



The present work was submitted to  
the German-Mongolian Institute for Resources and Technology,  
Faculty of Mechanical and Electrical Engineering

# DESIGN AND OPTIMIZATION OF VARIABLE FREQUENCY DRIVE SYSTEMS FOR OVERHEAD CRANES

**Bachelor's Thesis**

by

**UYANGA Altantsetseg**

Study Program: Energy and Electrical Engineering

Student ID: B2100612

1<sup>st</sup> Supervisor/Examiner: **Prof. Ph.D., Ariunbolor Purvee**  
**Associate Professor of Electrical Engineering**

2<sup>nd</sup> Supervisor/Examiner: **Mr. Tuvshin Ganhuyag**

Ulaanbaatar/Nalaikh

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## Statutory Declaration

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Last Name, First Name

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

### **DESIGN AND OPTIMIZATION OF VARIABLE FREQUENCY DRIVE SYSTEMS FOR OVERHEAD CRANES**

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Nalaikh,  
2025.05.28

\_\_\_\_\_  
Place, Date



\_\_\_\_\_  
Signature

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## **Abstract**

This thesis examines the configuration and optimization of a variable frequency drive (VFD) system for an overhead crane to enhance its operational efficiency and reliability. The overhead crane is operated via a Telecrane remote control system and powered by a squirrel cage motor. It is equipped with two hooks: a 20-tonne hook and a 5-tonne hook. However, the 5-tonne hook was not functioning properly, resulting in downtime for the workshop operations.

To address these issues, variable frequency drive was installed, along with an AC magnetic contactor, electromechanical relay and two intermediate power relay. Furthermore, a brake resistor was integrated to improve deceleration, with additional cabling for the control circuit and power line to interconnect motor and hoist, ensuring signal integrity and electromagnetic compatibility. The implementation of the VFD offers several advantages, including precise speed control, reduced mechanical stress, smoother movement, and improved energy efficiency.

This study systematically documents the Variable Frequency Drive (VFD) configuration process, highlighting the integration of adaptive programming for predictive protection, dynamic braking, and intelligent load-handling strategies. The analysis evaluates performance gains, addresses implementation challenges, and outlines system-level improvements. The findings contribute to best practices for industrial VFD retrofits in crane systems, demonstrating their potential to enhance operational reliability, reduce mechanical wear, and improve energy efficiency in continuous-use workshop environments.

## 1. Introduction

Overhead cranes play a critical role in industrial operations by enabling the safe and efficient handling of heavy materials. Found in manufacturing plants, workshops, shipyards, and logistics centers, these systems support repetitive lifting and transportation tasks across defined workspaces. Their contribution to productivity, safety, and spatial optimization has made them indispensable in both heavy and light-duty industrial environments.

At the core of most overhead crane systems are squirrel cage induction motors, which are favored for their mechanical simplicity, durability, and minimal maintenance requirements. These motors, paired with conventional control architectures, have enabled decades of reliable service in crane applications. However, many of these systems still operate with legacy relay-based controls and fixed-speed motor starters. As such equipment ages, it becomes increasingly prone to performance issues such as abrupt load movements, excessive mechanical wear, and limited fault detection capabilities. These limitations not only raise the risk of operational failure but also compromise safety and energy efficiency.

To address these challenges, this thesis explores the retrofitting of an aging overhead crane with a Variable Frequency Drive (VFD) system, aimed at enhancing motion control, reducing mechanical wear, and improving operational safety. The selected VFD solution enables soft-start and controlled braking, greater adaptability to varying load conditions, and integrated fault-handling logic, capabilities that were previously unattainable with the legacy relay-based system. By tailoring these features to the existing mechanical infrastructure, the strategy to the system seeks to extend the crane's service life while minimizing the need for large-scale structural replacements.

### 1.1 Research Background of Overhead Cranes in Industry

Industrial cranes, particularly overhead traveling cranes, play a key role in streamlining workflows in environments that require the movement of heavy or delicate equipment. Their operations are characterized by high load duty cycles, constant motion, and exposure to varying mechanical and electrical stresses. Organizations such as the Crane Manufacturers Association of America (CMAA) and the International Organization for Standardization (ISO 4301/1) classify cranes based on their load spectrum and operating time. For example, a crane operating frequently with heavy or near-rated loads is classified under CMAA Class D or ISO Class M5/M6, indicating severe service conditions. A significant concern with long-serving cranes is their reduced structural and electrical integrity, especially after surpassing their designed operational life, typically 25–30 years with maintenance becoming increasingly difficult, and failures become more frequent, necessitating system upgrades. [\[1\]](#) [\[2\]](#)

In recent decades, the use of Variable Frequency Drives has grown significantly all industries. VFDs provide precise control over motor speed and torque, allowing for smoother acceleration and deceleration profiles along with embedded safety features. This not only reduces wear on mechanical components but also enhances safety by minimizing swing and abrupt movements.

### **1.2 Case Study Overview: Baganuur Workshop Crane**

The subject of this study is an overhead crane installed within a medium-scale industrial workshop in Baganuur, Mongolia. Manufactured in 1986 and commissioned in 1987, the crane has remained in near-continuous service for over three decades. It operates on a 380 V, 50 Hz, three-phase supply system and 11 kW squirrel cage induction motor. Mechanically, the crane is equipped with two hooks: a 20-tonne unit and a 5-tonne unit. Of the two, the 5-tonne hook is used most frequently to handle a wide range of loads, typically between 20 kg and 4.5 tonnes. Given its frequent operation and varied load profile, the crane's duty classification is consistent with FEM Class 3m or 4m, indicating medium-to-heavy service conditions.

The crane serves a critical role in supporting daily workshop operations. Its ability to safely and consistently move materials under variable and dynamic loading conditions is essential to the facility's workflow. Any malfunction, especially in its lifting mechanism, leads to a complete halt in production activities, affecting both efficiency and safety. In recent years, the 5-tonne hook began showing signs of mechanical fatigue and control instability. These issues were further compounded by the crane's aging relay-based control system, which lacked ramp control, diagnostic capability, and adaptability to varying load dynamics.

This study centers on this very system and investigates a targeted, cost-effective solution. Rather than replacing the mechanical structure, a retrofit was implemented to address the control limitations while preserving the existing hardware. The intervention involved replacing the older standard starter system with an ABB ACS880-01 Variable Frequency Drive (VFD), accompanied by two intermediate relays (for brake control and circuit activation), a magnetic contactor, electromechanical relay and a braking resistor. The control logic was redesigned to support digital input commands and adaptive acceleration/deceleration ramps. With these upgrades, the crane regained operational reliability while achieving smoother motion, safer handling, and improved energy responsiveness, all important for meeting the demands of variable and dynamic load handling in an industrial setting.

### **1.3 Problem Statement and Reasoning for System Upgrade**

The need for a new system setup stems from a combination of aging infrastructure, recurring operational failures, and growing safety concerns. After nearly 40 years in operation, the crane's

electromechanical relay-based control system had become increasingly unreliable. It lacked the flexibility to adjust speed or torque in response to changing load conditions and offered no built-in fault diagnostics or motion profiling capabilities. This rigidity resulted in abrupt and sometimes hazardous load movements, which accelerated mechanical wear and increased the risk of workplace incidents. A critical relay failure and control instability in the frequently used 5-tonne pulley further highlighted the outdated nature of the system and the urgency for corrective action.

The decision to upgrade the crane's control system was driven by workplace safety concern, mechanical issues, and the need for improved operational performance. Replacing the outdated relay-based setup with a Variable Frequency Drive (ABB ACS880-01) offered a practical solution to address safety concerns, inefficient motion control, and limited load-handling precision. The new system introduced soft start and stop capabilities, smoother speed transitions, and controlled braking, which significantly reduced stress on mechanical components. While direct energy measurements were not taken, performance modeling and manufacturer data suggest that the upgrade also contributed to improved energy efficiency through load-responsive speed control.

This case presents more than a solution, as it demonstrates how well-targeted investment in control system upgrades can yield substantial improvements in performance, safety, and reliability. For industries in developing regions where full system replacements may be financially unfeasible, this project can serve as a reference model for modernizing aging crane systems through selective retrofitting. It demonstrates the benefits of integrating advanced drive technology into existing infrastructure without disrupting mechanical continuity or incurring excessive costs.

#### **1.4 Thesis objective and Research question**

This thesis focuses on the integration, and performance enhancement of a Variable Frequency Drive (VFD) system applied to an aging overhead crane operating in the Baganuur motor repair workshop. The study documents the current issues in the crane's operation and control, and the technical intervention using ABB's industrial-grade VFD and supporting components, and assesses the resulting improvements. Through the implementation of ABB's ACS880-01 VFD and supporting components such as digital input logic, braking resistor, magnetic contactors, and intermediate relays, the system was reconfigured to achieve more responsive control, safer motion handling, and improved energy behavior under load variability. Research based estimation was used to estimate energy efficiency improvements, compensating for the lack of direct power measurements.

The primary goals of this work are to restore the reliability of the crane's lifting operations, introduce smoother acceleration and deceleration through programmable ramp profiles, and enhance overall safety by minimizing abrupt movements and swing. The study also evaluates how adaptive

programming and parameter tuning can enable the system to respond intelligently to changes in load conditions, further reducing mechanical strain and extending equipment life.

This study is guided by the following several key research questions.

1. What are the underlying mechanical and electrical limitations of the existing overhead crane system, particularly those stemming from relay-based control?
2. How does the integration of a modern Variable Frequency Drive affect the crane's performance, with regard to motion smoothness, safety, and estimated energy use?
3. What configuration procedures are necessary to implement controlled braking, ramp logic, and digital input functions?
4. How do auxiliary components such as relays, magnetic contactors, and braking resistors contribute to system reliability?
5. How can ABB's adaptive programming and parameter tuning enable the crane to function more intelligently under varying load conditions?

These questions are explored throughout the following chapters, which establish the technical background, detail the configuration process, describe the electrical system architecture, and evaluate the observed operational improvements. While real-time monitoring tools were not available during testing, the project relies on simulation-based validation, supported by manufacturer documentation and observed functional behavior. The findings aim to provide a practical reference for engineers seeking cost-effective strategies to extend the life and performance of existing crane systems using reliable drive technology and structured electrical design practices.

## **2. Literature review**

### **2.1 Overhead Crane Systems: Classification and Operation**

The global demand for overhead cranes continues to grow in parallel with industrial expansion, automation efforts, and the modernization of material handling infrastructure. According to Grand View Research (2023), the global overhead crane market was valued at USD 5.18 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 6.8% through 2030. This steady growth reflects increasing demand for automation, enhanced safety, and improved process efficiency. As industrial processes evolve, so does the need for intelligent crane systems that support smoother operation, adaptable control, and integrated safety features. [\[3\]](#)

Overhead cranes, commonly referred to as bridge cranes, are a fundamental component of industrial infrastructure. These systems are designed to move heavy or bulky materials horizontally and vertically within a defined workspace. The typical configuration includes a bridge girder mounted on runway rails, spanning the width of the facility. A trolley equipped with a hoist travels along the bridge, enabling longitudinal movement, while the bridge itself traverses transversely along the runways. This dual-axis motion allows precise load placement and efficient coverage of large working areas.

