

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

BOOKLET ON MOTOR STARTERS

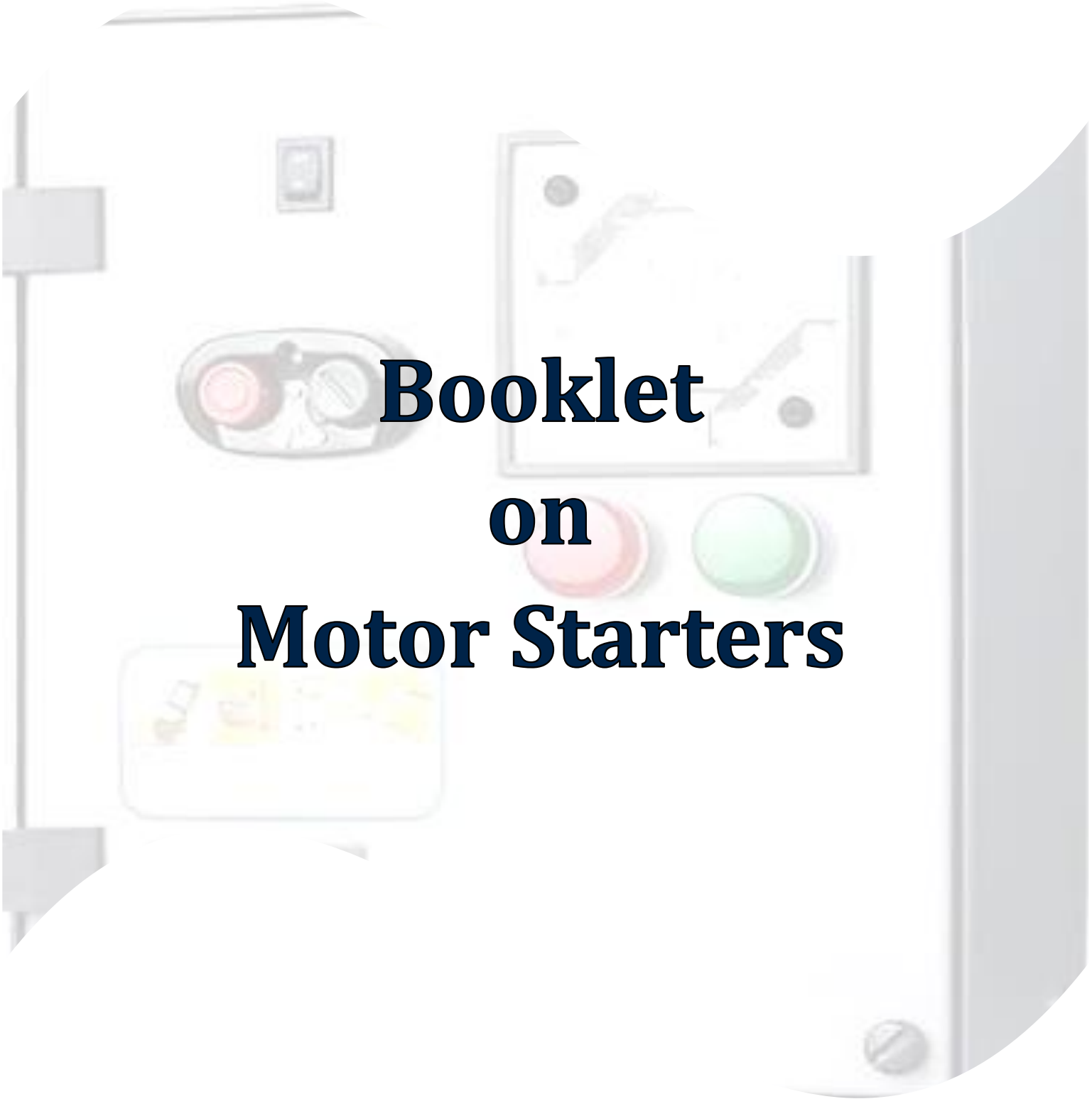
CAMTECH/E/2024-25/EP-04/MOTOR STARTER/1.0

END USER

RAILWAY ELECTRICAL ENGINEERS & TECHNICIANS
DEALING WITH LV INSTALLATIONS

DECEMBER 2024

EXCELLENCE IN MAINTENANCE
INDIAN RAILWAYS
Centre *for* **A**dvanced **M**aintenance **Tech**nology
(CAMTECH)
MAHARAJPURA, GWALIOR - 474005



Booklet on Motor Starters

QUALITY POLICY

"We at RDSO, Lucknow are committed to maintain and update transparent standards of services to develop safe, modern and cost effective railway technology complying with statutory and regulatory requirements, through excellence in research, designs and standards by setting quality objectives, commitment to satisfy applicable requirements and continual improvements of the quality management system to cater to growing needs, demand and expectations of passenger and freight traffic on the railways through periodic review of quality management systems to achieve continual improvement and customer appreciation. It is communicated and applied within the organization and making it available to all the relevant interested parties."

DISCLAIMER

It is clarified that the information given in this booklet does not supersede any existing provisions of Indian Standards (IS) on the subject, related matters, and other existing provisions laid down by the Railway Board, RDSO. This is not a statuary document and instructions given are for the purpose of guidance only. If at any point contradiction is observed, then Indian Standards, regulations issued by Government bodies, Railway Board/ RDSO guidelines shall be referred.

PREFACE

Electric motors are the backbone of modern industries, powering equipment across sectors like manufacturing, energy, and automation. However, effective motor operation depends on the ability to start, control, and protect motors efficiently. This is where motor starters play a crucial role.

CAMTECH has prepared this “Booklet on Lifts” with the objective to disseminate specific information on the subject. This booklet contains Working principles from simple Direct-On-Line (DOL) to advanced Variable Frequency Drives (VFDs), Selection criteria to identify the most suitable starter based on various factors of motor, supply system, load & application requirements etc, calculation of starting currents for clear decision-making, Single-line diagrams for power and control circuits to aid practical implementation and working principle etc. This booklet also includes the general maintenance practices, and troubleshooting common faults for reliable operation.

I am thankful to all field personnel & Shri Himanshu Singh Rajput, SSE/Electrical/ CAMTECH for their efforts in making this booklet useful.

Technological up-gradation & learning is a continuous process. Please feel free to write to us for any addition/ modification in this booklet. We shall highly appreciate your contribution in this direction.

Date: 31.12.2024
CAMTECH/ Gwalior

Himanshu Maheshwari
Director/ Electrical

CONTENT

CHAPTER 1 GENERAL DESCRIPTION 1

1.1 INTRODUCTION 1

1.2 NEED OF MOTOR STARTER 1

1.2.1 Control 1

1.2.2 Reduce High Starting Current 1

1.2.3 Motor Protection by Various Electrical Events 1

1.2.4 Smooth Operation 1

1.2.5 Long Lifespan of Equipment 1

1.3 VARIOUS PROTECTION OF MOTOR BY STARTER 2

1.3.1 Overload Protection 2

1.3.2 Short Circuit Protection 2

1.3.3 Phase Failure Protection 2

1.3.4 Undervoltage Protection 2

1.3.5 Reverse Phase Protection 2

1.3.6 Earth Fault Protection 2

1.3.7 Overheating Protection 2

1.3.8 Mechanical Protection 2

1.4 TYPES OF STARTERS FOR 3 Ph- SQUIRREL CAGE INDUCTION MOTORS 3

1.4.1 Manual Starters 3

1.4.2 Magnetic Starters 4

1.5 COMPARATIVE TABLE OF DIFFERENT TYPES OF MOTOR STARTERS 4

1.5.1 Comparison Between the Manual and Magnetic (Automatic) Motor Starters 5

1.5.2 Comparison Between the Different types of Magnetic Motor Starters 5

1.6 DIFFERENCES BETWEEN MPCB AND MOTOR STARTER 6

1.7 CLASSIFICATION AS PER STANDARDS 7

1.7.1 IEC (International Electrotechnical Commission) Rating 7

1.7.2 NEMA (National Electrical Manufacturers Association) Rating 8

CHAPTER 2 COMPONENTS AND THEIR FUNCTIONS 9

2.1 MAJOR COMPONENTS OF VARIOUS MOTOR STARTERS 9

2.1.1 Power Contactor 9

2.1.2 Thermal Overload Relay/ Protection 10

2.1.3 Circuit Breaker/ Fuse 11

2.1.4 Push Buttons 11
2.1.5 Auxiliary/ Feedback Contacts 11
2.1.6 Time Relay (optional in some starters) 12
2.1.7 Auto-transformer 12
2.1.8 Rectifier in Soft/ VFD Starter 13
2.1.9 DC Bus or Filter 13
2.1.10 Inverter in VFD 13
2.1.11 Heat Dissipation Unit 14
2.1.12 Current and Voltage Sensors 15
2.1.13 Enclosure 15
CHAPTER 3 DIRECT ON LINE (DOL) STARTER 16
3.1 CIRCUITS OF DOL STARTER 16
3.1.1 Power Circuit of DOL Starter 16
3.1.2 Control Circuit of DOL Starter 17
3.1.3 Operation of Motor in DOL Starting Method 17
3.2 Calculation of Current & Toque 18
3.2.1 Current Calculation of Motor 18
3.2.2 Torque Calculation of Motor 18
3.2.3 Toque & Current - Speed Characteristic 19
3.3 ADVANTAGES, DISADVANTAGES AND APLLICATIONS 19
3.3.1 Advantages 19
3.3.2 Disadvantages 19
3.3.3 Applications 19
CHAPTER 4 AUTO-TRANSFORMER STARTER (AUTOMATIC) 20
4.1 CIRCUITS OF AUTO-TRANSFORMER STARTER 20
4.1.1 Power Circuit 20
4.1.2 Control Circuit 21
4.1.3 Operation of Motor with Auto-transformer starter 22
4.2 CALCULATION OF CURRENT & TORQUE 22
4.2.1 Current Calculation of Motor 22
4.2.2 Torque Calculation of Motor 23
4.2.3 Torque – Speed Characteristic 23
4.2.4 Current – Speed Characteristic 24
4.3 ADVANTAGES, DISADVANTAGES AND APLLICATIONS 24
4.3.1 Advantages 24

4.3.2 Disadvantages 25
4.3.3 Applications 25
CHAPTER 5 STAR DELTA STARTER (AUTOMATIC) 26
5.1 CIRCUITS OF STAR-DELTA STARTER 26
5.1.1 Power Circuit 26
5.1.2 Control Circuit 27
5.1.3 Operation of Motor in Star Delta Starter 28
5.2 CALCULATION OF CURRENT & TORQUE 28
5.2.1 Current Calculation of Motor 28
5.2.2 Torque Calculation of Motor 29
5.2.3 Toque – Speed Characteristic 29
5.2.4 Current – Speed Characteristic 30
5.3 ADVANTAGES, DISADVANTAGES AND APPLICATIONS 30
5.3.1 Advantages 30
5.3.2 Disadvantages 30
5.3.3 Applications 31
CHAPTER 6 SOFT STARTER 32
6.1 CIRCUITS OF SOFT STARTER 32
6.1.1 Power Circuit 32
6.1.2 Control Circuit 33
6.1.3 Operation of Motor in Soft Starter 33
6.1.4 Torque – Speed Characteristic 34
6.1.5 Current – Speed Characteristic 35
6.2 ADVANTAGES, DISADVANTAGES AND APLLICATIONS 35
6.2.1 Advantages 35
6.2.2 Disadvantages 35
6.2.3 Applications 35
CHAPTER 7 VARIABLE FREQUENCY DRIVES (VFDs) 36
7.1 CIRCUITS OF VDF STARTER 36
7.1.1 Power Circuit 36
7.1.2 Control Circuit 37
7.1.3 Operation of Motor 37
7.1.4 Torque – Speed and Current – Speed Characteristic 38
7.2 ADVANTAGES, DISADVANTAGES AND APLLICATIONS 39
7.2.1 Advantages 39

