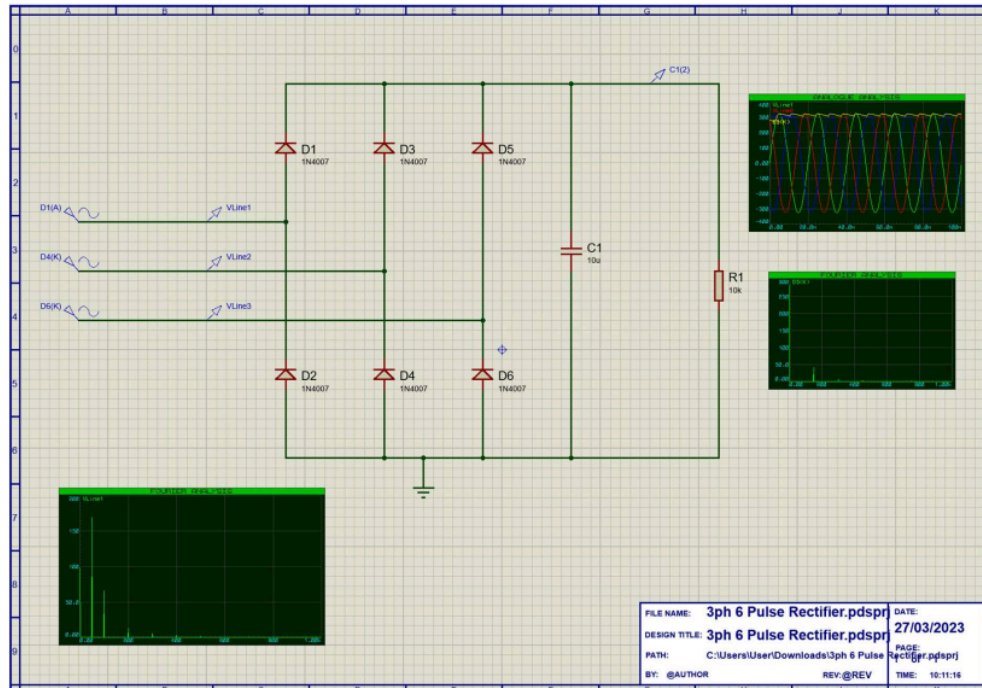


Figure 2 3 phase 6 pulse with graphs

Single phase rectifier diode

The single-phase rectifier diode is the simplest design, it produces only two pulses per cycle. Because of this there are significant gaps between the peaks of voltage, which we can see in the analogue analysis. This results in a high ripple DC output that is a lot less smooth than previous graphs. Without the natural smoothing effect of multiple phase voltages, the output is heavily dependent on capacitor filtering alone. The Fourier analysis shows prominent harmonic spikes across a wider frequency range than the six pulse design, as single-phase rectifiers produce both even and odd order harmonics, resulting in the highest level of harmonic distortion of all circuits tested.