### **2.1.1 Classification Standards and Usage Frequency**

The performance, reliability, and maintenance requirements of overhead cranes are governed by international classification standards. Among the most widely applied are those established by the International Organization for Standardization (ISO 4301/1) and the Fédération Européenne de la Manutention (FEM). These standards categorize cranes based on two main criteria: utilization frequency and load severity.

- Utilization Class (U1 to U9) refers to the total number of load cycles a crane is expected to perform over its service life.
- State of Loading (Q1 to Q4) indicates the typical load intensity relative to the rated capacity, with Q4 representing operation under frequent near-maximum loads.

A crane's duty class is defined by combining these two parameters using the formula:

Crane Class = Utilization Class (U) × State of Loading (Q)

The product of these two parameters yields the duty classification, expressed as ISO M1–M8 or FEM Classes 1m–5m, and for our case 3m or 4m. Cranes within these classifications are expected to operate reliably in continuous or near-continuous service environments, such as foundries, fabrication shops, or heavy manufacturing lines.[\[1\]](#) [\[2\]](#)

Crane Working Class & Service Life <sup>Ⓢ</sup>							
Standard <sup>Ⓢ</sup>	ISO/BS/DIN <sup>Ⓢ</sup>	M3 <sup>Ⓢ</sup>	M4 <sup>Ⓢ</sup>	M5 <sup>Ⓢ</sup>	M6 <sup>Ⓢ</sup>	M7 <sup>Ⓢ</sup>	M8 <sup>Ⓢ</sup>
	GB/EN <sup>Ⓢ</sup>	A3 <sup>Ⓢ</sup>	A4 <sup>Ⓢ</sup>	A5 <sup>Ⓢ</sup>	A6 <sup>Ⓢ</sup>	A7 <sup>Ⓢ</sup>	A8 <sup>Ⓢ</sup>
	FEM <sup>Ⓢ</sup>	1Bm <sup>Ⓢ</sup>	1Am <sup>Ⓢ</sup>	2m <sup>Ⓢ</sup>	3m <sup>Ⓢ</sup>	4m <sup>Ⓢ</sup>	5m <sup>Ⓢ</sup>
	CMAA <sup>Ⓢ</sup>	B <sup>Ⓢ</sup>	C <sup>Ⓢ</sup>	D <sup>Ⓢ</sup>	E <sup>Ⓢ</sup>	F <sup>Ⓢ</sup>	-- <sup>Ⓢ</sup>
	HMI/ASME <sup>Ⓢ</sup>	H2 <sup>Ⓢ</sup>	H3 <sup>Ⓢ</sup>	H4 <sup>Ⓢ</sup>	H5 <sup>Ⓢ</sup>	H5 <sup>Ⓢ</sup>	H6 <sup>Ⓢ</sup>
Safe working Period SWP(h) <sup>Ⓢ</sup>	400 <sup>Ⓢ</sup>	800 <sup>Ⓢ</sup>	1,600 <sup>Ⓢ</sup>	3,200 <sup>Ⓢ</sup>	6,300 <sup>Ⓢ</sup>	12,500 <sup>Ⓢ</sup>	
Lifting Motor Duty %ED <sup>Ⓢ</sup>	25 <sup>Ⓢ</sup>	30 <sup>Ⓢ</sup>	40 <sup>Ⓢ</sup>	50 <sup>Ⓢ</sup>	60 <sup>Ⓢ</sup>	60 <sup>Ⓢ</sup>	
Starts (s/h) <sup>Ⓢ</sup>	150 <sup>Ⓢ</sup>	180 <sup>Ⓢ</sup>	240 <sup>Ⓢ</sup>	300 <sup>Ⓢ</sup>	360 <sup>Ⓢ</sup>	360 <sup>Ⓢ</sup>	
Running Time(h) <sup>Ⓢ</sup>	3,200 <sup>Ⓢ</sup>	6,300 <sup>Ⓢ</sup>	12,500 <sup>Ⓢ</sup>	25,000 <sup>Ⓢ</sup>	50,000 <sup>Ⓢ</sup>	100,000 <sup>Ⓢ</sup>	
Starts <sup>Ⓢ</sup>	480,000 <sup>Ⓢ</sup>	1,134,000 <sup>Ⓢ</sup>	3,000,000 <sup>Ⓢ</sup>	7,500,000 <sup>Ⓢ</sup>	18,000,000 <sup>Ⓢ</sup>	42,000,000 <sup>Ⓢ</sup>	
Overloads <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	1,000 <sup>Ⓢ</sup>	

Table 1.1: Crane Working Levels under Different Standards [\[4\]](#)

These standards provide critical guidance on expected maintenance cycles, structural fatigue limits, and appropriate control system capabilities to ensure safety and longevity under defined working conditions.

### 2.1.2 Load Types and Mechanical Considerations

Effective crane design and control systems must account for various load conditions that influence mechanical stress and operational safety. Three principal types of loads are considered in crane engineering:

- Static Loads represent constant forces applied to the system, such as the self-weight of the crane and the weight of a stationary suspended load. These loads define the baseline structural demands on the system even when motion is absent.
- Variable Loads refer to fluctuations in the magnitude of the load being lifted. For example, a crane that alternates between handling lightweight components (e.g., 200 kg) and near-capacity loads (e.g., 4.5 tonnes) experiences variable loading conditions that affect control performance and energy consumption.
- Dynamic Loads arise from motion especially acceleration, deceleration, directional changes, or abrupt stops. These time-dependent forces generate additional stress on components due to inertia, load swing, and mechanical impact. Without proper motion control mechanisms, dynamic loads can lead to increased wear, reduced precision, and safety hazards.

Dynamic loading conditions require specialized engineering attention to mitigate transient forces through control mechanisms. In practice, all three load types interact during crane operation, and robust control strategies, such as those enabled by Variable Frequency Drives (VFDs), are essential to maintain system integrity and safe performance under varying load types and conditions.

### **2.1.3 Operational Procedures and Control Practices**

Safe and efficient overhead crane operation must adhere to standardized procedures aligned with ISO and national occupational safety guidelines (e.g., OSHA, EN 15011). Overhead crane operation follows a series of standardized procedures designed to ensure both efficiency and safety in industrial environments. Prior to any lifting activity, operators are expected to perform thorough pre-operational inspections, carefully assessing critical components such as wire ropes, hooks, safety latches, limit switches, and hoist brakes for signs of wear, damage, or malfunction. During lifting operations, it is essential that loads are hoisted vertically to avoid inducing torsional forces that could compromise the structural integrity of both the crane and the load. Movement along the bridge or runway must be smooth and controlled, typically managed through pendant stations, remote controls, or cab-based systems, depending on the crane's design and operational requirements. Load placement similarly demands precision, with gradual lowering procedures employed to maintain load stability and minimize the risk of sudden impacts or hazardous swinging.

Emergency preparedness forms an integral part of safe crane operation. Emergency stop systems must be readily accessible, and operators must be thoroughly trained to respond effectively to mechanical failures, power interruptions, or unexpected load behavior to mitigate risks to personnel and equipment. [\[5\]](#)

In many systems, including the original configuration of the Baganuur workshop crane, crane control is enhanced through the use of radio-frequency (RF) remote systems, providing operational flexibility but necessitating careful attention to signal reliability. As will be discussed in subsequent chapters, the integration of Variable Frequency Drive (VFD) systems further refines motion control, allowing for smoother, safer crane operations that align with contemporary industrial standards.

## **2.2 Challenges of Aging Crane Systems**

As overhead crane systems age beyond their intended service life, they face a range of mechanical, electrical, and operational challenges that compromise their performance, safety, and reliability. Mechanical aging is a primary concern, as structural components are subjected to cyclic loading over decades of service, leading to material fatigue, deformation, and, in many cases, corrosion. Repeated exposure to heavy loads and environmental factors gradually weakens critical

elements such as the bridge girders, trolley frames, and hoisting mechanisms, reducing the system's overall load-carrying capacity and increasing the risk of structural failure.

In parallel, electrical aging further erodes crane reliability. Traditional relay-based control systems, which were common in older installations, are prone to failures as mechanical relays suffer from contact wear, coil degradation, and general mechanical fatigue. Insulation of electrical wiring also deteriorates over time, particularly under conditions of thermal cycling and environmental contamination, leading to increased risks of short circuits, electrical faults, and operational inconsistencies.

The cumulative effect of these mechanical and electrical degradations is reflected in significant operational impacts. Aging cranes experience higher rates of unplanned downtime due to the frequent need for maintenance and component replacement. This leads to increased operational costs and disrupts production schedules, particularly in industries where crane reliability is critical to workflow continuity.

Moreover, safety risks associated with legacy systems cannot be overlooked. Older cranes often lack modern safety features such as advanced fault detection, soft-start mechanisms, load monitoring, and emergency stop redundancy, all of which are now considered standard in contemporary crane designs. Without these protections, the probability of accidents, including uncontrolled load drops, structural collapses, and equipment damage, increases substantially. Given that crane-related incidents can have severe personnel safety and economic consequences, addressing the challenges posed by aging systems is essential for maintaining safe and efficient industrial operations.

### **2.3 Squirrel Cage Induction Motors in Crane Applications**

Squirrel cage induction motors have long been the standard choice for industrial motion systems, including overhead cranes, owing to their mechanical simplicity, reliability, and economic efficiency. These motors operate based on electromagnetic induction principles: when three-phase alternating current is supplied to the stator, it creates a rotating magnetic field that induces currents in the rotor bars, producing torque that drives the rotor.

The rugged design of squirrel cage motors, featuring permanently short-circuited rotor bars without brushes or slip rings, minimizes maintenance needs and mechanical failure risks. This design has proven ideal for heavy industrial settings, supporting continuous or near-continuous operation under demanding conditions.

In overhead crane systems, squirrel cage motors are typically deployed in hoisting mechanisms, trolley travel, and bridge movement. High-torque motors power the hoisting systems, while lower-rated motors are utilized for horizontal movements.

The operational strengths of squirrel cage motors include their durability, low maintenance requirements, cost-efficiency, and resilience to electrical disturbances such as voltage dips and phase imbalances. These attributes are particularly advantageous in cranes, where any failure can halt critical industrial operations. Furthermore, their high power density allows significant mechanical output relative to their size, supporting compact crane designs.

Nonetheless, inherent limitations arise from traditional fixed-speed operation. Without external control, squirrel cage motors run at a speed determined solely by the supply frequency and motor pole count, limiting operational flexibility. High starting currents, often several times greater than rated operational currents, place additional stress on the electrical infrastructure. Moreover, abrupt starting and stopping contribute to mechanical wear on crane structures and gear mechanisms. Torque control at low speeds is also less effective, complicating precise load positioning without supplementary control technologies.

Despite these limitations, squirrel-cage motors continue to dominate industrial lifting applications. Their combination of mechanical robustness, operational simplicity, and economic viability has ensured their persistence even as control technologies have evolved. Recent industry trends focus on retaining these durable motors while enhancing their performance through external techniques, a strategy that balances cost control with improved operational outcomes. [\[6\]](#)

## **2.4 Evolution of Motor Control Systems**

Historically, motor control systems in industrial applications, including overhead cranes, relied heavily on simple electromechanical methods aimed at providing robust and reliable operation. Among the most prevalent of these were Direct-On-Line (DOL) starters and star-delta starting methods. In a DOL starter configuration, the motor is directly connected to the full supply voltage, resulting in immediate torque generation and full-speed operation. This method is favored for its simplicity, low cost, and minimal component count. Alternatively, the star-delta starter reduces the starting voltage applied to the motor by initially connecting the motor windings in a star configuration before transitioning to a delta configuration once the motor reaches a predefined speed. This method helps to moderate starting currents compared to DOL starters.