7.2.2 Disadvantages 39
7.2.3 Applications 39
CHAPTER 8 SELECTION CRITERIA OF STARTING METHOD 40
8.1 BASED ON POWER CAPACITY OF MOTOR 40
8.2 BASED ON TYPE OF LOAD AND TORQUE REQUIREMENTS 40
8.3 BASED ON SUPPLY SYSTEM CAPACITY 41
8.4 BASED ON COST AND COMPLEXITY CONSIDERATIONS 42
8.5 BASED ON APPLICATION SPECIFIC REQUIREMENTS 43
CHAPTER 9 MANITENANCE & TROUBLESHOOTING FOR COMMON FAILURES 44
9.1 MAINTENANCE 44
9.1.1 General Check Points of Maintenance for Each type of Starter 44
9.1.2 Specific Maintenance Activities for Each Type of Starter 44
9.2 TROUBLESHOOTING 46
9.2.1 DOL Starter 46
9.2.2 Auto Transformer Starter 47
9.2.3 Star Delta Starter 49
9.2.4 Soft Starter 50
9.2.5 Variable Frequency Drives Starter 52
REFERENCE 54
NOTES 55
CONTACT US 56

LIST OF TABLES

Table 1: A Comparative Table of Manual & Magnetic (Automatic) Motor Starters 5
Table 2: A Comparative Table of Different Types of Magnetic Motor Starters 5
Table 3: Comparison between MPCB and Motor Starter 6
Table 4: IEC Rating/ Utilization Category 7
Table 5: NEMA Sizes as per Motor Current & HP 8
Table 6: Starting Method based on Power Capacity of Motor 40
Table 7: Starting Method based on Starting Torque of Load and torque requirements 40
Table 8: Starting Method based on Supply system capacity 42
Table 9 Starting Method based on cost and complexity considerations 42
Table 10: Based on application specific requirements 43
Table 11: A troubleshooting for most common possible issues in a Direct-On-Line (DOL) starter 46
Table 12: A troubleshooting for most common possible issues in an Auto Transformer starter 47
Table 13: A troubleshooting for most common possible issues in a Star-Delta starter 49
Table 14: A troubleshooting for most common possible issues in a Soft starter 50
Table 15: A troubleshooting for most common possible issues in a VFD starter 52

LIST OF FIGURES

Figure 1: Manual Type Motor Starter circuits 3
Figure 2: Typical Motor Starters & their components 9
Figure 3: Pictorial view of Solenoid Type Contactors & Mechanism 10
Figure 4: Cross Sectional view of E Type Contactor and Position of Contacts 10
Figure 5: 3-Pole Thermal Overload Relay and Mechanism 10
Figure 6: Various Protection Devices 11
Figure 7: Push Button and Typical Control Scheme 11
Figure 8: Auxiliary Contactors and its Contacts 11
Figure 9: On Delay Type Electronic Timer & Connection Diagram 12
Figure 10: 3 units of Autotransformer with multiple tapings 12
Figure 11: Typical Silicon controlled rectifier 13
Figure 12: Typical IGBT used in VFD 14
Figure 13: Heat Sink of Power Semiconductor Device like SCRs, IGBTs etc. 14
Figure 14: Various sensors for feedback 15
Figure 15: Metallic Enclosure of Motor Starter 15
Figure 16: Typical 3 phase DOL Starter 16

Figure 17: Control Circuit of DOL Starter 16
Figure 18: Control Circuit of DOL Starter 17
Figure 19: Typical Connections of DOL starter 17
Figure 20: Typical Torque - Speed & Current - Speed Characteristics of Induction Motor 19
Figure 21: Typical Auto-transformer Starter 20
Figure 22: Typical Control Circuit of Auto-transformer Starter 21
Figure 23: Typical Control Circuit of Auto-transformer Starter 21
Figure 24: Typical Current during an Auto-transformer Starter 23
Figure 25: Typical Torque during an Auto-transformer Starter 24
Figure 26: Typical Star Delta Starter 26
Figure 27: Typical Power circuit of Star Delta Motor Starter 27
Figure 28: Typical Control Circuit of Automatic Star Delta Motor Starter 27
Figure 29: Motor Winding Connections (a) Star during Staring (b) Delta during Running 28
Figure 30: Typical Torque during a Star-delta Starter 29
Figure 31: Typical Current during a Star-delta Starter 30
Figure 32: Block Diagram of Typical Soft Starter 32
Figure 33: Typical Circuit of Soft Starter 33
Figure 34: Starting Principle of Soft Starter 34
Figure 35: Torque – Speed Characteristic of Motor in Soft Starter 34
Figure 36: Current – Speed Characteristic of Motor in Soft Starter 35
Figure 37: Typical VDF Starter 36
Figure 38: Circuit of Typical VFD Starter 37
Figure 39: Torque-Speed characteristics in VFD starter with Constant V/f ratio 38
Figure 40: Block Diagram of VDF for Motor Starting 38
Figure 41: Torque & Current-Speed characteristics in VFD starter 38

ISSUE OF CORRECTION SLIP

The correction slips to be issued in future for this handbook will be numbered as follows:

CAMTECH/E/2024-25/EP-04/Starter/1.0/C.S. # XX date-

Where “XX” is the serial number of the concerned correction slip (starting from 01 onwards).

CORRECTION SLIPS ISSUED

Sr. No.	Date of Issue	Page no. & Item no. modified	Remarks

ABBREVIATIONS

ABBREVIATION	FULL FORM
AC	Alternating Current
Aux	Auxiliary
CB	Circuit breaker
COM	Common
CT	Current Transformer
DC	Direct Current
DOL	Direct on Line
DSP	Digital Signal Processor
FC	Fuse Circuit
FLC	Full load Current
GI	Galvanized Iron
HVAC	Heating, Ventilation, and Air Conditioning
IEC	International Electro-technical Commission
IGBT	Isolated Gate Bipolar Transistor
IM	Induction Motor
IP	Ingress Protection
IS	Indian Standard
LRA	Locked Rotor Amperage
MCB	Miniature Circuit Breaker
MCCB	Mold Case Circuit Breaker
NC	Normally Closed
NEMA	National Electrical Manufacturers Association
NO	Normally Opened
NVC	No Volt Coil
OC	Over Current
OEM	Original Equipment manufacturer
OLD	Over Load Relay
PB	Push Button
PLC	Programmable Logic Circuit
PWM	Pulse Width Modulation
RDSO	Research Design Standard Organization
RPM	Revolution per Minute

ABBREVIATION	FULL FORM
SCR	Silicon Controlled Rectifier
SLD	Single Line Diagram
TB	Terminal Block
VFD	Variable Frequency Drive
VVVF	Variable Voltage Variable Frequency

CHAPTER 1

GENERAL DESCRIPTION

The mostly used motor in the industrial applications is squirrel cage type induction motor due to its simple construction, less costly, high reliability, self-starting capability, adjustability and fairly high efficient. Therefore, **this booklet "on Motor starters"** is prepared for **Squirrel Cage type 3-Ph Asynchronous Motor (Induction Motor) which is generally used for pumps in General Service Dept. of Indian Railways**.

1.1 INTRODUCTION

A motor starter is an electrical device, used to start, control, and protect electric motors. It is provided to regulate the initial high inrush current and provide protection against overloads and faults. Motor starters are commonly used in industrial, commercial, and residential applications to increase the motor efficiency, safety, and lifespan.

1.2 NEED OF MOTOR STARTER

The need for a motor starter arises from the specific requirements and challenges associated with operating electric motors. Some of the features are given to show why motor starters are essential:

1.2.1 Control

The control function is mainly carried out by a starter. It controlled the starting and stopping of the motor by means of opening and closing of the power electrical circuit through contactors.

1.2.2 Reduce High Starting Current

When an electric motor starts, it draws a significantly higher current (up to 6-8 times its normal operating current). This can damage motor windings and affect the stability of the electrical system. A motor starter limits and controls this inrush current.

1.2.3 Motor Protection by Various Electrical Events

Motor starters protect the motor from damage caused by Overcurrent (overload & Short circuit), Phase Failure, Under-voltage, Reverse Phasing etc by monitoring the voltage & current flow and disconnecting the feed power if necessary. This prevents overheating and potential failure of motor and also ensure the safety of personal & equipment.

1.2.4 Smooth Operation

Motor starters allow motors to start, stop, and reverse smoothly, reducing mechanical stress on the motor and connected equipment, such as belts and gears by controlling the torque.

1.2.5 Long Lifespan of Equipment

By minimizing electrical and mechanical stresses, motor starter extends the lifespan of motors and reduce maintenance costs.

1.3 VARIOUS PROTECTION OF MOTOR BY STARTER

A motor starter provides protection to the motor and the connected system by safeguarding it against various electrical and mechanical risks. Here's how a motor starter ensures protection:

1.3.1 Overload Protection

- This device monitors the motor's current and disconnects the power supply if the current exceeds a threshold limit for the period of time defined by various standards.
- Prevents overheating of motor windings due to prolonged overload condition.
- Typically, this protection is done by using thermal or electronic overload relays.

1.3.2 Short Circuit Protection

- This device detects the excessive current caused by a short circuit and immediately disconnects the motor from the power supply.
- This uses fuses or circuit breakers (MCCB, MCB etc.) to prevent the damage to the motor and connected equipment.

1.3.3 Phase Failure Protection

- It detects loss of one or more phases in a three-phase system.
- It ensures the motor to shut down to prevent unbalanced currents, resulting overheating.

1.3.4 Under-voltage Protection

- It monitors voltage levels and prevents the motor from operating at low voltages, which can cause insufficient torque and overheating.
- This restarts the motor only after voltage returns to nearly normal levels which is given as a percentage of standard supply voltage or rated voltage of device.

1.3.5 Reverse Phase Protection

- This device detects incorrect phase sequence or reverse rotation in three-phase motors.
- It ensures safe operation by preventing damage to equipment that depends on correct motor rotation.

1.3.6 Earth Fault Protection

- This device detects leakage currents or insulation faults and disconnects the motor to prevent damage and ensure safety.

1.3.7 Overheating Protection

- It monitors the motor's temperature using thermistors or temperature sensors.
- This shuts down the motor, if it overheats to prevent damage to motor.

1.3.8 Mechanical Protection

- It reduces mechanical stress by ensuring smooth starting and stopping, preventing damage to gears, belts, and other connected equipment.
- This prevents sudden torque changes, which could cause mechanical failure.

These protective features make motor starters essential for safe, reliable, and efficient motor operation across various applications.

1.4 TYPES OF STARTERS FOR 3 Ph- SQUIRREL CAGE INDUCTION MOTORS

There are several types of motor starters. However, the two most common types are manual & magnetic type.

1.4.1 Manual Starters

Manual starters are devices that are operated manually. These starters are extremely simple and easy to operate and do not require expert technical knowledge. The starter includes a button (or rotary knob) which enables a user to turn the connected equipment on or off. The buttons feature mechanical linkages, which make the contacts open or close to start or stop or control the motor. Such as DOL starter, Manual Auto-transformer starter, Star-delta starter etc. Generally these types of starters are not in use or very limited use.