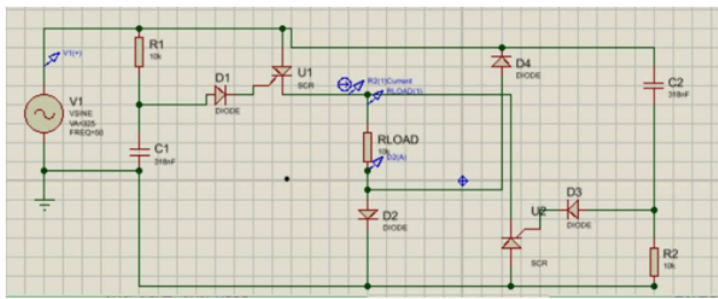


Figure 3 Single wave rectifier diode

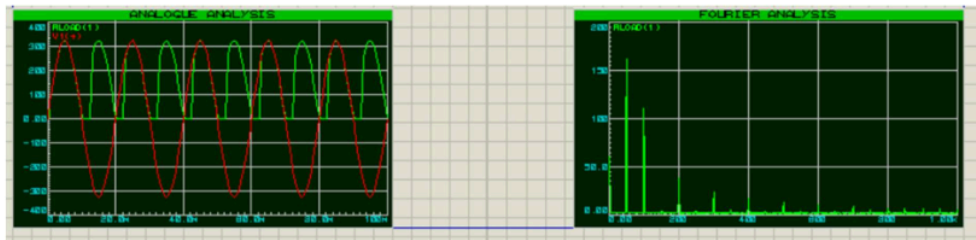


Figure 4 graphs for single wave rectifier diode

SCR Full-wave Rectifier

The SCR full-wave rectifier introduces controllability over the diode rectifier by using thyristors that are triggered via a gate signal, allowing the output voltage to be regulated by adjusting the firing angle. The analogue analysis shows a smoother DC output than the single-phase diode rectifier, though still considerably more ripple than a three-phase design due to only producing two pulses per cycle. The Fourier analysis shows two dominant harmonic peaks before dropping off quickly, indicating that whilst harmonic content is still present, the controlled firing angle helps produce a slightly cleaner output than a passive diode rectifier.

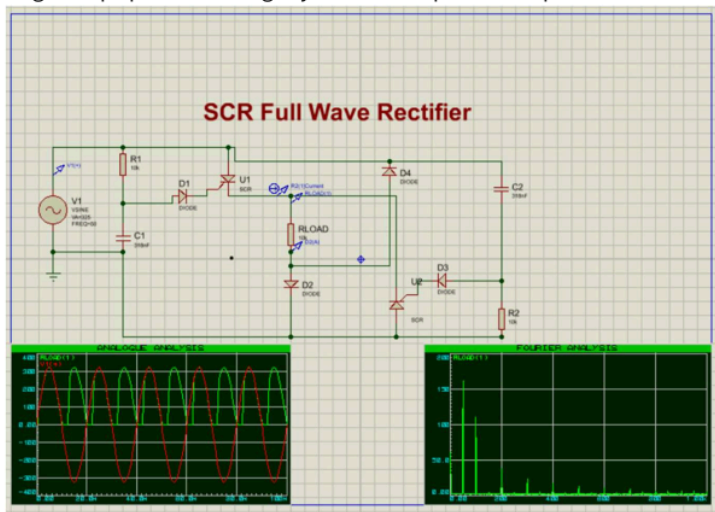


Figure 5 SCR full wave rectifier with graphs

IGBT

Unlike diodes and SCRs, IGBTs can be switched on and off at high frequency via the gate signal, giving full control over the output waveform. The simulation output clearly shows the high frequency switching behaviour of the IGBT, with rapid transitions visible across the waveform. This switching allows the output voltage to be precisely regulated, significantly reducing harmonic distortion compared to both diode and SCR designs. The ability to control both turn on and turn off also enables bi-directional power flow, making IGBTs the preferred choice for Active Front End rectifiers where regenerative braking is required.

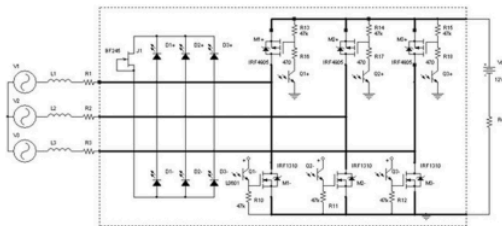


Figure 6 IGBT circuit diagram

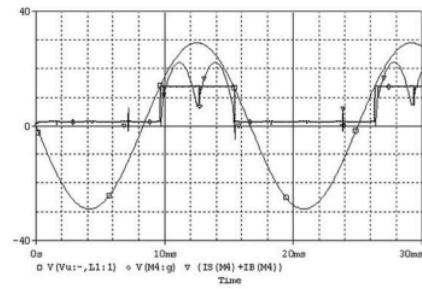


Figure 7 IGBT graph

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FINAL GRADE

GENERAL COMMENTS

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QM

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GRADING FORM: SMU GENERIC_SMOSEY

RHYS JONES**71.23****ENGAGEMENT WITH LITERATURE**

including reading, referencing, academic conventions and academic honesty



Engagement with a wide range of literature, including sources retrieved independently. Selection of relevant and credible sources. Views and findings mostly unsupported and non-authoritative High-level referencing skills consistently applied. Sources used are informed by the latest research.

8.68**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.

22.2

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.

25.55

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.

 An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Application and deployment extend beyond established conventions. Can identify complex problems and propose excellent solutions. Innovation and creativity evident.

7.2

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.

7.6