Despite their operational simplicity, traditional motor control methods present significant challenges, particularly in applications requiring delicate load handling and high operational precision, such as overhead cranes. One major drawback is the occurrence of high inrush currents during motor startup. In DOL starters, the motor can draw starting currents up to six to seven times its rated

operational current, placing substantial electrical stress on the supply network and on the motor windings themselves. While star-delta starters partially alleviate this issue, they do not eliminate it entirely, nor do they offer any dynamic control over acceleration or deceleration.

Furthermore, both DOL and star-delta configurations operate motors at essentially fixed speeds, determined by the supply frequency and motor pole count. This lack of speed variability severely limits the ability to fine-tune crane movements, making precise load positioning and smooth material handling difficult. The abrupt starting and stopping inherent in these methods also contribute to mechanical shocks, leading to accelerated wear of crane gearboxes, hoists, and supporting structures.

In contrast, modern industrial requirements have shifted towards achieving soft starting and stopping, precise speed control, and energy-efficient operation. Smooth acceleration and deceleration minimize mechanical stress, enhance load stability, and improve overall safety. Variable speed control allows operators to match crane movement more closely to operational demands, enabling delicate load placement and reducing swing. [\[7\]](#)

The Autotransformer starter offers more flexibility by using taps on a transformer to reduce the starting voltage, thereby allowing adjustable starting current and torque. It is suitable for large motors requiring better control during startup, though it is more expensive and complex than DOL or Star-Delta starters.

Soft starters introduce a modern electronic alternative using thyristors to gradually increase the voltage applied to the motor. This provides smooth starting with reduced mechanical and electrical stress, and adjustable starting torque. Soft starters are often used in applications like conveyors, HVAC systems, and pumps where minimizing shock to the system is important. However, they offer limited control over motor speed once running.

For applications requiring precise and continuous control of both speed and torque, Variable Frequency Drives (VFDs) are the most advanced option. VFDs control the motor by varying the frequency and voltage supplied, enabling smooth acceleration, deceleration, and operational speed control. They offer excellent energy efficiency and protect against mechanical wear and electrical surges. Due to their higher cost and complexity, VFDs are typically used in applications demanding dynamic speed control and high performance, such as cranes, elevators, and precision manufacturing equipment.

In terms of motor control methods, manual switches represent the most basic and outdated approach, offering only on/off functionality without any protective features. Electromechanical relay-based control systems are a step up, enabling basic automation using contactors and timers, but still lack fine control over speed and torque. Soft starters provide limited speed control during

startup and shutdown phases but not during normal operation. In contrast, VFDs offer full motor control during the entire operating cycle, with the added benefit of torque control when vector or sensorless vector modes are used.

Advanced motor control systems often integrate Programmable Logic Controllers (PLCs) with VFDs or starters to achieve intelligent automation. This allows for fully customizable motor behavior, integration with sensors and feedback loops, and compatibility with industrial control systems such as SCADA or DCS.

In summary, the selection of a motor starting and control method depends on factors such as motor size, load characteristics, required level of control, energy efficiency goals, and budget. DOL and Star-Delta starters are cost-effective for smaller or simpler systems, while soft starters and VFDs offer smoother operation and greater control for more demanding applications. VFDs, in particular, stand out as the most versatile and energy-efficient solution for modern industrial needs.

## **2.5 Variable Frequency Drive Technology**

In recent years, the intergration of inverters in crane systems has been strongly influenced by the widespread adoption of advanced motor control technologies, particularly Variable Frequency Drives (VFDs). As industries face increasing pressure to improve operational efficiency, safety, and energy management, VFDs have emerged as a central solution in upgrading aging crane systems. According to Grand View Research (2023), the global VFD market was valued at USD 20.0 billion in 2022 and is projected to grow steadily due to the rise of automation and energy optimization demands across industrial sectors. [\[3\]](#)

### **2.5.1 Working Principle of Variable frequency Drive**

A Variable Frequency Drive (VFD) is a type of power electronic converter designed to control the speed and torque of alternating current (AC) motors by varying the supply frequency and voltage. The standard VFD architecture consists of three main components: a rectifier, which converts the incoming AC power into direct current (DC); a DC bus, which smooths and stores the electrical energy using capacitors or inductors; and an inverter, which converts the DC power back into a variable-frequency AC output through high-speed switching devices such as Insulated Gate Bipolar Transistors (IGBTs). By modulating the output frequency and voltage in real time, the VFD provides precise motor control, allowing for smooth start-up, gradual acceleration, and dynamic load matching. Compared to traditional fixed-speed or contactor-based motor starters, VFDs offer significantly greater operational flexibility, improved process efficiency, and enhanced stability under fluctuating load conditions.

### **2.5.2 Research Trends in Inverter Integration**

Several case studies demonstrate the practical benefits of integrating VFD technology into crane operations. A notable example is the Tata Steel project in India, where aging crane systems were retrofitted with ABB ACS880 series drives. This upgrade led to a 30% improvement in load handling precision and a marked reduction in mechanical wear and energy consumption. Such successful implementations illustrate how VFD integration not only extends the operational life of cranes but also aligns with modern safety and performance expectations. [\[8\]](#)

Another trend is the increasing deployment of smart diagnostics and remote monitoring technologies. Modern VFDs and control systems now incorporate built-in diagnostic features, providing real-time feedback on system health, operational parameters, and fault histories. Remote monitoring platforms, such as ABB Ability™ and similar IoT-based services, enable operators to access crane performance data from centralized control rooms or even offsite locations, facilitating faster maintenance responses and reducing unplanned downtime.

Furthermore, there is a strong push toward predictive maintenance strategies. Instead of relying on scheduled maintenance or reactive repairs, industries are moving toward data-driven maintenance models where system parameters such as motor temperature, vibration levels, and operational cycles are continuously monitored to predict potential failures. According to the International Energy Agency (IEA) Energy Efficiency 2022 report, the implementation of predictive maintenance combined with intelligent drive control can result in up to 20–30% reductions in industrial downtime and significant energy savings over the lifespan of the equipment. Studies, such as those by Mazzella Companies (2021) and ABB (2020), have shown that VFD retrofitting in older crane systems can extend equipment lifespan by up to 40% and reduce energy consumption by 20–50%, depending on the load cycle. [\[9\]](#) [\[10\]](#) [\[11\]](#)

Overall, these industry trends underline a broader shift from traditional, manually controlled crane systems toward highly automated, efficient, and intelligent solutions. The integration of VFDs, smart diagnostics, and predictive maintenance frameworks represents not just a technical upgrade but a fundamental transformation in how crane systems are operated, maintained, and optimized in modern industrial environments.

### **2.5.3 Overview of ABB Drives and PLCs**

ABB is a global leader in industrial automation, offering a comprehensive range of variable frequency drives (VFDs) and programmable logic controllers (PLCs) used across various sectors including manufacturing, infrastructure, energy, and transportation. Among ABB's most widely used drives are the ACS880 series, designed for high-performance motor control in demanding applications, and the ACS580 series, suitable for general-purpose industrial systems. These drives

support advanced features such as direct torque control (DTC), adaptive programming, and integration with fieldbus protocols like Modbus, Profibus, EtherNet/IP, and Profinet. On the PLC side, ABB's AC500 family offers modular, scalable control platforms with variants like AC500-eCo for compact applications and AC500-S for safety-critical systems. [\[12\]](#) [\[13\]](#)

In terms of market trends, the adoption of ABB drives and PLCs is increasingly driven by the demand for energy efficiency, real-time connectivity, and digital integration with Industry 4.0 systems. Modern drives are often equipped with cloud connectivity and predictive maintenance features, while PLCs are evolving to support distributed control, remote programming, and edge computing capabilities.

Common usage cases include motor speed and torque control in cranes, conveyors, HVAC systems, pumps, and fans, while PLCs are central to sequence control, safety logic, interlocking, and machine automation. In material handling and overhead crane applications, ABB drives provide smooth speed regulation and braking, while PLCs manage interlocks, timing, and coordination between motion systems. [\[14\]](#)

Selection of ABB drives depends on several criteria: motor type and power rating, control complexity, environmental conditions, I/O requirements, and communication protocols. Drives must be chosen based on load characteristics, overload capacity, and compatibility with the motor.

Despite their strengths, ABB drives do present limitations. Drives may require detailed tuning for non-linear loads or regenerative braking systems and may face derating in harsh environments. Furthermore, integrating systems require trained personnel for programming, troubleshooting, and maintenance, which can be a barrier in regions with limited technical expertise.

Overall, ABB's automation solutions are highly reliable, flexible, and aligned with modern industrial requirements, making them a preferred choice in sectors prioritizing performance, safety, and scalability.

## **2.6 Research Gaps in Retrofitting Crane System**

While the benefits of crane system upgrade through Variable Frequency Drives (VFDs) and intelligent control systems are well-documented, existing research tends to focus predominantly on new crane installations or high-end automation projects in large industrial settings. Studies and case reports typically highlight newer system initiatives in developed economies, where budgetary constraints are less critical and where entire crane systems are often replaced rather than retrofitted.

However, there is a noticeable lack of systematic research addressing the challenges of aging crane systems in developing economies, where infrastructure investment is limited and cranes

often operate decades beyond their intended service life. In such contexts, replacing an entire crane system is often not feasible due to economic constraints, making targeted retrofitting strategies a more practical solution. Nevertheless, real-world studies examining how partial implementation, such as upgrading only the control systems while retaining the existing mechanical structure, can be implemented effectively and economically are still limited (Mazzella Companies, 2021). [\[10\]](#)

Furthermore, there is a shortage of empirical data on the performance, reliability, and cost-benefit outcomes of low-cost inverter integration strategies. Much of the existing literature assumes access to new equipment, comprehensive digital infrastructure, and advanced maintenance resources, conditions which are often not representative of industrial environments in many developing regions (International Energy Agency, 2022). This creates a critical knowledge gap regarding the practical challenges and solutions for extending the operational life of legacy crane systems under realistic budgetary and infrastructure constraints. [\[9\]](#)

Addressing this gap requires case studies that demonstrate practical and scalable retrofitting solutions, such as the selective integration of VFDs, braking systems, and modern control logic. Providing such data would offer valuable insights for industries seeking to modernize safely and efficiently without incurring the prohibitive costs associated with full system replacement.

### **3. Methodology**

This chapter outlines the systematic approach adopted to design, implement, and evaluate the optimization of an aging overhead crane system using a Variable Frequency Drive (VFD). The methodology includes an initial assessment of the existing crane infrastructure, the selection and integration components, the development of adaptive programming within the drive, and an approximate evaluation of the system's expected performance improvements. Given the lack of direct field measurements from the operating environment, certain estimations are based on equipment specifications, manufacturer guidelines, and referenced industrial case studies. The primary objective of this methodology is to demonstrate a practical, cost-effective approach for upgrading aging crane systems, improving operational safety, enhancing precision control, and optimizing energy usage.