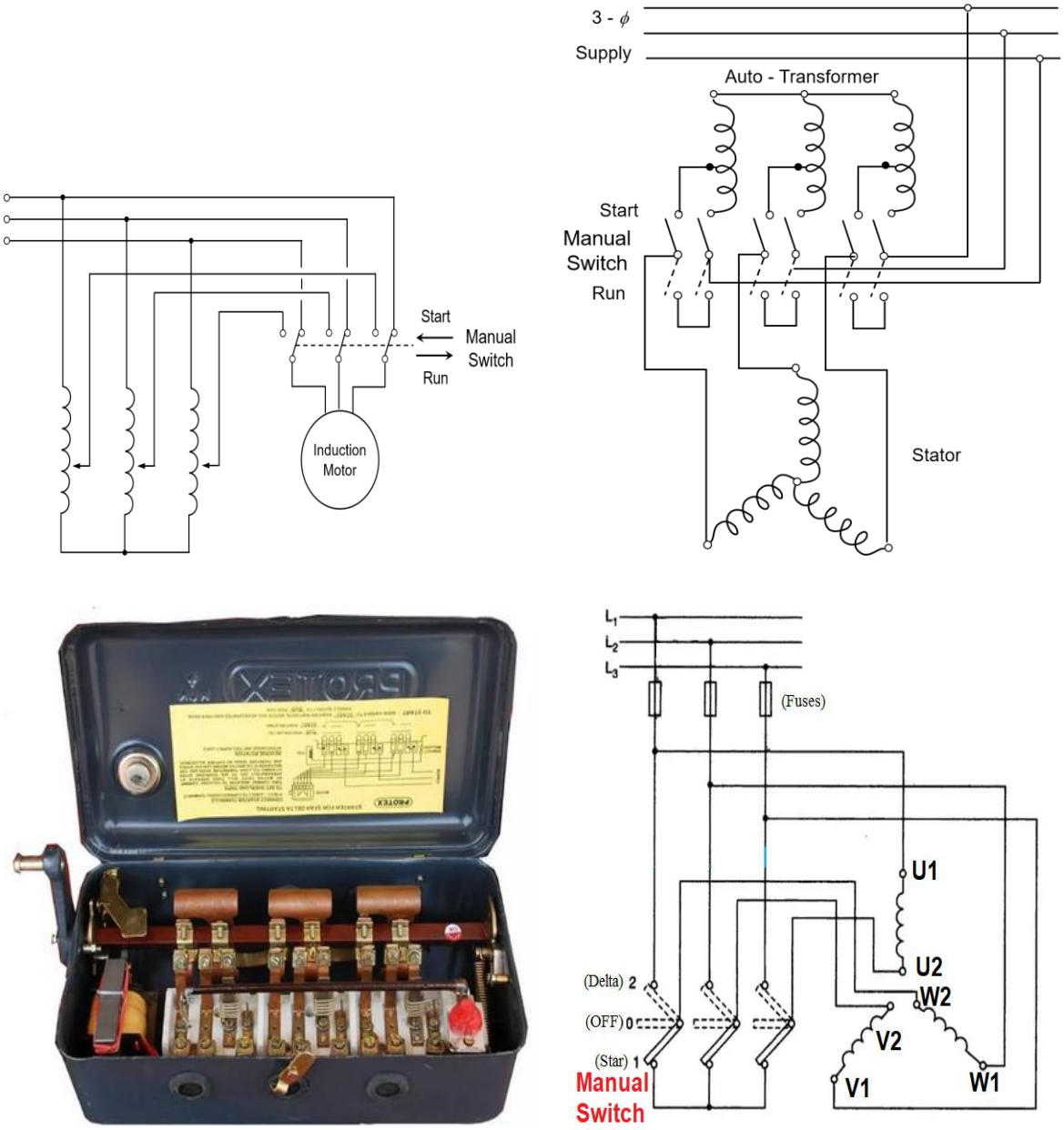


Figure 1: Manual Type Motor Starter circuits

1.4.2 Magnetic Starters

This is another main type of motor starters. These are operated electromagnetically, it means that the motor connected to the starter is typically started and stopped using an equally or lower voltage of supply to the motor. The magnetic starter also has an electrical contactor and overload relay to protect the device from too much current or thermal relay for overheating etc.

These types of starters are similar to manual starters but with additional contactors to control or start or stop the motor automatically to limit the human involvement.

Some other types of starters based on their method of controlling the electrical parameters, functionality, and applications are soft starters and variable frequency drives.

Each type serves specific purposes depending on motor size, load requirements, and operational conditions. Here are the common types of magnetic motor starters:

1.4.2.1 Direct on line (DOL) starters

This starter connects the motor directly to the power supply. They are simple, cost-effective, and easy to install. These are suitable for small motors with low starting current requirements. They have drawback like causes high inrush current during startup and voltage dip in supply which may not be suitable for large motors.

1.4.2.2 Automatic star delta starters

It starts the motor in a star connection (reducing voltage) and transitions to a delta connection for full-load operation. They reduce starting current and limits electrical stress. These are commonly used for Low to medium voltage large motors having light load during starting in industries. This type of starters requires more space and wiring complexity compared to DOL starters, reduced starting torque w.r.t. DOL.

1.4.2.3 Automatic auto-transformer starters

It uses an auto-transformer to reduce the voltage during startup. It offers multiple voltage reduction levels as per available tapings to reduce starting current. They are suitable for large motors where a significant reduction in starting current is needed. In these starters by reducing the starting voltage torque decreases which results in higher cost and complexity.

1.4.2.4 Soft starters

It gradually increases voltage to the motor, providing a smooth acceleration. They reduce mechanical stress, prevents electrical surges and smoothen the starting current and starting torque. Such type of starters is ideal for applications requiring smooth starts, such as conveyor belts and pumps. These are more expensive than traditional starters.

1.4.2.5 Variable frequency drive (VFD) starters

It controls both the voltage and frequency supplied to the motor, allowing precise speed control. They provide a soft start, speed regulation, and energy efficiency. It is used in advanced systems requiring speed control, such as elevators and HVAC systems. These are higher in cost and complexity.

1.5 COMPARATIVE TABLE OF DIFFERENT TYPES OF MOTOR STARTERS

1.5.1 Comparison Between the Manual and Magnetic (Automatic) Motor Starters

Table 1: A Comparative Table of Manual & Magnetic (Automatic) Motor Starters

Starters / Aspect	Manual Motor Starter	Magnetic Motor Starter
Operation	Operated manually by physically flipping a mechanical latch or lever.	Operated electrically via a control circuit (like contactors).
Control Voltage	Does not require external control voltage, purely mechanical.	Requires external control voltage for the electromagnetic coil.
Starting Mechanism	Simple, direct on/off switching.	Uses electromagnetic relays, contactors to start, stop & control the motor.
Automation Capability	Not suitable for automation, requires manual intervention.	Can be automated using control circuits, timers, or PLCs.
Overload Protection	Typically includes built-in overload protection.	Includes overload relays as part of the system.
Remote Operation	Cannot be operated remotely.	Can be operated remotely.
Size and Complexity	Compact and simple design.	Larger and more complex due to additional components.
Applications	Best for small, simple motor setups with low automation needs.	Suitable for industrial and automated motor control applications.
Cost	Generally lower cost due to simplicity.	Higher cost due to complexity and additional components.
Maintenance	Minimal maintenance required.	Requires periodic maintenance of relays and contacts.
Safety Features	Basic safety features.	Advanced safety features like interlocks and auxiliary contacts.
Reliability	Reliable for basic operations but limited for complex systems.	More reliable for high-demand and automated operations.

1.5.2 Comparison Between the Different types of Magnetic Motor Starters

Table 2: A Comparative Table of Different Types of Magnetic Motor Starters

Starters / Aspect	Direct On Line (DOL)	Star-Delta Starter	Auto-transformer Starter	Soft Starter	Variable Frequency Drive (VFD)
Working Principle	Directly connects motor to full supply voltage	Starts in star (reduced voltage) then shifts to delta (full voltage)	Reduces initial voltage using an auto-transformer	Gradually increases motor voltage electronically	Varies both voltage and frequency to control motor speed

Starters / Aspect	Direct On Line (DOL)	Star-Delta Starter	Auto-transformer Starter	Soft Starter	Variable Frequency Drive (VFD)
Voltage Reduction Method	None	Star connection reduces line voltage by $1/\sqrt{3}$	Transformer taps provide selectable voltage levels	Thyristors (or SCRs) ramp up voltage smoothly	PWM (Pulse Width Modulation) adjusts output
Inrush Current	Very High (5-8 x FLC)	Moderate (Reduced during start)	Low (Significantly reduced at start)	Low (Controlled acceleration)	Very Low (Precise current control)
Complexity	Very Low (Simple wiring)	Moderate (Additional contactors and timer required)	High (Transformers and switching devices needed)	Moderate (Electronic circuitry)	High (Advanced electronics)
Cost	Low	Moderate	High	High	Very High
Energy Efficiency	Low	Moderate	Moderate	High	Very High
Applications	Small motors with low starting torque requirements like pumps, fans, and mixers	Industrial equipment like conveyors, crushers, and heavy machinery requiring moderate starting torque	Large industrial motors requiring multiple levels of voltage reduction during startup	Applications requiring smooth starts, such as water pumps, compressors, and conveyor belts	Modern automation systems like elevators, HVAC, and machines requiring precise speed and torque control

1.6 DIFFERENCES BETWEEN MPCB AND MOTOR STARTER

Both Motor Protection Circuit Breakers (MPCBs) and motor starters are used with motors, their functions and components are different.

Table 3: Comparison between MPCB and Motor Starter

Items / Aspect	MPCB (Motor Protection Circuit Breaker)	Motor Starter
Primary Function	Protects the motor from overcurrent, short circuits, and phase imbalances.	Facilitates starting, running, and stopping the motor safely.

Items / Aspect	MPCB (Motor Protection Circuit Breaker)	Motor Starter
Components	Integrated device with thermal and magnetic trip mechanisms.	Composed of multiple components like contactors, overload relays, and push buttons.
Protection Offered	Comprehensive motor protection (overload, short circuit, phase loss, etc.).	Overload protection (via relays) but often requires an external circuit breaker for short circuit protection.
Control Feature	Does not directly control motor start/stop, works with a contactor for control.	Directly starts and stops the motor using push buttons or switches.
Complexity	Compact and simpler to install (single unit).	More complex with multiple components.
Applications	Common in smaller, less complex setups where direct protection is needed.	Used in more complex setups, such as star-delta or soft starters.
Cost	Typically, lower cost than a full motor starter setup.	Higher cost due to multiple components.
Manual vs Automatic	Primarily automatic; trips when faults occur.	Can be manual or automatic depending on design.
Voltage Range	Suitable for low-voltage motors.	Can be used for low and high-voltage motor systems.

NOTE:

- MPCB: Focuses on protection; ideal for setups where a simple solution is required to safeguard the motor against electrical faults.
- Motor Starter: Focuses on control and operation, allowing manual or automated starting/stopping along with motor protection.

Both devices are often used together, where the MPCB provides protection, and the motor starter manages operation and control.

1.7 CLASSIFICATION AS PER STANDARDS

The rating of the motor starter is based on the size and type of load for which it was designed. Starters confirm to the various standards and their ratings are given below:

1.7.1 IEC (International Electrotechnical Commission) Rating

Standard sizes are not specified by the IEC. The typical duty cycle of IEC devices is defined by utilization categories.

Table 4: IEC Rating/ Utilization Category

Utilization Category	Description of IEC Category
AC1	Non-inductive or slightly induction rows

Utilization Category	Description of IEC Category
AC2	Slip-ring motors or mixed resistive and inductive loads, including moderate overloads
AC3	Squirrel-cage motors: starting, switching off motors during running, reversing* (*This category may be used for occasional inching (jogging) or plugging for limited time periods such as machine set-up; during such limited time periods, the number of such operations should not exceed five per minute or more than ten in a 10-min period).
AC3e	Squirrel-cage motors with higher locked rotor current: starting, switching off motors during running, reversing# (#This category may be used for occasional inching (jogging) or plugging for limited time periods such as machine set-up; during such limited time periods, the number of such operations should not exceed five per minute or more than ten in a 10-min period).
AC4	Starting of squirrel-cage motor: starting, inching and plugging

As far as general motor starting applications are concerned, the AC3 and AC4 are the most common utilization categories.

1.7.2 NEMA (National Electrical Manufacturers Association) Rating

The NEMA ratings of a starter depends largely on the maximum horsepower (HP) ratings given in the (NEMA) **ISCS2** standard. The selection of the NEMA starters is done on the basis of their NEMA size, which varies from Size 00 to Size 9.

Starters confirms to the standards and ratings are given below:

Table 5: NEMA Sizes as per Motor Current & HP

NEMA Size	Continuous Rating (A)	HP at 230 V (AC)	HP at 460 V (AC)
00	9	1	2
0	18	3	5
1	27	5	10
2	45	15	25
3	90	30	50
4	135	50	100
5	270	100	200
6	540	200	400
7	810	300	600
8	1215	450	900
9	2250	800	1600

The NEMA starter, at its stated rating, can be used for a wide range of applications, ranging from simple on and off applications to plugging and jogging applications, which are more demanding. It is necessary to know the voltage and horsepower of the motor when selecting the proper NEMA motor starter. In the case where there is a considerable amount of plugging and jogging involved, then derating a NEMA-rated device will be required.

CHAPTER 2

COMPONENTS AND THEIR FUNCTIONS

A motor starter for a three-phase induction motor includes several components, each serving a specific function to ensure safe and efficient operation. The main components are magnetic contactor, overload relay, auxiliary contacts, time relay. The starters have some more components such as MCBs, fuses, push buttons, indication lights, enclosures etc.

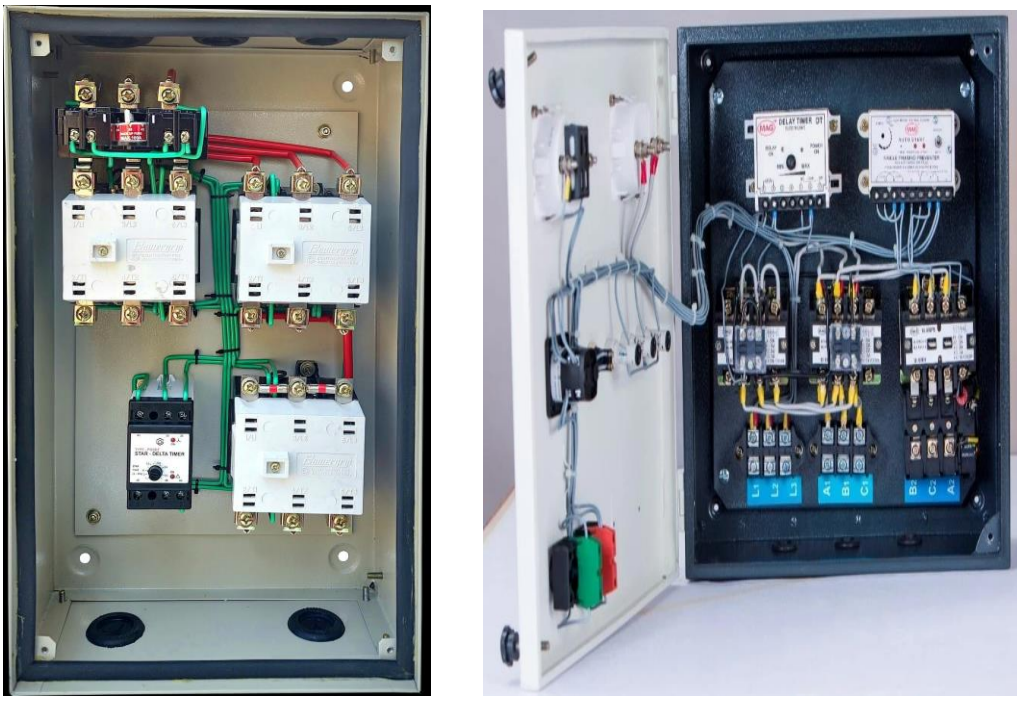


Figure 2: Typical Motor Starters & their components

NOTE:

i. The components of motor starter for 3 - phase squirrel cage Induction Motors depends on type of starters such as DOL starter has MCB/ Fuse, Auxiliary Contactor, Power Contactor, Overload relay, enclosure but does not contain timer which is provided in Star Delta Starter (Automatic type).

ii. All components or combination of components given below are works together to ensure the motor starts and operates safely, with protection against electrical faults, mechanical failures and operational errors etc.

2.1 MAJOR COMPONENTS OF VARIOUS MOTOR STARTERS

The components of motor starter and their functions are given below:

2.1.1 Power Contactor

It acts as a switch to control the power supply to the motor. These are an electrically operated switch with contacts that close when the coil is energized, allowing current to flow to the motor. That means the contractor contacts are nromally opened (NO) type. A contactor may have power

contacts and auxiliary contacts together, but the auxiliary contacts serves the controlling function only.

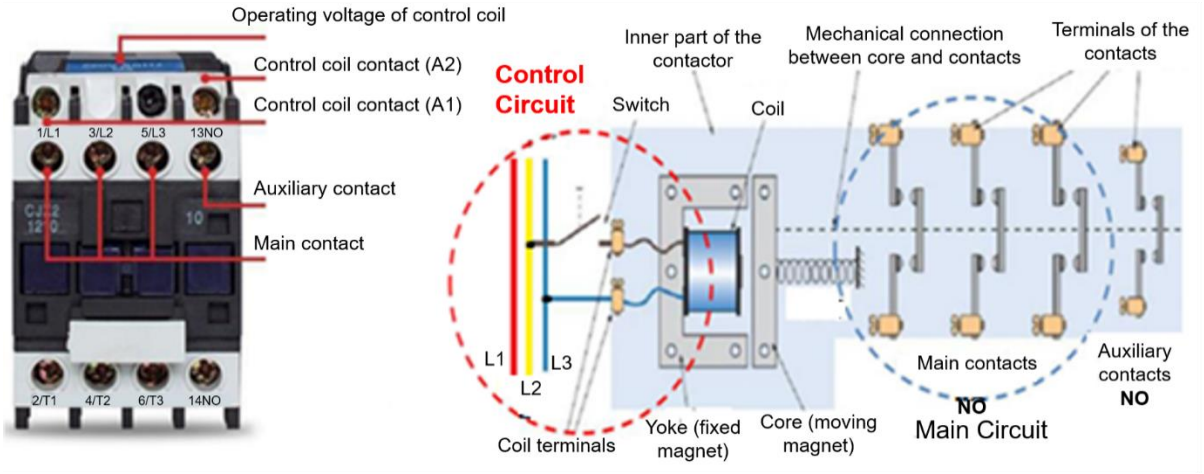


Figure 3: Pictorial view of Solenoid Type Contactors & Mechanism

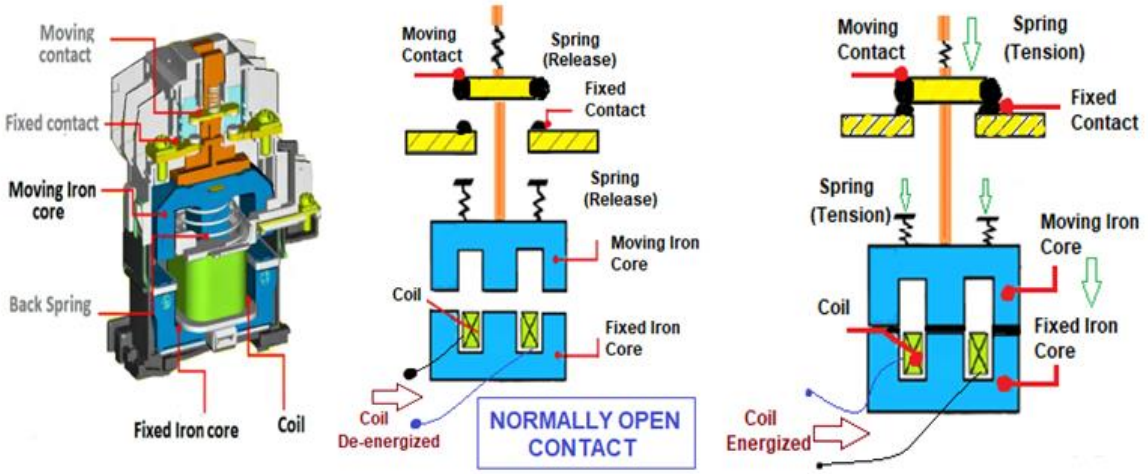


Figure 4: Cross Sectional view of E Type Contactor and Position of Contacts

2.1.2 Thermal Overload Relay/ Protection

It Protects the motor from overheating due to overcurrent or prolonged overload conditions. Relay Uses a bimetallic strip to disconnect the motor when it overheats or the motor current exceeds a preset value, preventing motor damage.

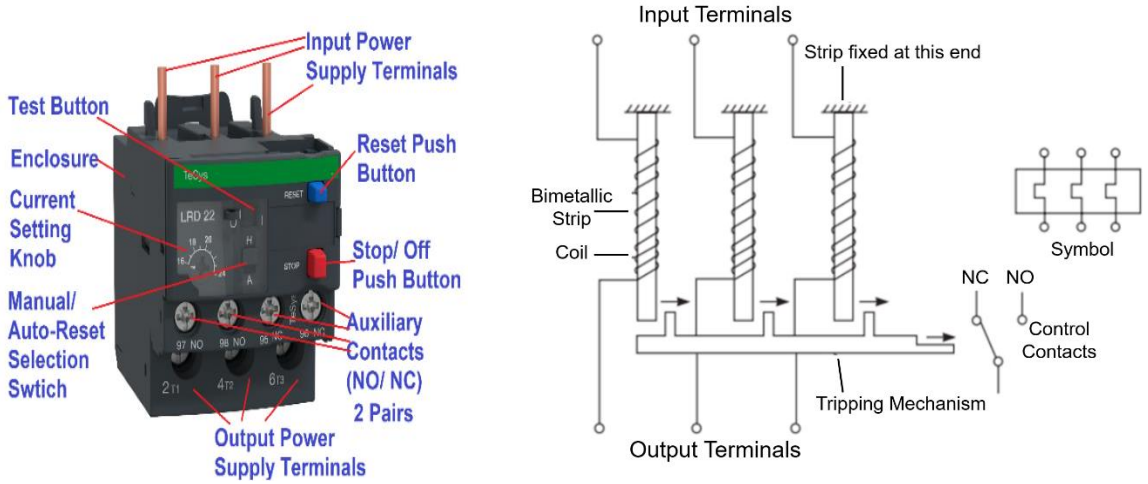


Figure 5: 3-Pole Thermal Overload Relay and Mechanism

2.1.3 Circuit Breaker/ Fuse

It provides the short-circuit protection by interrupting the circuit in the event of a fault. They protects the starter and motor from high currents caused by faults like phase-to-phase or phase-to-ground short circuits.



MCCB MCB MPCB gM type Fuse

Figure 6: Various Protection Devices

Note:

Depends on the applications, motor load and requirement the correct rating and type of protection is used like MCB, MCCB, MPCB and fuses.

2.1.4 Push Buttons

It manages the manual control for starting and stopping the motor. Start Button- Energizes the contactor to supply power to the motor and Stop Button-De energizes the contactor to cut power to the motor.

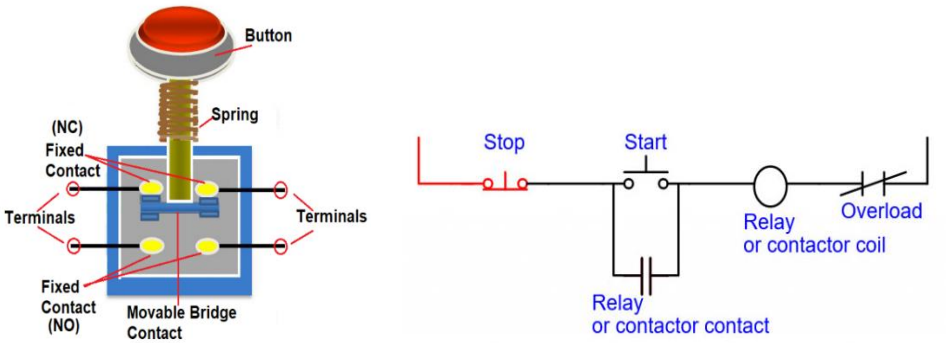


Figure 7: Push Button and Typical Control Scheme

2.1.5 Auxiliary/ Feedback Contacts

It provides the additional control, alarm, indication, signaling and feedback features. These are used for interlocking, indicating motor status, or controlling pilot lights and alarm's function.

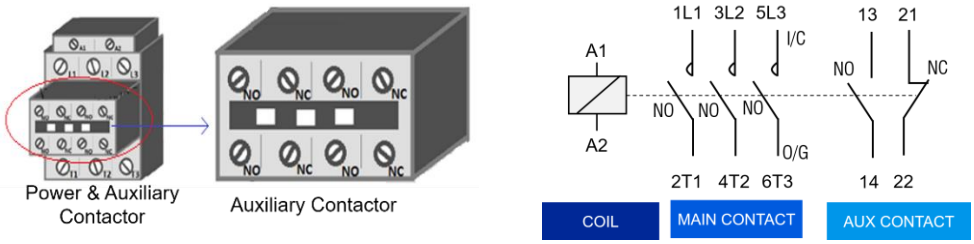


Figure 8: Auxiliary Contactors and its Contacts

Note:

Generally, the Auxiliary contactors used in motor starters are mechanically linked with the mechanism of power contactor.

2.1.6 Time Relay (optional in some starters)

It provides the timing functions, such as controlling the delay for star-delta transition. It is commonly used in starters like star-delta starters, where it controls the transition from "star" to "delta" configuration.