#### **3.1 Assessment of the Existing Crane System**

The overhead crane system assessed in this study was installed in 1987 at the Baganuur workshop and had been in operation for nearly four decades. It is powered by a squirrel cage induction motor operating on a 380 V, 50 Hz three-phase supply. The mechanical setup has two hoisting mechanism: one rated for 20 tonnes and another for 5 tonnes. Daily workshop operations primarily

relied on the 5-tonne hoist system, lifting loads that varied between approximately 20 kilograms and 4.5 tonnes. Although the crane structure remained generally robust, the 5-tonne hook had been replaced due to a structural crack two years prior to the inverter installation, highlighting the effects of long-term mechanical fatigue under frequent usage.

The crane's original control system consisted of a relay-based architecture combined with a DOL motor starting method. At startup, the motor would be connected to the supply power directly which led to immediate torque generation and full-speed operation. As a result, load movement was often abrupt, with noticeable jerking during start and stop phases. This abrupt behavior posed significant safety hazards, especially during the lifting and lowering of heavy or delicate loads, as it increased the likelihood of load swinging, unstable handling, and potential accidents.

Despite the crane's continued mechanical reliability apart from the hook replacement, the operational safety risks associated with its abrupt movement profile became a growing concern. Moreover, the original system lacked any form of electronic diagnostics or automated fault detection. Maintenance and fault identification relied entirely on manual inspections and operator observations, which inherently delayed responses to developing issues and increased the risk of unexpected operational failures over time.

Given the crane's essential role in supporting workshop activities, where interruptions directly impacted productivity, it was clear that improvements to the system were necessary. However, a complete mechanical overhaul was neither economically practical nor structurally necessary. Therefore, a focused strategy was developed to modernize the electrical control system. This strategy involved the integration of an ABB ACS880-01 Variable Frequency Drive (VFD), a braking resistor to manage deceleration, a magnetic contactor for motor circuit switching, and two intermediate relays to refine control logic. Adaptive programming was implemented as a preventive control measure to reduce mechanical and electrical stress during high-load conditions. By dynamically adjusting operational behavior, such as limiting acceleration or triggering controlled deceleration when predefined load thresholds were approached, the system aimed to minimize unnecessary trips and reduce the need for manual intervention, thereby enhancing both equipment protection and operational continuity.

## **3.2 Variable Frequency Drive: Overview of Installation and Configuration**

### **3.2.1 Installation and Connection of Variable Frequency Drive**

To replace the electrical control of the overhead crane while preserving its mechanical integrity, a Variable Frequency Drive (VFD) based control system was selected. The chosen model, the ABB ACS880-01 rated at 18.5 kW, serves as the core component for this upgrade, replacing the original relay-based star-delta system. The ACS880 series is well-regarded in the industrial sector for its

precision control, safety features, and adaptability to both new and retrofit applications. Its integration within this project was based on its compatibility with squirrel cage motors, its modular design, and its support for embedded adaptive programming and diagnostics. The squirrel cage motor at the workshop is rated at 11kW and VFD is sized 150% higher than the motor. The inverter was mounted adjacent to the main electrical cabinet.



*Figure 3.1 Inverter installation at electrical cabinet*

The ABB ACS880-01 supports both scalar (V/f) and vector control but is most notably designed around Direct Torque Control (DTC), a high-performance real-time control algorithm that enables direct control of motor torque and flux without requiring encoders. This results in faster torque response and better dynamic performance compared to conventional VFDs. The drive also features a comprehensive I/O interface, built-in Safe Torque Off (STO) functionality, a brake chopper connection, and high immunity to electrical noise. It is designed to operate reliably under harsh industrial environments and supports extensive customization through parameter setting and programmable logic blocks. [\[12\]](#)

For the inverter to function properly within the existing system, several auxiliary components were integrated. These components serve to support signal interfacing, improve safety, and enable controlled braking and motion. Externally, the VFD's input terminals (L1, L2, L3) were connected to the main power supply. Its output terminals (U, V, W) were connected to the squirrel cage induction motor. Each component was chosen based on its function within the overall system design:

- **Brake Resistor:** In this setup, the brake resistor is connected directly across the DC bus terminals (R+ and R-) of the ABB ACS880-01 drive and functions to absorb regenerative energy during deceleration. When the crane slows down rapidly, such as when lowering a heavy load or stopping suddenly, the motor operates as a generator, converting kinetic energy back into electrical energy. This causes a rise in DC bus voltage, which, if uncontrolled, can lead to overvoltage faults and possible VFD shutdown. The resistor used is an externally mounted, wire-wound type, with aluminum casing selected based on resistance value and power dissipation capability in accordance with ABB's ACS880 technical documentation. It does not include a thermal switch, which means the system relies on proper resistor sizing, sufficient ventilation, and operational parameters of the VFD to ensure safe dissipation of heat. It helps the crane slow down smoothly, especially when handling heavy or shifting loads.



*Figure 3.2 Brake resistor*

- **Magnetic Contactor:** The magnetic contactor(CHNT NC1-09) serves as the primary isolation and switching device for the three-phase power circuit. It enables the physical disconnection of line voltage during system downtime, maintenance, or in case of faults. It acts as a safeguard that ensures full electrical disconnection of the motor from the power circuit. The contactor is not energized by default; rather, it receives a control signal only after the VFD has successfully initialized, and once the brake mechanism has been released. This

coordinated control ensures that power is applied to the motor only when the mechanical brake is open and the system is ready for movement.



*Figure 3.3 NC1 Magnetic Contactor*

- Electromechanical Relays: The electromechanical relay used in this system is a Finder 55.34 relay with a 220V AC coil. It functions as a central control interface between the VFD's low-voltage logic output and the high-voltage circuits of the motor and brake system. This relay receives a 24V logic signal from one of the VFD's digital outputs, which causes the relay to switch its contacts. Two of these contacts are used in parallel: one to energize the coil of the magnetic contactor, thereby closing the contactor and allowing current to flow to the motor, and another to activate the brake coil, releasing the mechanical brake. This dual-function relay allows coordinated control of both the electrical and mechanical drive systems through a single logical command, simplifying system integration and enhancing operational safety.



*Figure 3.4 Finder electromechanical relay*

- Intermediate relay: Additionally, two intermediate relays (DELIXI JTX-3C) are implemented in the system, one designated for starting connection and the other for controlling the brake release. These are standard 24V DC relays connected to the digital outputs of the VFD. The first relay controls the activation of the magnetic contactor, and is energized only when the VFD output logic confirms that conditions are safe to start the motor. The second relay is dedicated to the brake system and is activated to release the brake prior to motor startup. This sequencing ensures that the mechanical brake is released slightly before the motor is energized, preventing torque buildup against a locked rotor. These relays also provide an added layer of flexibility and reliability to the system by decoupling the logical control from the power circuits, allowing for future modifications such as time-delay modules or adaptive brake timing.