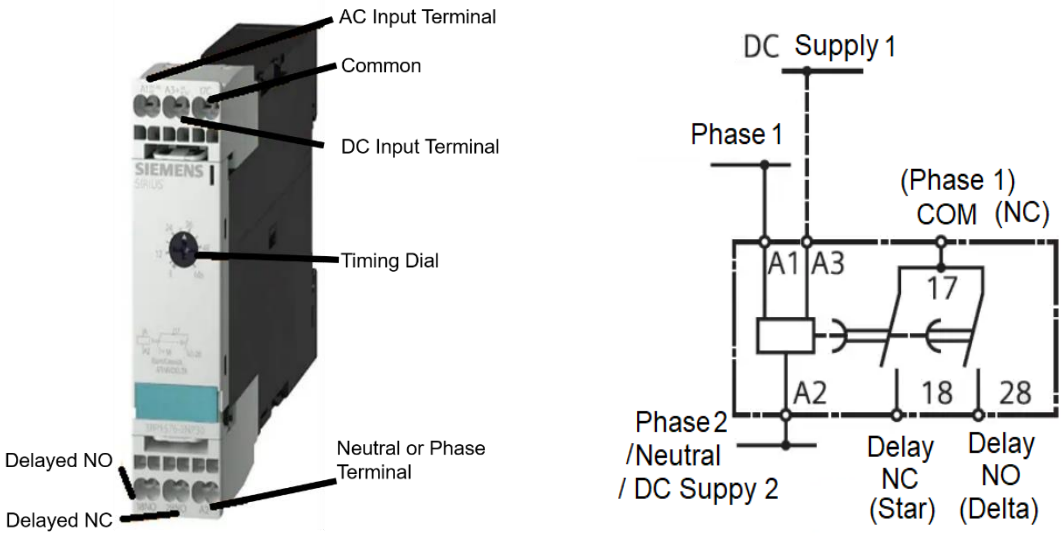


Figure 9: On Delay Type Electronic Timer & Connection Diagram

2.1.7 Auto-transformer

An auto-transformer is used to reduce the voltage during starting of the motor in auto transformer starter. It has a nos. of terminals as per the percentage of voltage to be applied to the motor. Three terminals are the main input terminals that are connected to the incoming power supply through the transformer contactor. Another three input terminals are connected with the shorting contactor. The other terminals are brought out from the tapping of the winding of auto-transformer and they are connected to the Induction Motor.



Figure 10: 3 units of Autotransformer with multiple tapings

2.1.8 Rectifier in Soft/ VFD Starter

There are various types of rectifiers based on the main component used like diode, thyristor, TRIAC connected etc. According to the use of semiconductor device, there are various configurations (Bridge, half wave, Full wave, Anti-Parallel connected etc) which may be used as per the requirement and need. Soft starters use the TRIAC (for lower rating motor) & SCR in anti-parallel configuration (For large rating motor) are used and VFD starter use the Diode and Thyristor as 6 pulse-rectifier.



Figure 11: Typical Silicon controlled rectifier

2.1.8.1 Microcontroller or Control Circuit in Soft Starter

A microcontroller serves as the central control unit, managing and coordinating various functions to ensure smooth motor operation. It processes input signals, executes control algorithms, and generates precise commands to regulate the firing angles of the thyristors (SCRs), enabling controlled voltage application to the motor.

Gate Firing circuit in Soft Starter

The microcontroller calculates and adjusts the firing angles of the thyristors to control the voltage ramp-up during motor startup.

2.1.9 DC Bus or Filter

The DC Link (also called DC Bus) is used in VFD starter. It serves as the intermediary stage between the rectifier and the inverter in a VFD system. After the AC power is converted into DC by the rectifier, the DC Link stores and smooths this DC voltage before it's supplied to the inverter, which then converts it back to variable frequency AC to control the motor's speed and torque.

Capacitors and Inductors are used in the DC bus to smooth the DC voltage, fluctuations or high-frequency ripple and reduce harmonic distortion coming from the rectifier. The combination of capacitors and inductors in a LC filter ensures that the DC voltage remains stable and free from excessive noise or ripple.

2.1.10 Inverter in VFD

The inverter in a VFD starter, converts the DC power from the DC bus into variable-frequency AC power that is supplied to the motor. By adjusting the frequency and amplitude of the AC voltage, the inverter precisely controls the motor's speed, torque, and direction.

Power Switches (IGBTs / MOSFETs)

Power switching devices, typically IGBTs (Insulated-Gate Bipolar Transistors) or MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are used for convert the DC voltage to Variable AC supply of variable frequency. These switches control the flow of current through the inverter, rapidly turning on and off to generate the AC output. By adjusting the on/off switching times, the inverter controls the voltage and frequency of the output signal.



Figure 12: Typical IGBT used in VFD

Gate Drivers or PWM Generator

Gate drivers are responsible for providing the correct control signals to the power switches (IGBTs or MOSFETs). They regulate the timing and sequence of switching to ensure proper inverter operation. Gate drivers help optimize the switching process and improve the overall efficiency of the inverter.

Control Circuit (Microcontroller/ DSP)

The inverter is controlled by a microcontroller or digital signal processor (DSP), which adjusts the switching pattern of the power switches according to the desired frequency and voltage.
The control circuit receives feedback from the motor and adjusts the inverter output to meet specific speed, torque, or power requirements.

2.1.11 Heat Dissipation Unit

The Heat Dissipation Unit in a soft starter/ VFD is essential in managing the heat generated by internal components, particularly by thyristors (SCRs), during its operation. It ensures the device operates within safe temperature limits by effectively dissipating heat, thereby maintaining reliability, efficiency, and longevity of the soft starter.

Heat Sinks

Metal fins, often made of aluminum or copper, provide a large surface area to dissipate heat effectively through conduction and convection.

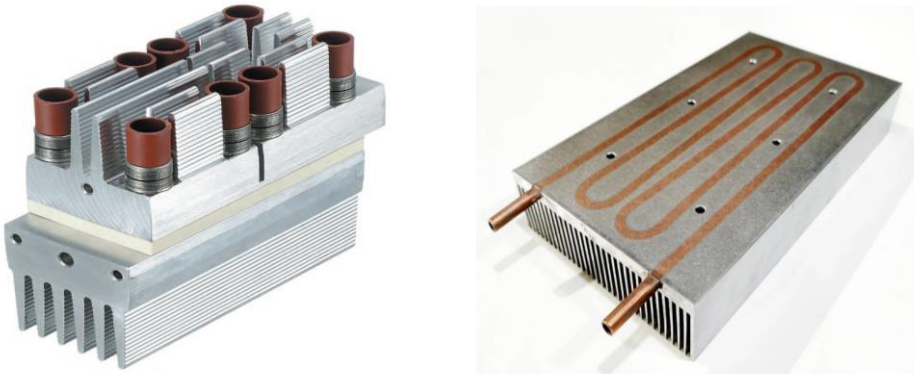


Figure 13: Heat Sink of Power Semiconductor Device like SCRs, IGBTs etc.

Cooling Fans

Forced air cooling is employed to enhance heat dissipation, ensuring adequate airflow over the heat sinks for high-power applications.

2.1.12 Current and Voltage Sensors

Current and voltage sensors are essential components in a soft starter/ VFD, providing real-time feedback to the control system to ensure safe and efficient operation. These sensors monitor the motor's electrical parameters, allowing the starter to adjust the voltage applied to the motor and protect against faults such as overcurrent or undervoltage.

These sensors consist of following items:



Figure 14: Various sensors for feedback

Current Transformers (CTs)

Commonly used for measuring high currents. Converts the high current into a proportional low current that can be safely measured by the control circuit.

Hall Effect Sensors

Used to measure both current and magnetic fields. Provide accurate feedback without direct electrical contact, making them ideal for monitoring the current in the motor circuit.

Potential Transformers (PTs)

Used to step down high voltages to lower, measurable levels, providing accurate voltage readings to the control system.

2.1.13 Enclosure

It protects the starter components from environmental factors like dust, moisture, and accidental contact. It also ensures safe and reliable operation by housing all components in a robust structure.



Figure 15: Metallic Enclosure of Motor Starter

CHAPTER 3

DIRECT ON LINE (DOL) STARTER

The Direct-On-Line (DOL) motor starter is the simplest and inexpensive method of starting a squirrel cage induction motor. As the name implies, it switches the motor directly onto the three-phase supply i.e. full voltage. This results in high starting torque and a straightforward design but may also cause high inrush currents. The use of DOL starters is restricted up to smaller rating motors, because starters do not limit the starting current.



Figure 16: Typical 3 phase DOL Starter

3.1 CIRCUITS OF DOL STARTER

There are two types of circuit. One circuit deliver the power to the motor is known as power circuit and another circuit controls the on/off of the motor, is control circuit.

3.1.1 Power Circuit of DOL Starter

The power circuit is responsible for delivering the required electrical power to the motor. It comprises components (Like CB/Fuse, overload thermal relay, power contactor etc.) that connect the motor to the uncontrolled three-phase power supply.

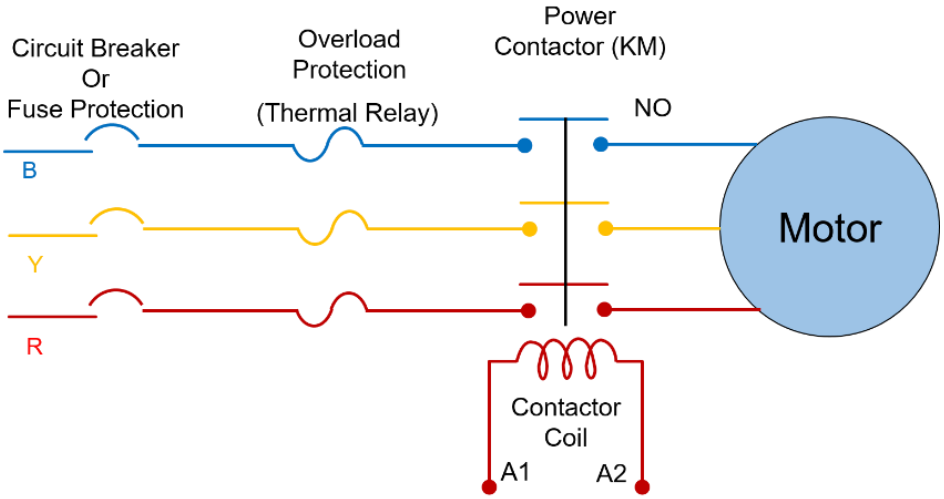


Figure 17: Control Circuit of DOL Starter

3.1.2 Control Circuit of DOL Starter

The control circuit governs the operation of the contactor, enabling the motor to start, stop, or protect against overload. This circuit have push buttons, overload protection, auxiliary contacts (holding contacts) & coil of contactor etc.

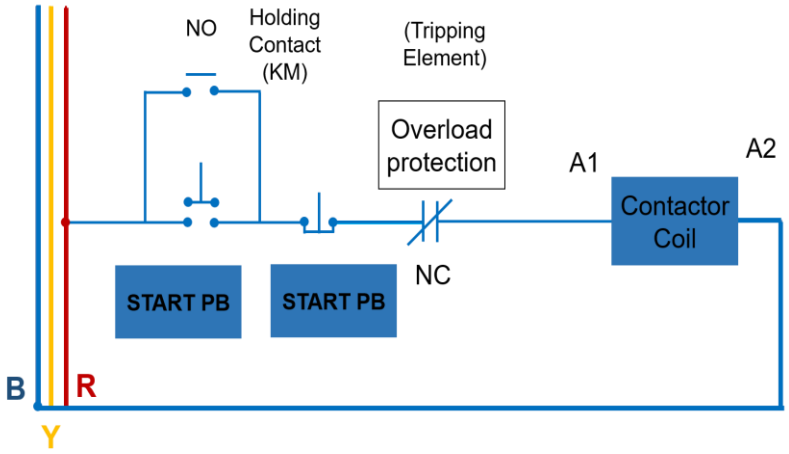


Figure 18: Control Circuit of DOL Starter

3.1.3 Operation of Motor in DOL Starting Method

The figure below illustrates the typical connections of all the components in a DOL starter, and working is explained:

- By pressing the start push button, it energizes the contactor coil A1-A2, which closes the main contacts and power delivered to the motor by applying the full line voltage. The motor starts with maximum torque and a high inrush current.
- By releasing the start push button, keeps the contactor coil energized through an auxiliary contact (holding contact) in parallel with the start push button and motor keeps running even when the contact of start push button is opened.
- Pressing of the stop push button or operation of overload relay, the control circuit is de-energized that means the coil of contactor don't get any supply so the main & holding contacts are opened which disconnect the power supply to motor and motor stopped.