*Figure 3.5 Intermediate relay*

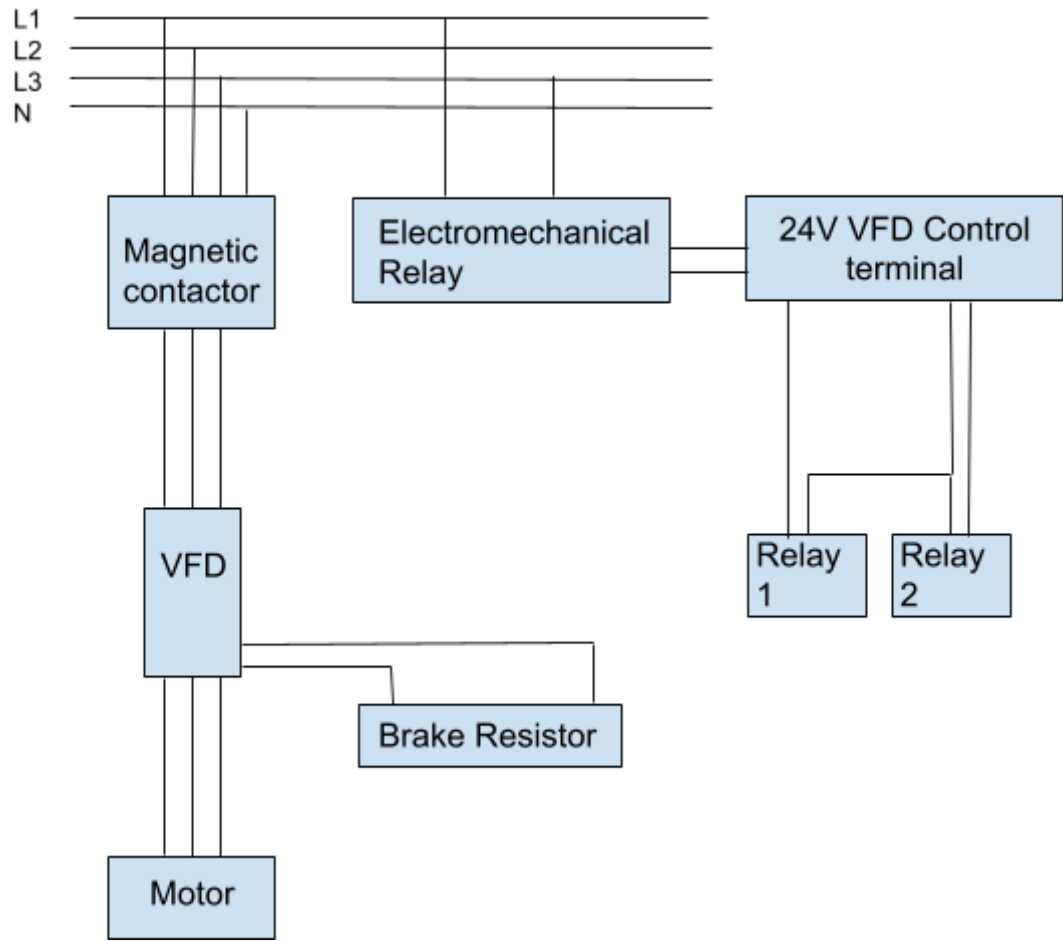


Figure 3.6 Simplified VFD Connection Diagram

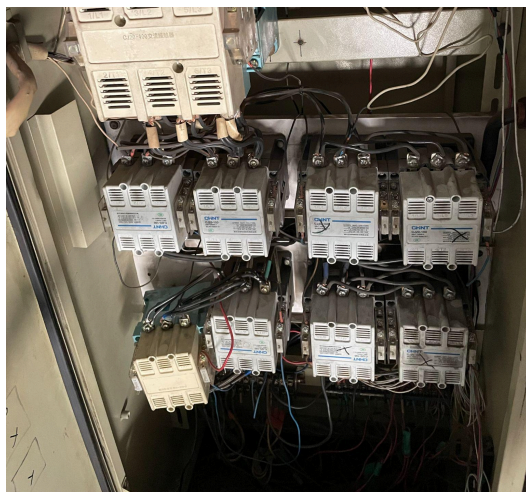


Figure 3.7 Initial electrical cabinet connection

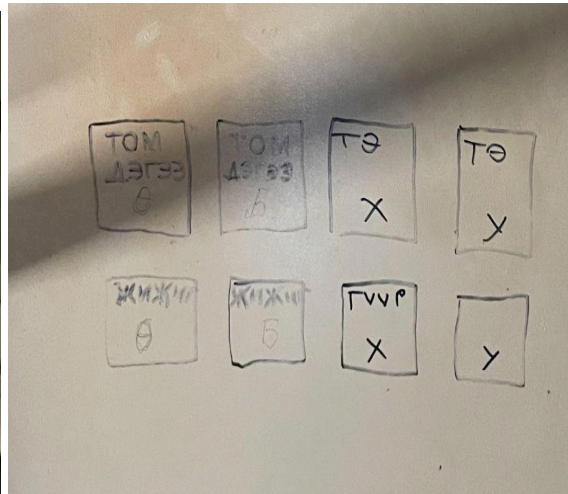
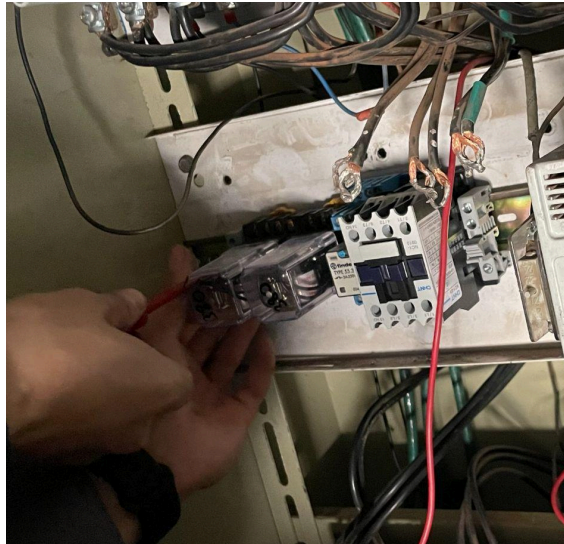


Figure 3.8 Marking of corresponding components



*Figure 3.9 VFD Connection*

### **3.2.2 Variable Frequency Drive Configuration**

The VFD operates by first receiving three-phase 380 V, 50 Hz AC power, which is converted to DC through a rectifier using a six-pulse diode bridge. This DC is smoothed by capacitors in the DC link, which also serves as the connection point for a brake resistor during regenerative braking. The smoothed DC is then converted back to variable-frequency AC by an inverter stage using IGBTs controlled by PWM to regulate motor speed and torque. An internal control board processes user commands and motor feedback to dynamically adjust the IGBT switching for optimal performance and safety. [\[12\]](#)

#### **1. Identification Run**

The ACS880-01 operates using Direct Torque Control (DTC), which enables the drive to regulate motor torque and magnetic flux directly and without encoders. This is particularly advantageous for hoist systems where load stability, slow-speed control, and immediate torque response are critical. The ABB Drive Composer can connect to the control interface via bluetooth or USB. The nameplate data is uploaded to parameter group 99. Motor data and through a motor identification routine (ID Run), the drive calculates electrical parameters such as stator resistance and rotor time constant, which are then stored in parameter group 98 (User Motor Parameters). The drive parameters are configured either via the ACS-AP control panel or the Drive Composer software. The initial configuration involves entering motor nameplate data:

- 99.03 - Motor type: Asynchronous
- 99.04 - Motor control mode: DTC
- 99.06 - Motor nominal current: Nameplate Data [A]

- 99.07 - Motor nominal voltage: Nameplate Data [V]
- 99.08 - Motor nominal frequency: Nameplate Data [Hz]
- 99.09 - Motor nominal speed: Nameplate Data [rpm]
- 99.10 - Motor nominal power: Nameplate Data [kW]
- 99.11 - Motor nominal cosφ: Nameplate Data
- 99.14 - Motor ID Run: Set to Standstill



*Figure 3.10 Motor Nameplate*



*Figure 3.11 Motor Nameplate*

## 2. Control Connections

The ABB ACS880-01 Variable Frequency Drive (VFD) supports a comprehensive set of digital inputs (DI), analog inputs (AI), and relay outputs (RO) that enable flexible integration with crane control systems. These inputs and outputs serve as the interface between the drive and external

control elements such as pushbuttons, PLCs, potentiometers, brake coils, and safety interlocks. The proper configuration of I/O is essential for safe, responsive, and coordinated crane operation.

The XDI terminal block is central to command logic, where digital inputs such as DI1 are used for start/stop control, DI2 for forward/reverse control, DI3 to toggle between speed and torque control modes, and DI5 for switching between two acceleration/deceleration profiles. These inputs are connected to operator pushbuttons, PLC outputs, or control panel switches, and define the basic motion commands for the crane motor. For speed regulation, the XAI block provides analog input functionality, where AI1+ and AI1- are connected to a potentiometer for speed reference, and AI2+ / AI2- optionally receive a 4–20 mA signal for torque reference. The onboard +10 V reference output (+VREF) and AGND terminals enable stable potentiometer integration without an external supply. Critical feedback and output signaling are handled through the XRO relay outputs, where XRO2 (Running) is wired directly to the electromagnetic brake coil, energizing it only when the motor is actively running, thereby preventing accidental load descent. XRO3 (Fault) can be wired to an alarm or shutdown circuit to signal fault conditions. The XAO block offers analog outputs such as AO1 and AO2, which can send motor speed and current data to PLCs or monitoring panels for real-time diagnostics. For safety, the XSTO (Safe Torque Off) circuit must be hardwired and closed, often through an emergency stop relay or safety interlock, before the drive is permitted to energize the motor.

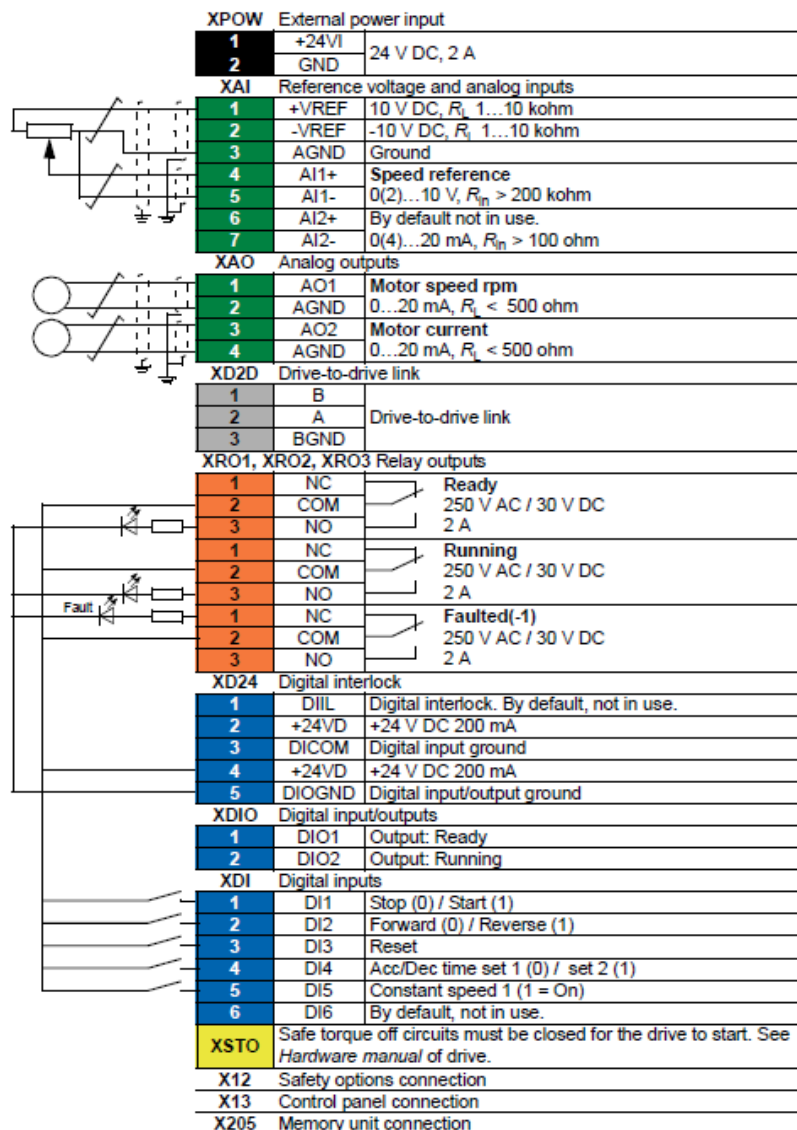


Figure 3.12 Default Control Connections for the Factory Macro

### 3. Coast and Ramp

The ramp function in a VFD allows the drive to control motor acceleration and deceleration rates by linearly adjusting the output frequency and voltage over time. This ensures smooth transitions in speed, critical in crane applications to prevent load sway, minimize mechanical stress, and synchronize with brake mechanisms. Ramp behavior is defined using specific acceleration and deceleration times, unlike the coast function which allows uncontrolled freewheeling.

It is configured using:

- 21.01 - Start mode
- 21.03 - Ramp stop mode enabled [1]

- 23.11 - Ramp set selection
- 23.12 - Acceleration time 1
- 23.13 - Deceleration time 1

The coast function in a VFD is a stopping mode in which the drive disables its output voltage immediately, allowing the motor to decelerate solely due to its own inertia and load friction. It is not influenced by power factor or input load dynamically, but rather operates as a direct control decision. While coast is acceptable in some low-risk applications, it is unsuitable for hoisting systems due to the absence of braking torque, which may lead to uncontrolled load descent or instability.

It is configured using:

- 21.01 - Start mode
- 21.03 - Coast mode enabled [0]
- 23.11 - Ramp set selection
- 23.12 - Acceleration time 1
- 23.13 - Deceleration time 1

#### **4. Brake Parameter Configuration**

The system includes a brake resistor connected across terminals R+ and R- on the DC bus to handle regenerative energy during load lowering. Group 43. Brake Chopper controls how the VFD handles excess DC bus voltage through braking and thermal limits are also used for overload protection. The internal brake chopper is a built-in transistor circuit that switches the external resistor ON/OFF based on DC bus voltage. Configuration is done through the following parameters:

- 43.06 – Brake chopper enable: 1
- 43.10 – Brake resistance: resistance value of the brake resistor [ohm]

Mechanical brake control is typically achieved through a relay output (RO1) wired to an electromagnetic brake coil. The brake is released only after the motor has been enabled and sufficient torque is available. Likewise, the brake is re-engaged only after the drive has confirmed zero-speed or torque hold conditions, minimizing shock or drift. Parameter group 44. Mechanical Brake Control uses 44.06 - Brake control Enable, and following open delay and open torque threshold for brake actuator control.

#### **5. Speed reference**

The speed reference is a fundamental input parameter in variable frequency drive (VFD) control systems, as it determines the desired rotational speed of the motor shaft. In the ABB ACS880 series drives, the speed reference can originate from various configurable sources, including analog inputs, fieldbus communications, digital preset speeds, or keypad settings. The selected reference is processed through a chain of internal parameters before being executed by the drive's motor control algorithm. The primary parameter governing the source of the speed reference is Parameter Group 22, specifically: 22.11 – Speed reference 1 source. Common options include:

- Analog Input 1 (AI1)
- Analog Input 2 (AI2)
- Keypad reference
- Fieldbus (e.g., Modbus, ProfiNet)
- Preset speed references (defined under macro control logic)

For applications that require closed-loop speed regulation, the drive supports PID tuning through proportional gain and integral time settings. Lastly, minimum and maximum speed limits can be defined to constrain the drive's output, ensuring that the motor operates within safe mechanical and electrical boundaries regardless of the input source.