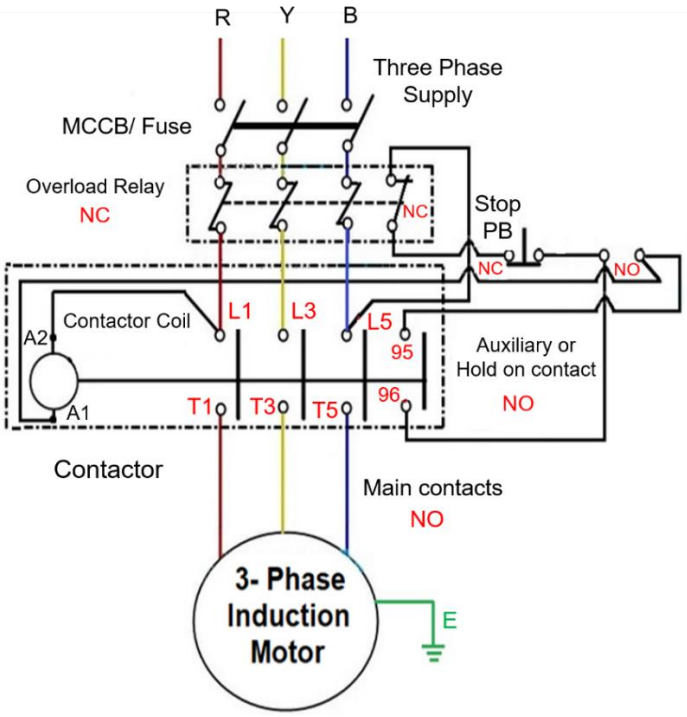


Figure 19: Typical Connections of DOL starter

3.2 Calculation of Current & Toque

3.2.1 Current Calculation of Motor

$$I_{2r} = \frac{E_{2r}}{Z_{2r}}$$

$$I_{2r} = \frac{sE_2}{Z_{2r}}$$

$$I_{2r} = \frac{sE_2}{\sqrt[2]{R_2^2 + (sX_2)^2}}$$

$$\boldsymbol{V \propto \phi \propto E_2}$$

The **starting current I_2** for an induction motor is typically **6 to 8** times the **I_{fl} full-load current**, It can be calculated using the formula:

$$I_2 = m \times I_{fl} \qquad m = 6 \text{ to } 8$$

$$I_{fl} = \frac{P}{\sqrt[2]{3 \times V \times \eta \times \cos\phi_{2r}}}$$

Where,

V: Line voltage (V), ɳ: Motor efficiency
T: Torque (N-M), $T_{fl:}$ Full load Torque (N-M)
T_{st}: Starting Torque (N-M)
P: Motor Power (watt)
ω: Angular speed (in rps)
ø: Flux (T), I_{fl} : Full-load current A
I_2: Rotor current A at Standstill (Starting current)
m: Starting current multiplier (**6 to 8** for most motors)
I_{2r}: Rotor Current (Running) (Amp)
E_{2r}: Rotor Induced emf (Running) (Volt)
E_2: Rotor Induced emf (Standstill) (Volt)
Z_{2r}: Rotor Impedance (Running) (Ohm)
R_{2r}: Rotor Resistance (Running) (Ohm)
R_2: Rotor Resistance (Standstill) (Ohm)
X_{2r}: Rotor Reactance (Running) (Ohm)
X_2: Rotor Reactance (Standstill) (Ohm)
s: Slip, S_{fl}: Full load slip
Cosø$_{2r}$: Power Factor of Rotor (Running)
P: Motor power in watts (W)
ω: Angular speed in radians/second, and
N_s: Synchronous speed in rpm

3.2.2 Torque Calculation of Motor

$$T = \frac{P}{\omega} \quad \& \quad \omega = \frac{2\pi N_s}{60}$$

$$T \propto P$$

$$T \propto \emptyset\, I_{2r} \cos\phi_{2r} \qquad \because P \propto \emptyset\, I_{2r} \cos\phi_{2r}$$

$$T \propto E_2 \left(\frac{E_{2r}}{Z_{2r}}\right)\left(\frac{R_{2r}}{Z_{2r}}\right) \qquad \because \emptyset \propto E_2$$

$$T \propto \frac{s \times E_2^2 \times R_2}{R_2^2 + (sX_2)^2} \qquad \because E_{2r} \propto sE_2$$

Approximately, $\boldsymbol{T \propto sE_2^2 \propto sV_2^2}$ & $\boldsymbol{T \propto \frac{I_2^2}{s}}$

Starting Torque, $\boldsymbol{T_{st} \propto E_2^2 \propto V_2^2}$ & $\boldsymbol{T_{st} \propto I_2^2}$ $\because s = 1$

Full Load Torque, $\boldsymbol{T_{fl} \propto s_{fl}E_{2r}^2 \propto s_{fl}V_{2r}^2}$ & $\boldsymbol{T_{st} \propto \frac{I_2^2}{s_{fl}}}$ $\because s = s_{fl}$

Relationship between Starting and full load torque

$$\boldsymbol{\frac{T_{st}}{T_{fl}} \propto \left(\frac{I_2}{I_{2fl}}\right)^2 s_{fl} = m^2 \times s_{fl}}$$

For an example let, S_{fl}=4%, and m=6, then, $T_{st}=T_{fl}$ x $(6)^2$x0.04 = T_{fl} x 1.44

It means that the starting torque is 1.44 times of Full load torque, while the starting current is 6 times the full load current (running current).

3.2.3 Toque & Current - Speed Characteristic

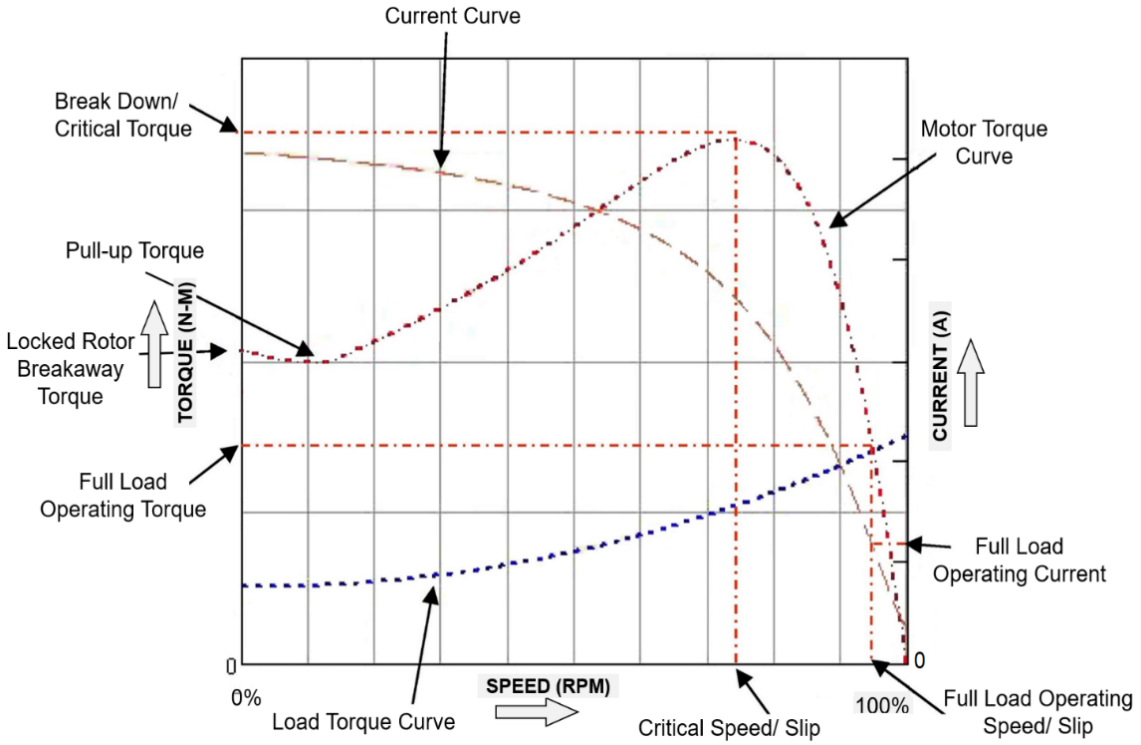


Figure 20: Typical Torque - Speed & Current - Speed Characteristics of Induction Motor

NOTE:
When full supply voltage is applied on motor, the above characteristics of motor are similar to their typical characteristics, there is no change in characteristics by providing DOL starter.

3.3 ADVANTAGES, DISADVANTAGES AND APLLICATIONS

3.3.1 Advantages

- Cheap and economical amongst all other starters.
- Easy to design, operate, and carry out maintenance.
- Has the simplest control circuit.
- Offers higher torque during starting time due to high starting torque.
- Easy to troubleshoot.
- Motor connection is in the delta method at the terminals of the motor.

3.3.2 Disadvantages

- The starter does not minimize the motor starting current.
- Very high motor starting current.
- Reduced life due to thermal stress.
- It experiences very high starting torque; it may damage the motor or load due to sudden jerk.

3.3.3 Applications

The DOL starter finds many applications in smaller motors like water pumps, compressors, conveyor belts, and fans/ blowers etc.

CHAPTER 4

AUTO-TRANSFORMER STARTER (AUTOMATIC)

An auto-transformer motor starter is used to reduce the voltage supplied to a motor during its startup phase/ period to minimizing inrush current and mechanical stress. It uses an auto-transformer with adjustable taps which provides a reduced voltage to the motor for a short duration before switching to full line voltage for normal operation as in the case of DOL starter.

This method is particularly useful for starting large motors, because it balances efficient operation with reduced electrical and mechanical impact. The auto-transformer starter is used in industrial settings where smooth motor acceleration and lower energy consumption during startup are critical.



Figure 21: Typical Auto-transformer Starter

4.1 CIRCUITS OF AUTO-TRANSFORMER STARTER

Same circuits are named in all type of starter i.e. two types with different components & connections. One circuit deliver the power to the motor is power circuit and control circuit controls on/off of the motor through the operation of contactor.

4.1.1 Power Circuit

The power circuit is delivering the required electrical power to the motor. It has various components (Like Auto-transformer, CB/Fuse, overload thermal relay, power contactor) that connect the motor to the controlled three-phase power supply.

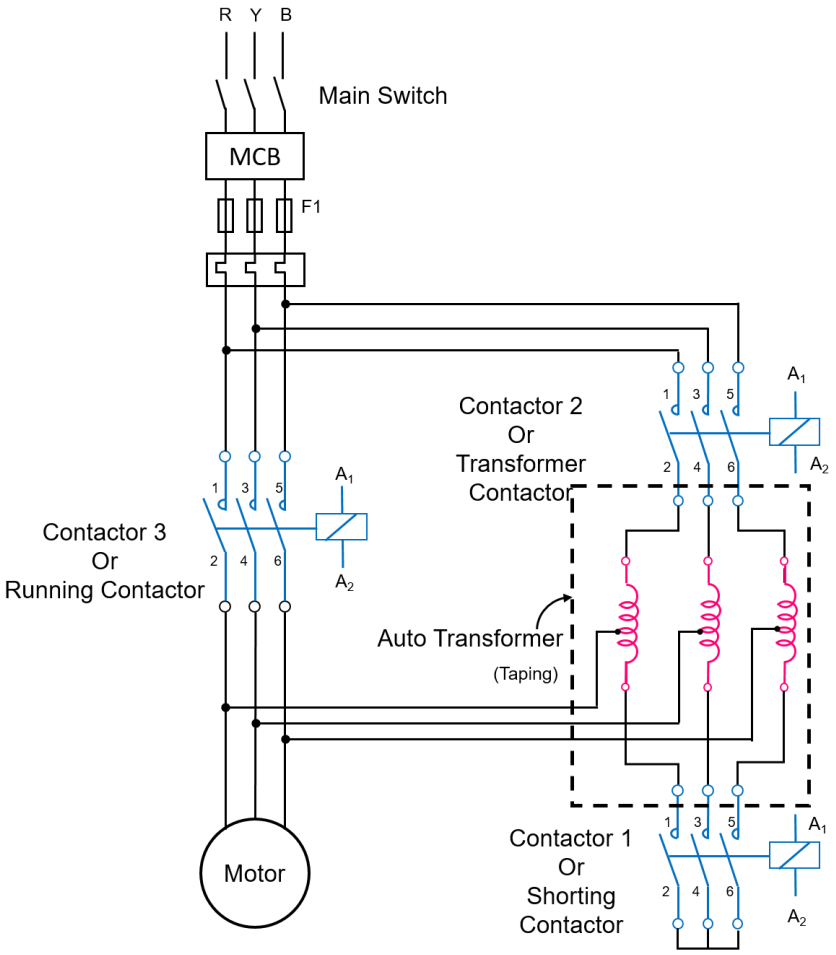


Figure 22: Typical Control Circuit of Auto-transformer Starter

4.1.2 Control Circuit

The control circuit governs the operation of the contactor, enabling the motor to start, stop, or protect against overload. This circuit have push buttons, overload protection, auxiliary contacts (holding contacts) & coil of contactor.