### **3.3 Local and External Control Modes in ABB ACS880 Drives**

The ABB ACS880 drive supports two primary control modes: local control and external (or remote) control, each intended for different operational scenarios and user interfaces. The selection between these modes determines how start/stop commands, direction, and speed reference signals are received and processed by the drive.

Local control mode allows the operator to control the drive directly from the built-in control panel or connected assistant panel (e.g., ACS-AP-I). In this mode, the operator can issue start/stop commands, adjust speed references manually, and monitor drive status via the panel interface. This configuration is commonly used during commissioning, testing, or maintenance procedures, where hands-on interaction with the drive is required and automated or fieldbus control is temporarily disabled. Local control also overrides external commands, ensuring that manual interventions are prioritized for safety or troubleshooting purposes.

In contrast, external control mode is used during normal operation when control signals are received from external devices such as programmable logic controllers (PLCs), remote I/O modules, wireless remote systems (e.g., Telecrane), or fieldbus networks (e.g., Modbus, Profibus, Profinet). In this mode, all operational commands, including speed reference, start/stop signals, and

directional inputs, are processed via the drive's digital and analog inputs or communication interface. External control enables integration with automated systems and allows for real-time remote operation of the motor based on process demands.

The drive's control location can be configured using parameter 19.01 – Control location, or it can be toggled from the control panel. Proper configuration ensures that the drive responds correctly to either manual or automated inputs, depending on the operational context. The use of control macros and I/O logic further enhances flexibility by allowing seamless switching between local and external control modes as needed.

### **3.4 Telecrane Wireless Remote Control System**

As part of the overhead crane control system, a Telecrane F24 series wireless remote control unit is used to enable operator interaction with crane motion functions. The receiver module, shown in Figure 3.13, is mounted adjacent to the main control cabinet and translates wireless signals from the handheld transmitter into electrical commands for crane operation.

The receiver is powered by a single-phase 220V AC or 24V DC supply (depending on the model) and includes internal relay contacts dedicated to motion functions. The drive's logic is configured accordingly using Drive Composer software or via the local control panel interface. The digital inputs of the ACS880 are designed for 24 V DC logic levels, which align with the output specifications of the Telecrane relay contacts. The connection is completed by wiring the COM (common) terminals from the Telecrane receiver to the digital input common terminal (DI COM) of the drive to establish a consistent signal reference. These relays manage directional commands such as East/West bridge travel, North/South trolley movement, and Up/Down hoisting, each assigned to specific relay outputs (e.g., UP 1S, DOWN 2S), which are wired into the control circuit to activate corresponding contactors or interface with the ABB ACS880-01 VFD's digital inputs. The relay closure signals are interpreted by the VFD's programmable digital inputs (DI) as discrete control commands. For instance:

- DI1 may be configured to initiate hoisting upward (UP),
- DI2 for downward hoisting (DOWN),
- DI3–DI4 for horizontal travel (EAST/WEST),
- DI5 for triggering an emergency stop (STOP MAIN1 or STOP MAIN2 relays).

Emergency shutdown capability is provided via redundant stop relays (e.g., STOP MAIN1 and STOP MAIN2), which are routed to digital input terminals (e.g., DI4) of the VFD to execute safe stop procedures through programmable logic or Safe Torque Off (STO). Auxiliary relay outputs (e.g., R0, R1, R2) are available for secondary functions such as horn activation, speed level

selection, or operational interlocks. Shared common terminals (COM1–COM5) facilitate reference grounding, and internal inline fuses (e.g., 10AF, 5AF) protect the system against overcurrent damage.

The wireless control system significantly improves ergonomic operation by allowing untethered control of crane motions. Its integration with the ACS880-01 VFD ensures precise execution of commands, including ramping, braking, and safety protocols, enhancing operational safety and flexibility.



Figure 3.13 Telecrane Remote control system

### 3.5 Adaptive Programming for Predictive Protection of Crane Overload and Ramping Control

To enhance the operational safety and mechanical integrity of the overhead crane at the Baganuur motor repair workshop, a customized Adaptive Program was developed and implemented using the ABB Drive Composer environment. The purpose of this program is to extend beyond the drive’s embedded protections by enabling predictive, real-time control strategies tailored to the crane’s load conditions.

#### 3.5.1 Embedded Protections of the ACS880 Drive

The ACS880 series VFD includes a range of embedded protection features that are designed to prevent the motor, drive, and connected systems under abnormal operating conditions. The drive incorporates both internal and external supervision mechanisms to ensure comprehensive system protection. Internal supervision monitors the drive's own components, including DC link voltage, heatsink temperature, IGBT status, and internal current sensors, enabling prompt detection of electrical or thermal faults. External supervision extends this protection to connected systems by monitoring motor temperature (via sensors), encoder feedback, input phase conditions, and braking circuits. These include:

- Overcurrent protection (fault code 2310): The drive monitors the motor current continuously and trips if it exceeds the pre-defined limit, thereby preventing thermal and mechanical stress on both the motor and power electronics.
- Overvoltage and undervoltage protection (codes 3210 and 3310): These protections monitor the DC link voltage and respond to fluctuations caused by supply disturbances or regenerative conditions. If voltage levels break safe operating limits, the drive disconnects to prevent component damage.
- Short-circuit and ground fault detection: Instantaneous fault detection logic is used to trip the drive in the event of phase-to-phase, phase-to-ground, or internal short circuits. This fast-acting protection minimizes the risk equipment failure.
- Thermal protection (fault codes 4210 and 4310): The system actively monitors both the internal heatsink temperature and the motor temperature (either calculated or sensor-based) to prevent overheating. If critical temperature thresholds are exceeded, the drive initiates a controlled shutdown.

### **3.5.2 Predictive Overload Protection Program**

According to the engineers, typical failure cases were when an overload occurs, the crane halts entirely and requires manual intervention to resume operation. This shutdown is typically triggered at severe overload levels, often approaching 200% of the motor's rated current, by which point significant thermal and mechanical stress has already been imposed on the system. The predictive protection measure is designed to protect the motor from sustained overload stress.

The predictive overload protection logic is implemented using adaptive programming blocks that dynamically monitor operating conditions and initiate preventive slowdowns before an actual fault occurs. The core of this logic is centered on real-time supervision of motor current (P1.7) compared against a set threshold.



*Figure 3.14 Adaptive Programming logic for Predictive overload protection*

### **3.5.3 Dynamic Acceleration and Deceleration Ramping**

To enhance operational smoothness during heavy load handling, the program implements a dynamic ramping logic that adjusts both acceleration and deceleration times in real time based on current draw.

The core of this logic monitors motor current (P1.7) and compares it against a threshold value using a Greater Than block with 2 A hysteresis. When the current exceeds the predefined limit for more than 3 seconds, a TON (on-delay) timer triggers an SR (Set/Reset) latch, activating a Boolean flag that indicates HeavyLoadMode.

Once latched, this signal is used to modify the drive's acceleration and deceleration behavior through two Switch Value blocks:

- The first block overrides the default acceleration time (P23.12) by selecting an extended value (calculated as  $P23.12 \times 2$ ), effectively doubling the ramp-up time under heavy load conditions.
- The second block performs the same logic for deceleration time (P23.13), applying a gentler slowdown slope ( $P23.13 \times 2$ ) when required.

This dynamic adjustment ensures smoother motion under elevated load, reducing mechanical stress on components such as the hoisting drum, gear assembly, and crane frame. When the load condition normalizes, determined by the motor current dropping below the defined threshold, the system resets the HeavyLoadMode flag, automatically restoring default ramp parameters.

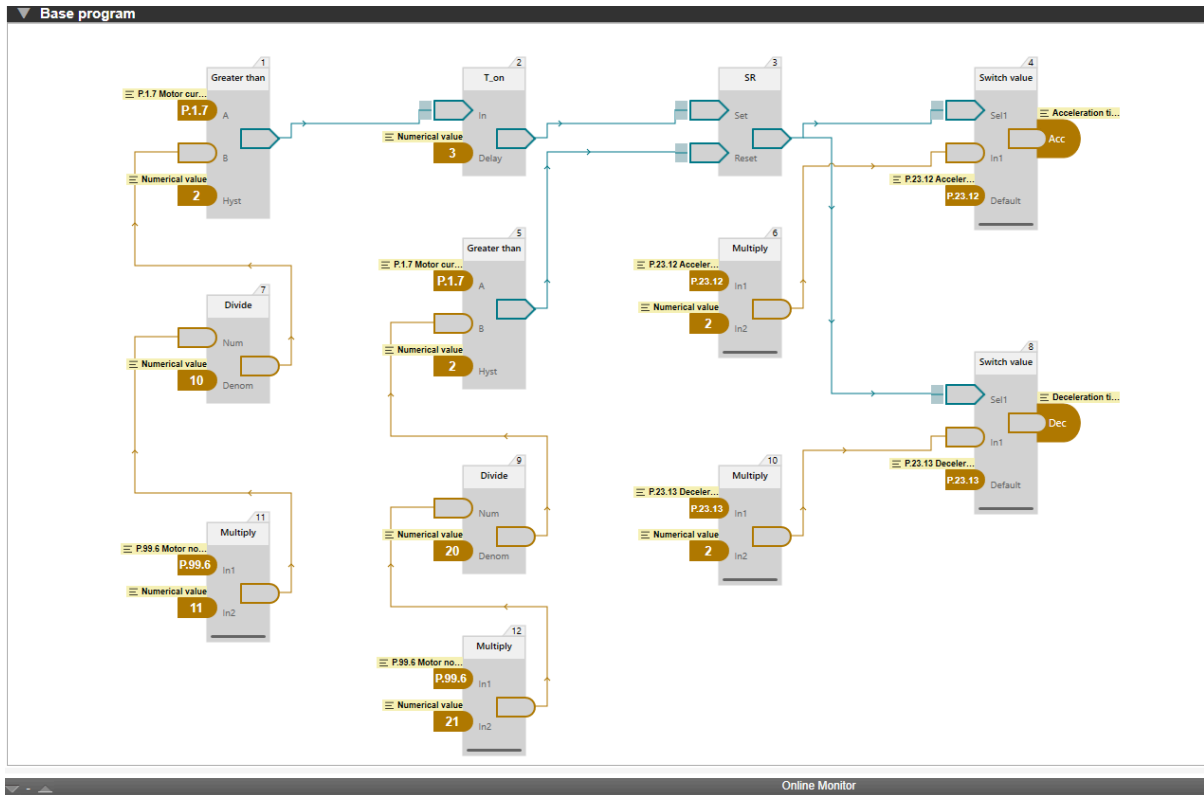


Figure 3.15 Adaptive Programming logic for Dynamic Ramping

### 3.6 Cost-Benefit Analysis of Retrofitting ABB ACS880-01 VFD into the Overhead Crane System

To assess the economic viability of modernizing the 40-year-old overhead crane system, a cost-benefit analysis was conducted for the installation of an ABB ACS880-01 variable frequency drive (VFD). The original crane utilizes an 11 kW squirrel cage induction motor operating under direct-on-line (DOL) control. The proposed retrofit includes an 18.5 kW-rated ACS880-01 VFD, selected to provide adequate thermal and overload margins.