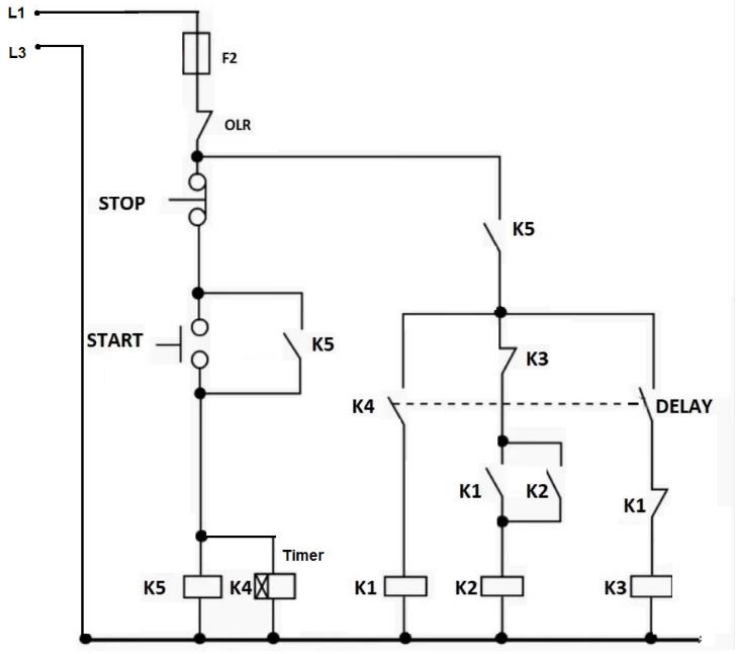


Figure 23: Typical Control Circuit of Auto-transformer Starter

4.1.3 Operation of Motor with Auto-transformer starter

The auto-transformer starter can be used for the both star and delta connected induction motor. It works in four different stages.

Stage 1
At the first stage, contactor 1 or shorting contactor is in closed condition and contactor 2 gets turned on. Once contactor 2 gets turned on, the motor will get the supply voltage and starts running. This initial supply voltage depends upon the number of tapping selected on the auto-transformer which may be 50% or 65% or 80% of the full voltage. This shorting contactor connects the transformer coils in star configuration.

Stage 2
After some time (preset time set in the timer), the shorting contactor gets opened and the coils of the auto-transformer act as series inductors with the induction motor.

Stage 3
Once the motor gets a stable speed, the contactor 3 or running contactor gets closed. It is also set by the timer. In this condition, the auto-transformer act as a shunt with the induction motor.

Stage 4
The contactor 2 or transformer contactor is opened and the auto-transformer got isolated from the circuit and the motor running with the full supply voltage. At the running condition, only contactor 3 or running contactor will be in closed condition, remaining all the contactors will be in open condition.

4.2 CALCULATION OF CURRENT & TORQUE

4.2.1 Current Calculation of Motor

If the V is the per phase supply voltage in DOL starter and the auto-transformer of transformation ratio K is used, then applied phase voltage V′ in Auto-transformer starter is,

$$V' = K \times V \qquad per\ phase \qquad where \quad K < 1 \text{ (Step down)}$$

Voltage multiplied by K is applied to the motor by auto-transformer that is reduced voltage.

Per phase current in case of DOL starter,

$$I = \frac{V}{Z} \quad per\ phase \quad where, Z = Motor\ imedance\ per\ phase$$

Now the phase current I′ in auto-transformer starter,

$$I' = \frac{V'}{Z} = \frac{KV}{Z} = KI \qquad per\ phase$$

The current in case of auto-transformer is reduced by transformer ratio K (or percentage of tapping) as compare to DOL starter.

Reduced voltage is applied to motor by auto-transformer at starting only. When motor starts gain the considerable speed then the full voltage is applied to the motor.

Then the starting current in auto-transformer starter I'_{st} as compared to DOL starting method I_{st} is,

$$\frac{I'_{st}}{I_{st}} = K$$

Full load current in auto-transformer starter as compared to DOL starting method I_{fl} is,

$$\frac{I'_{fl}}{I_{fl}} = 1 \qquad \because Full\ voltage\ applied\ to\ motor\ in\ both\ cases$$

4.2.2 Torque Calculation of Motor

If the V is the per phase supply voltage in DOL starter and the auto-transformer of transformation ratio K is used & applied phase voltage V′ in Auto-transformer starter.

Then Toque T in DOL starter is,

$$T \propto (V)^2$$

Toque T' in auto-transformer starter is,

$$T' \propto (V')^2 \propto (KV)^2 \propto K^2 (V)^2 \propto K^2 \times T$$

The torque T' in auto-transformer starter is reduced by square of the ratio K (or percentage of tapping) as compared to DOL starter.

The starting torque T'_{st} in auto-transformer starter as compared to DOL starting method T_{st} is,

$$\frac{T'_{st}}{T_{st}} \propto K^2$$

The relationship between starting & full load torque in auto-transformer starter is,

$$\frac{\boldsymbol{T'_{st}}}{\boldsymbol{T'_{fl}}} \propto \left(\frac{\boldsymbol{I'_{st}}}{\boldsymbol{I'_{fl}}}\right)^2 \boldsymbol{s_{fl}} = \left(\frac{\boldsymbol{KI_{st}}}{\boldsymbol{I_{fl}}}\right)^2 = \boldsymbol{K^2 \times m^2 \times s_{fl}}$$

4.2.3 Torque – Speed Characteristic

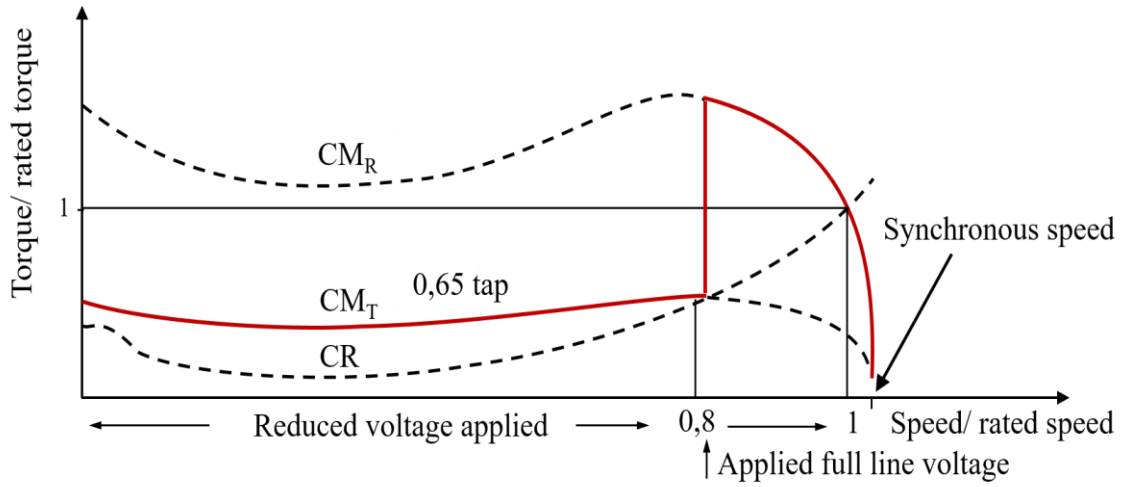


Figure 24: Torque-Speed Characteristic of Auto-transformer Starter

Where, CR: Load torque;
CM_R: Motor torque at rated voltage;
CM_T: Motor torque at reduced voltage

4.2.4 Current – Speed Characteristic

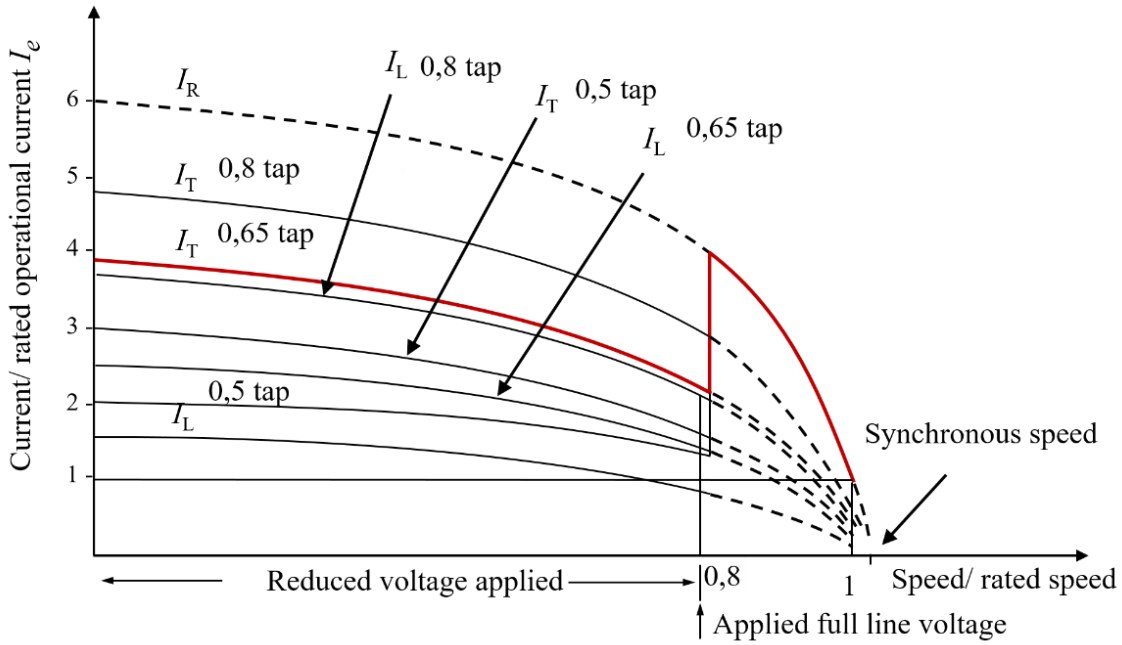


Figure 25: Current-Speed Characteristic of Auto-transformer Starter

Where, I_R: Motor current at rated Voltage; I_T: Motor current at reduced Voltage at respective taps
I_L: Line current at reduced Voltage

Note:

(i) It is observed that the applied voltage in auto-transformer starter at the time of starting is reduced by transformation ratio which is as per the percentage of tapings connected. This reduces the starting current by the same factor w.r.t. DOL starter.

(ii) It is also found that the starting torque in auto-transformer starter is reduced by square of the transformation ratio. This reduces the starting torque by the square of ratio w.r.t. DOL starter.

(iii) There is no change in full load current and full torque in auto-transformer starter w.r.t. DOL starter due to no change in applied voltage.

4.3 ADVANTAGES, DISADVANTAGES AND APLLICATIONS

4.3.1 Advantages

- The auto transformer helps in limiting the inrush currents.
- There is the possibility of adjusting the starting voltage because the auto-transformer provides different tapings to meet the requirements.
- These types of starters have draws less starting current.
- The auto-transformer starters have higher efficiency when compared to conventional starters.
- They offer a much better voltage regulation function.

4.3.2 Disadvantages

- The auto-transformer offers a very low power factor.
- The auto-transformer circuit is somehow complex and fairly expensive because of the involvement of the auto-transformer.
- The starter is somehow bigger and, therefore, cannot be used in machines with limited access.

4.3.3 Applications

Auto Transformer Starter is best suited when maximum reduction of inrush current is desired or motor requires longer acceleration time with good starting torque for applications like Submersible, Boosting Dewatering pumps, Mixers in industry, Centralized air-conditioning, Chillers, Compressors, Blowers/Fans, Grinders and Crushers etc.