#### 3.6.1 Operational Assumptions

The crane is assumed to operate 8 hours per day, 5 days per week, over 50 weeks per year, amounting to approximately 2,000 operating hours annually. The local electricity tariff is €0.07 per kilowatt-hour. Energy savings with VFD integration are estimated at 20–25%, consistent with empirical studies of similar hoisting applications that experience frequent start-stop cycles, partial loads, and idle running.

#### 3.6.2 Energy and Cost Saving Estimation

Prior to retrofitting, annual energy consumption is estimated as:

$$\text{Energy}_{\text{before}} = 11 \text{ kW} \times 2,000 \text{ h} = 22,000 \text{ kWh/year}$$

$$\text{Cost}_{\text{before}} = 22,000 \text{ kWh} \times \text{€}0.07/\text{kWh} = \text{€}1,540/\text{year}$$

With a conservative 25% reduction in energy consumption, the annual savings amount to:

$$\text{Energy}_{\text{Saved}} = 0.25 \times 22,000 = 5,500 \text{ kWh/year}$$

$$\text{Cost}_{\text{Savings}} = 5,500 \text{ kWh} \times \text{€}0.07 = \text{€}385$$

### 3.6.3 Investment Costs

The estimated cost of the VFD and associated integration is detailed below:

Item	Estimated Cost (€)
ABB ACS880-01 VFD (18.5 kW)	2,000
Brake resistor	300
Control panel integration	400
Installation and wiring	300–500
<b>Total Estimated Cost</b>	<b>€3,000–€3,200</b>

*Table 3.1 Cost estimation*

### 3.6.4 Payback period and Financial Evaluation

The simple payback period is calculated as follows:

$$\text{Payback}_{\text{Period}} = \text{€}3,000 / \text{€}385 \approx 7.8 \text{ years}$$

Although the payback period is relatively long under current energy pricing, the retrofit brings several non-monetary benefits that enhance overall feasibility:

- **Reduced mechanical wear:** Smooth acceleration and deceleration minimize stress on mechanical components, reducing maintenance costs and extending system life.
- **Improved reliability:** The VFD's built-in protections and diagnostics decrease downtime, which is critical given the crane's essential role in workshop operations.
- **Enhanced control and safety:** Adaptive speed control improves handling precision, reducing the risk of load swings and accidents.

Furthermore, sensitivity analysis indicates that even a modest rise in electricity prices would substantially shorten the payback period. For instance, at €0.10/kWh, the payback drops to approximately 5.7 years.

## **4. Results and Discussion**

### **4.1 Operational Improvements**

#### **4.1.1 Smoothness and Accuracy of Movement**

Prior to the installation of the Variable Frequency Drive (VFD), the overhead crane's motion was characterized by abrupt acceleration and deceleration, particularly during lifting and trolley movement according to engineers Munkhnasan and Naranbaatar at Baganuur workshop. This led to rough positional control and increased mechanical wear on components such as gearboxes and brakes. With the integration of the ABB ACS880-01 drive and its Direct Torque Control (DTC) technology, the crane achieved major improvement in motion control. The VFD allowed for controlled speed ramping, which lowered the jolting movements, particularly under no-load and light-load conditions. This enhancement reduced mechanical stress while also enabling operators to execute finer adjustments, improving the precision of hook positioning during load handling.

#### **4.1.2 Load Swing Reduction**

While engineers did not consider pre-retrofit load swing to be excessive, the abrupt motion transitions which created slight load/hook sway were identified as a safety concern. The introduction of the VFD addressed this by allowing for slower movement, smoother acceleration and deceleration profiles. This adjustment reduced the kinetic impulse imparted to the suspended load, minimizing the tendency of the 5-tonne and 20-tonne hooks to swing. Improved motion control contributed to greater load stability during both lifting and travel, an important enhancement in high-elevation operations and when precise placement was required. This refinement in swing control led to safer crane operation, and more accurate and effective load transfers

#### **4.1.3 Improved Brake Handling**

The addition of the VFD also brought noticeable improvements in how the crane's brake system operates. Previously, the brake would engage and release based on fixed delays or external relays, which sometimes caused load shifts or harsh stops. With the VFD, the brake now works in better coordination with the motor.

Instead of releasing the brake too early or engaging it too suddenly, the VFD ensures that the brake only releases after the motor starts producing enough torque, and only engages once the crane has fully stopped. This makes the overall motion smoother and prevents sudden jerks during lifting or lowering.

As a result, the brake components experience less wear, reducing the need for frequent maintenance. It also makes crane movements safer and more predictable, especially when stopping a heavy load or during downward motion.

## **4.2 Safety Enhancements**

### **4.2.1 Controlled Acceleration and Deceleration**

An important safety enhancement introduced through the VFD retrofit was the implementation of programmable acceleration and deceleration ramps. Under the previous starter system, the crane experienced instantaneous torque application upon motor energization, leading to mechanical stress on components and unpredictable load dynamics. With the ACS880-01 drive, these transitions are now precisely managed through ramp-time parameters and braking logic. This functionality not only protects mechanical assemblies, such as couplings, drum brakes, and motors, but also enhances the safety of operators working in proximity to the crane by reducing the likelihood of sudden, unexpected movements during crane operation. Additionally, the reduced shock loading contributes to longer service life of components and less frequent maintenance interventions.

### **4.2.2 Emergency Handling**

The retrofit also introduced a more effective and coordinated emergency handling protocol. In the previous configuration, emergency stop scenarios would result in an immediate disconnection of power, often causing torque spikes, uncontrolled deceleration, and electrical faults such as DC bus overvoltage due to regenerative braking effects. These reactions not only endanger equipment but also introduce safety hazards for nearby personnel. The current system, enabled by the ACS880-01, integrates emergency stop functionality through a dedicated digital input (e.g., DI4) configured to trigger a rapid yet controlled deceleration curve. During such events, the drive actively manages torque reduction while redirecting regenerative energy to an external braking resistor, avoiding electrical overstress and mechanical instability.

### **4.2.3 Fault Supervision and Diagnostic Capabilities**

The ACS880-01 drive introduces an advanced layer of internal and external system monitoring through its integrated fault supervision and diagnostic framework. Unlike the previous system, which relied heavily on manual intervention and discrete protection relays, the VFD has integrated supervision functions directly within its control logic and parameter structure.

Real-time monitoring is continuously applied to parameters such as DC bus voltage, output current, supply phase loss, motor temperature, and drive overheating. This allows the drive to react preemptively to unsafe operating conditions. Common protections include overvoltage,

undervoltage, overcurrent, earth fault, motor stall, and overload scenarios, each of which can trigger predefined protective actions or generate warnings depending on severity.

The drive's firmware (parameter groups: 04. Warnings and Faults, 05. Diagnostics, 31. Fault Functions, and 32. Supervision) provides an extensive library of fault codes and alarm messages, which are accessible via the control panel or remotely through Drive Composer. In addition, the drive supports programmable fault responses such as coast stop, ramp stop, automatic restart, or external acknowledgment, ensuring that recovery strategies align with the operational context and safety requirements.

The ability to log and retrieve historical faults enhances troubleshooting accuracy, allowing operators to diagnose the root cause of failures without guesswork.

Collectively, this built-in diagnostic ecosystem enhances the crane's reliability, minimizes downtime, and aligns the system with modern standards for intelligent fault handling and equipment protection.

### **4.3 Response Time and Productivity**

The transition from a conventional relay-based control system to a Variable Frequency Drive (VFD)-centered architecture improves in both response time and operational productivity. In the previous system, command execution relied on electromechanical relays and contactors to manage functions such as motor start-up, direction reversal, and stop operations. These components inherently introduced latency due to their mechanical switching nature and were prone to contact wear, leading to reduced responsiveness and occasional reliability issues. The VFD-centered system delivers smoother and more controlled operation, with a measurable reduction in movement speed.

In the upgraded system, the ABB ACS880-01 drive serves as the central controller for motion execution, processing inputs electronically through high-speed digital input terminals. While the wireless Telecrane F24 series remote control system continues to utilize relay outputs at the receiver unit, these relays now serve solely as logic-level signal providers. They interface with the VFD's input terminals to initiate motion commands, such as lifting, lowering, or directional travel, without physically switching motor power. The VFD governing motor behaviour, applies programmable ramp profiles and torque limits to ensure controlled transitions, which inherently moderates acceleration and top speed.

As a result, the crane's movements, while slower, are far more stable and predictable. Operators benefit from improved positional control, particularly during load placement or when operating near obstacles. The reduction in speed has also contributed to enhanced safety, minimizing abrupt load shifts and reducing the risk of overshoot or load swing. While cycle times for certain tasks may be

longer than before, the improved accuracy has reduced the need for repeated corrective maneuvers.

The overall productivity impact is nuanced. In scenarios where speed was previously prioritized over precision, a slight decline in throughput may be observed. However, in tasks requiring accurate placement, delicate handling, or frequent directional changes, the improved control has minimized errors and improved task quality. The reduction in stress on mechanical components and increased confidence for operators also contribute to longer-term operational gains, including reduced downtime and extended equipment life.

In summary, although the crane's maximum speed decreased after the VFD installation, this trade-off has brought substantial improvements in motion smoothness, load control, and operational safety, factors that collectively support more consistent and sustainable productivity in the long term.

#### **4.4 Comparative Analysis: Before vs After VFD**

Comparing the crane's performance before and after the retrofit helps to better understand the practical outcomes of switching from a star-delta starter to a VFD-based system. The previous setup, while functional and relatively simple, relied on fixed-speed control through mechanical contactors. It allowed the crane to operate at full speed but offered limited control during acceleration, deceleration, and emergency stops. Because of the sudden application of torque when power was applied, this often led to mechanical jolts, noticeable load swing, and increased stress on the gearbox, couplings, and brakes. Over time, these effects also contributed to more frequent maintenance needs and occasional reliability issues.

In contrast, the ABB ACS880-01 drive introduced variable speed control and digital signal processing, which made the crane's motion more gradual and controlled. Acceleration and braking could now be fine-tuned through ramp settings, reducing abrupt mechanical load transitions and making movements more predictable. This was especially helpful when handling loads at height or positioning them in tight spaces, where smoother control improved both safety and operator confidence.

It's true that the crane operates more slowly after the retrofit, mainly because the VFD limits the acceleration rate to preserve mechanical integrity and reduce peak power draw. At first, this slower pace might seem like a step back, particularly when operators are accustomed to full-speed travel. However, the improved handling accuracy helps avoid overshooting, bouncing, or unintended swinging, which means fewer corrections are needed and overall task completion can still be

efficient. For delicate or repeated lifting tasks, the gain in control arguably outweighs the slight loss in speed.

The energy efficiency aspect is also worth noting. Unlike the original system, which always ran the motor at full voltage regardless of load, the VFD adjusts power delivery based on torque demand and speed reference. This not only reduces unnecessary energy use during low-load or standby periods but also allows for better thermal performance, which contributes to longer motor life. Additionally, the VFD's built-in diagnostics and fault supervision functions give early warnings of potential issues, reducing unplanned downtimes and helping plan maintenance more effectively.

Overall, while the change introduced some adjustments for operators, the system now performs with greater consistency and safety. The crane feels less aggressive but more deliberate, which can be a significant advantage in environments where precision and reliability are more important than speed alone. This kind of control flexibility also opens the door for further system improvements in the future, such as multi-speed presets, load-based speed profiles, or integration with safety PLCs, all of which would have been difficult to implement in the older configuration.

#### **4.5 Reliability Enhancement and Reduced Downtime**

In the context of an industrial workshop where the crane is expected to operate consistently throughout the workday, system reliability is a critical performance requirement. Prior to the retrofit, the crane's control system was largely based on relay-driven logic and electromechanical starters, which had served for several decades. While functional, this setup became increasingly unreliable over time. Contact degradation, coil failures, and inconsistent relay operation, often influenced by temperature changes, humidity, or voltage instability, led to intermittent faults and unplanned stoppages. These failures were disruptive to the workflow and required manual intervention, frequently involving time-consuming inspections and part replacements.

With the installation of the ABB ACS880-01 VFD, a number of changes were introduced that directly improved the system's reliability. One of the most immediate improvements was the reduction in mechanical switching components. The relay responsible for the 5-tonne hoist unit, was renewed during the retrofit for functional control. The actual motor control is handled entirely within the drive itself. By shifting the main control logic to the VFD's internal firmware and digital I/O system, the number of potential failure points has been significantly reduced, resulting in a more stable and maintainable setup with minimal downtime.

The VFD now actively monitors operating conditions such as current, voltage, temperature, and fault events. Built-in protections respond automatically through either controlled shutdown or, when

suitable, auto-reset procedures, reducing the need for manual intervention and preventing minor issues from escalating.

The inclusion of event logs and fault tracking could also improved maintenance practices, allowing technicians to quickly diagnose issues using real-time data rather than relying solely on visual inspections or operator reports.

So far, no major unplanned failures have been reported since the retrofit. The workshop has experienced consistent crane availability, even during periods of extended use. In practical terms, the system has moved from a reactive maintenance model to a more predictive and preventive one, aligning better with modern industrial expectations for reliability.

#### **4.6 Adaptive Programming Setup and Potential Use**

As part of the broader control system upgrade, adaptive programming was configured within the ABB ACS880-01 drive, not as a core operational feature, but rather as an optional logic layer intended to enhance protection and motion handling if needed. Specifically, logic blocks were prepared to enable slow-down behavior based on torque feedback, with the aim of reducing swing or mechanical stress in situations where load inertia exceeds predefined thresholds. However, this programming was not activated in the final operational configuration and no field data was gathered to assess its performance.

Even so, its inclusion reflects a readiness for more advanced crane behavior management in the future. Adaptive programming in the ACS880 platform allows users to create conditional control sequences using internal drive parameters and logic blocks—without requiring external PLCs or rewiring. In a workshop environment like Baganuur's, where operating conditions can vary based on load size, task type, or scheduling pressure, having this logic layer pre-configured offers flexibility for future adjustments.

Although no measurable outcomes were observed during the scope of this thesis, the groundwork for implementation has been laid. Should issues such as frequent load sway, abrupt deceleration, or unbalanced loading begin to affect productivity or safety, the existing logic could be tested and adapted with minimal disruption. From a design and engineering standpoint, the inclusion of adaptive programming reflects a forward-compatible approach that anticipates future system tuning needs without requiring additional hardware investment.

#### **4.7 Economical Considerations**

Although the estimated payback period for the VFD retrofit is around 7–8 years based on energy savings alone, the overall benefits go far beyond electricity costs. Installing a variable frequency

drive like the ABB ACS880-01 significantly improves how the overhead crane operates, especially in an aging system.

One of the main advantages is the smooth start and stop that the VFD provides. Unlike the old direct-on-line starting method, which causes sudden movements and mechanical stress, the VFD gently ramps the motor speed up and down. This reduces wear on parts like the gearbox, brake system, and ropes, helping them last longer and lowering maintenance costs.

The VFD also gives the operator better control over the crane's speed. This makes lifting and lowering loads more accurate and reduces the risk of swinging or damaging goods. In a workshop where the crane is used often and handles important materials, this extra control improves safety and productivity.

Another important benefit is the built-in protection features. The VFD can detect problems like overheating or electrical faults and protect the motor from damage. This helps prevent unexpected breakdowns. Since the crane is critical to the workshop's daily work, avoiding downtime is a big advantage—each interruption could cost more than the VFD saves in electricity.

Finally, if electricity prices increase in the future, the VFD will save even more money each year, shortening the payback period.

## **5. Conclusion and Recommendation**

### **5.1 Summary of Findings**

This thesis examined the performance impact of retrofitting an aging overhead crane at an industrial workshop with an ABB ACS880-01 Variable Frequency Drive (VFD), replacing its previous star-delta starter system. The retrofit was carried out to address long-standing limitations in control precision, safety, and system reliability without altering the crane's mechanical structure.

Following the installation, the most evident improvement was in the smoothness and accuracy of crane movement. By introducing programmable ramp-up and ramp-down parameters, the system enabled more controlled acceleration and deceleration, allowing operators to place loads with greater precision. Compared to the abrupt, full-voltage transitions of the previous system, the crane now operates with more predictable and deliberate motion. While the maximum travel speed decreased slightly, the trade-off resulted in improved handling and reduced need for corrective actions.

One of the most notable outcomes was the control over motion precision, which had previously posed safety concerns, especially during sudden stops. This improvement was achieved through smoother torque application and refined deceleration behavior. Although adaptive programming was not actively implemented in the final control logic, it was configured as a standby feature, with logic blocks prepared for future use. This added a flexible layer of control that could be activated if needed for more responsive load management or predictive braking.

From a safety standpoint, the introduction of a braking resistor provided a far more controlled emergency stop function compared to the previous hard cutoff method. Early challenges with braking behavior, including overshooting and starting faults, were linked to the configuration of 'coast.' This caused the drive to release torque control immediately upon stopping, resulting in uncontrolled deceleration. After adjusting the stop mode and tuning the deceleration profile, the braking response became much more reliable and consistent.

The retrofit also enhanced system reliability through the VFD's built-in diagnostics, thermal protection, and automatic fault handling capabilities and no major unplanned failures were reported following the retrofit.

In summary, the VFD retrofit introduced number of improvements in the crane's operational control, safety, energy performance, and long-term reliability. These benefits were achieved without extensive mechanical modifications, making the solution practical and scalable for similar aging crane systems in workshop environments. While the VFD may take several years to pay for itself through energy savings alone, its full value comes from better performance, fewer repairs, improved safety, and avoiding crane downtime. These long-term benefits make it a smart and practical upgrade for an older overhead crane system.

## **5.2 Contributions to Industrial Crane Optimization**

This thesis presents a practical example of how industrial crane performance can be optimized through targeted electrical control upgrades, particularly within aging systems where full mechanical replacement is neither economical nor necessary. By replacing the original star-delta starter and relay-based control with a Variable Frequency Drive (VFD)-centric system, the study shows that substantial improvements in control accuracy, energy use, safety, and reliability can be achieved using existing infrastructure. The approach adopted, centered on the ABB ACS880-01 VFD, illustrates a modular and adaptable upgrade path suitable for similar crane applications across various industrial environments.

One of the key contributions of this work lies in demonstrating the role of flexible control logic in improving crane responsiveness. Although adaptive programming was not fully integrated into

active operation, its configuration provided a framework for future enhancements, such as torque-based slow-down logic or conditional ramp adjustments during overload or approach-to-limit conditions. This highlights the potential of adaptive logic as a non-invasive way to extend the functional range of standard VFD installations, particularly in systems that encounter varying loads or require more refined motion control.

The study also addressed safety through configuration-based improvements rather than hardware expansion. For example, braking behavior was stabilized after resolving initial issues related to configuration of coast. Once corrected, the system offered reliable deceleration and energy dissipation during emergency stops using the braking resistor, reducing mechanical stress and eliminating overvoltage faults. These refinements align with current industrial safety practices, offering a low-cost way to enhance protection without external safety PLCs or dedicated braking systems.

Overall, this project contributes a replicable strategy for modernizing aging crane systems through intelligent control upgrades. It bridges the gap between theoretical VFD capabilities and real-world workshop conditions, showing that targeted retrofits can deliver measurable improvements in performance, reliability, and operational consistency. The work offers a grounded and cost-conscious reference for other industrial users seeking to extend the lifespan and effectiveness of existing lifting equipment through smart, scalable upgrades.

### **5.3 Suggestions for future research**

While this thesis has demonstrated the technical and practical benefits of retrofitting an aging overhead crane with a Variable Frequency Drive (VFD)-based control system. However, as with many applied engineering projects, the outcomes achieved here open the door to additional research opportunities that could refine, expand, or deepen the impact of such retrofits in other settings. The following areas offer particularly promising directions for further exploration.

1. One area involves the continued investigation of energy efficiency in real-time industrial crane operations. The parameter group 45 (Energy Efficiency) provides real-time insights into power consumption and the readings can be systematically analyzed and compared over time. Key read-only parameters within this group, such as total energy consumption, motor efficiency, and cumulative energy savings, allow operators and engineers to assess performance relative to a baseline. For the purposes of analysis, the Direct-On-Line (DOL) starter is used as the reference model, representing constant full-voltage operation without speed or torque regulation.

Energy efficiency in crane operations is influenced by loading conditions. During steady hoisting, power usage increases predictably with speed, but rapid changes during acceleration or deceleration can cause short power spikes, especially with variable loads. These fluctuations are affected by factors like mass, inertia, and friction. VFDs help manage this by applying smooth ramping and precise torque control, reducing both energy use and mechanical stress. Future studies could explore real-time energy monitoring and adaptive control strategies to further enhance efficiency

2. Further research on this project would be to integrate the 20-tonne hoist unit into the VFD control framework. At present, only the 5-tonne unit benefits from variable speed control, torque ramping, and braking optimization. Introducing a dedicated VFD for the 20-tonne unit, or coordinating both units under synchronized or parallel drive control, which could unify operational behavior. Research in this direction would help clarify how VFD systems scale across multiple motors in heavy lifting applications and could explore the communication and safety protocols needed for stable coordination between drives.
3. From an electrical perspective, further investigation may be needed into the harmonics and electromagnetic interference (EMI) that VFDs can introduce into older systems. Although this was not a limiting factor in the present case, older crane installations, especially those without shielded cables or modern grounding, may be more susceptible to VFD-induced distortion. Future work could evaluate the impact of switching frequencies and modulation strategies on system stability, as well as the effectiveness of countermeasures like passive or active filters, cable shielding, and proper EMI-compliant layouts.
4. In addition, future studies can conduct a cost-benefit analysis of VFD-based upgrades, including metrics such as return on investment (ROI), payback periods, and total life cycle cost comparisons between partial electrical upgrades and full mechanical replacements. These financial insights would be particularly valuable for industrial facilities considering system upgrade when working within constrained maintenance budgets.

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