CHAPTER 5

STAR DELTA STARTER (AUTOMATIC)

A star-delta starter is a widely used method for starting three-phase induction motors, particularly for high-power applications. It operates by connecting the motor windings in a star (Y) configuration during startup, reducing the voltage and limiting the inrush current to approximately one-third of its full load value and also with reduced starting torque. After a preset time, the starter switches to the delta (Δ) configuration, allowing the motor to run at full line voltage and deliver its full torque. This minimizes stress on the motor & the electrical system, making it efficient and economical for applications requiring a smooth start.

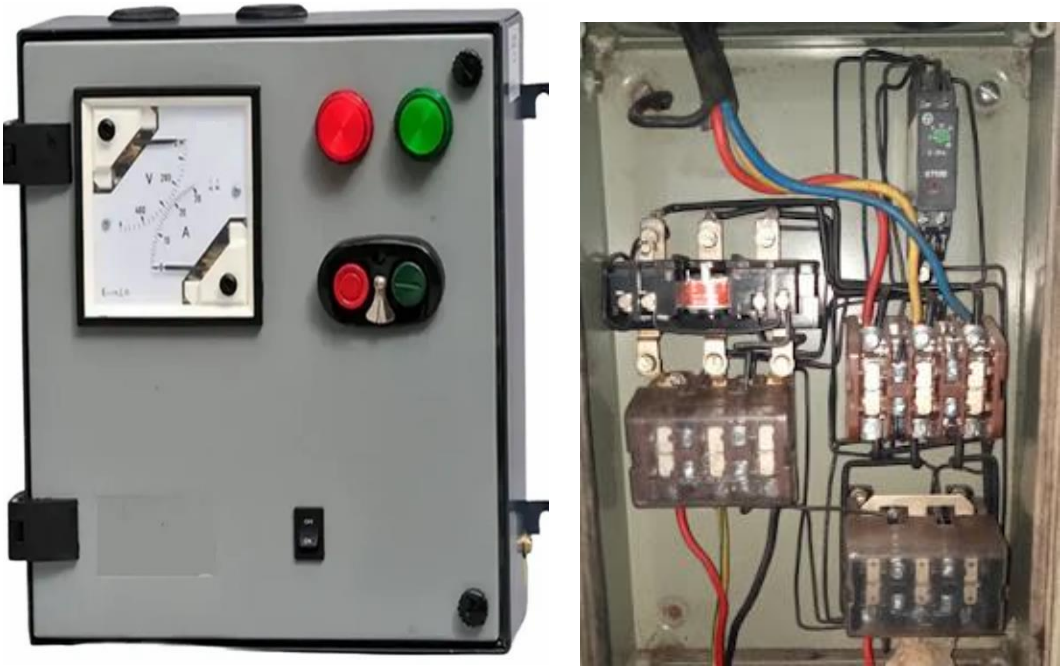


Figure 26: Typical Star Delta Starter

5.1 CIRCUITS OF STAR-DELTA STARTER

One circuit supply the power to the motor is power circuit and second circuit controls the operation or on/off of the motor, is control circuit.

5.1.1 Power Circuit

The power circuit is delivering the required electrical power to the motor. It has various components (Like Auto-transformer, CB/Fuse, overload thermal relay, power contactor) that connect the motor to the reduced three-phase power supply.

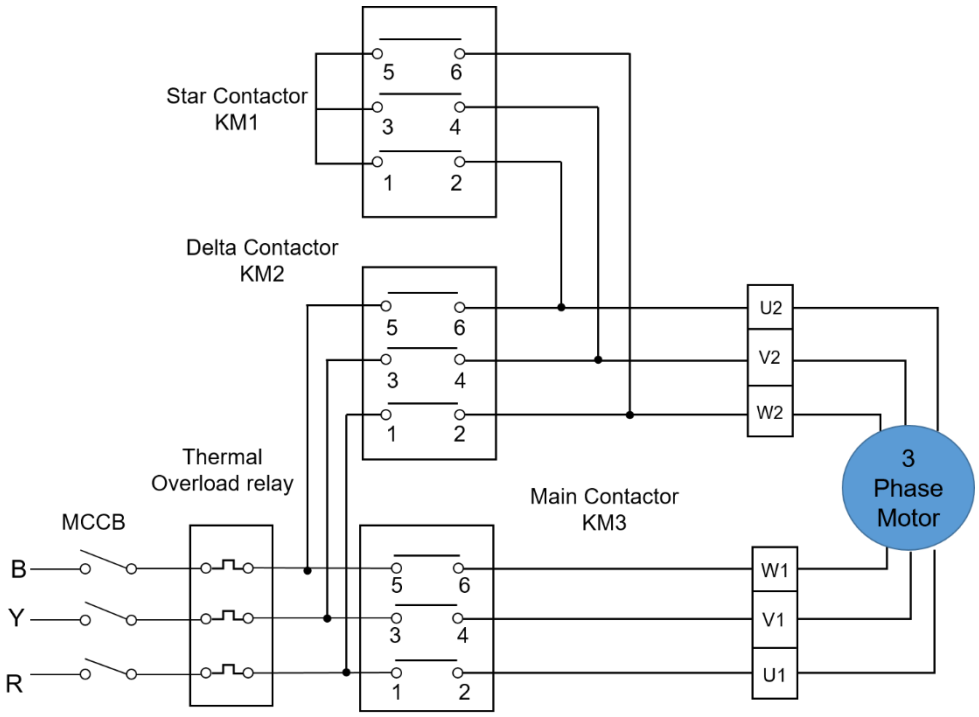


Figure 27: Typical Power circuit of Star Delta Motor Starter

5.1.2 Control Circuit

The control circuit controls the operation of the contactor to start or stop motor and protect against overload. This circuit have push buttons, overload protection, auxiliary contacts (holding contacts) & coil of contactor. In this control circuit more nos. of contractors are used along with timer & contacts of the additional power contactor, changes the configuration of motor winding (star or delta connection).

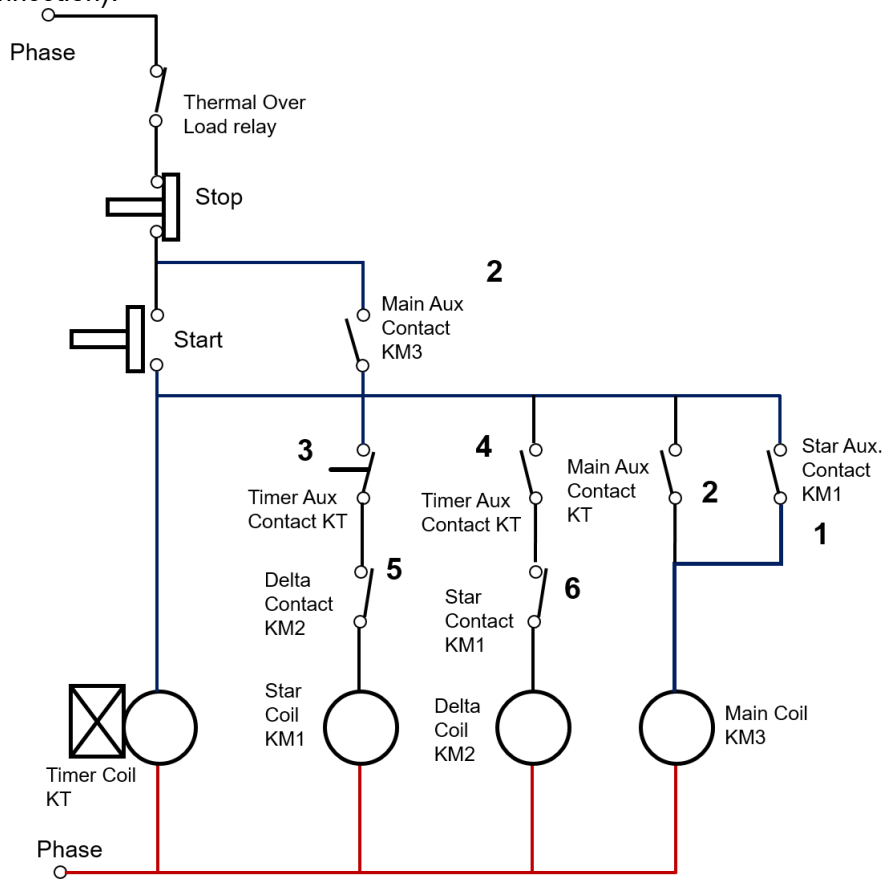


Figure 28: Typical Control Circuit of Automatic Star Delta Motor Starter

5.1.3 Operation of Motor in Star Delta Starter

Initially the motor winding connected in star configuration, then it switches to delta configuration. This starter works in four stages:

Stage 1 **OFF State:** All Contactors are opened.

Stage 2 **Star State:** The Main [KM_3] and the Star [KM_1] contactors are closed and the delta [KM_2] contactor is opened. The motor is connected in star and will produce one third torque at one third of current w.r.t. torque & current in DOL.

Stage 3 **Open State:** This type of operation is called open transition switching because there is an open state between the star state and the delta state. The Main contractor is closed and the Delta and Star contactors are opened. There is voltage on one end of the motor windings, but the other end is opened so no current can flow. The motor has a spinning rotor and behaves like a generator in this state.

Stage 4 **Delta State:** The Main and the Delta contactors are closed. The Star contactor is opened. The motor is connected to full line voltage and full power and torque are available.

5.2 CALCULATION OF CURRENT & TORQUE

5.2.1 Current Calculation of Motor

(a) The motor winding during starting connected in star configuration then the voltage across each phase of winding V_{PS} is,

$$V_{PS} = \frac{V_L}{\sqrt{3}}$$

& the motor current per phase, I_{ps}

$$I_{PS} = I_{LS} = \frac{V_{PS}}{Z} = \frac{V_L}{Z\sqrt{3}}$$

Where,
V_L is the line voltage,
I_{LS} is line current in star configuration,
Z is winding impedance at standstill condition

(b) The motor winding connections during running changed to delta configuration, then the voltage across each phase of winding V_{PD} is,

$$V_{PD} = V_L$$

& the motor current per phase, I_{PD}

$$I_{PD} = \frac{I_{LD}}{\sqrt{3}} = \frac{V_L}{Z\sqrt{3}} = \frac{V_{PD}}{Z\sqrt{3}}$$

Where,
I_{LD} is line current in delta configuration,

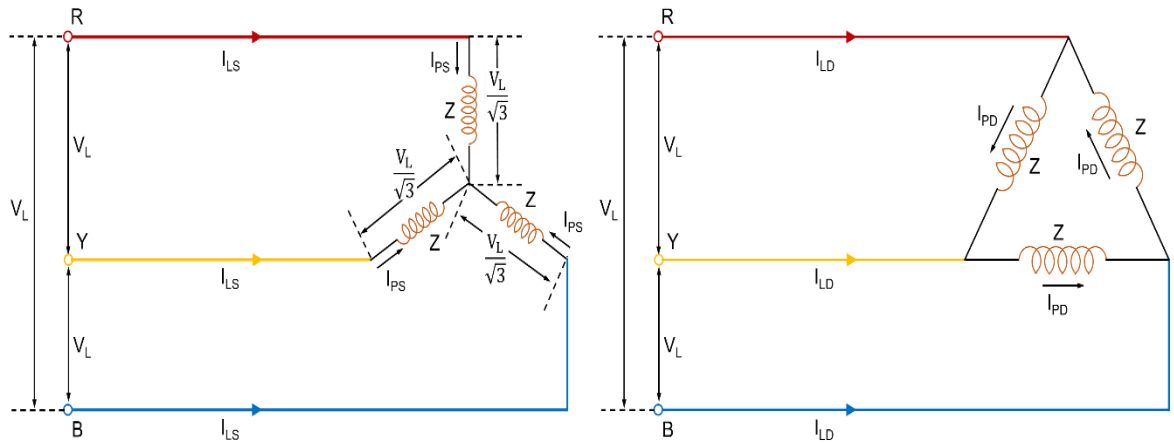


Figure 29: Motor Winding Connections (a) Star during Staring (b) Delta during Running

Now, by comparing supply line currents drawn by an induction motor with star and delta-connected winding, we get

$$\frac{I_{LD}}{I_{LS}} = \frac{V_L\sqrt{3}/Z}{V_L/Z\sqrt{3}} = 3$$

$$I_{LS} = \frac{I_{LD}}{3}$$

Thus, we can say that the starting current from the mains in case of star is one-third of direct switching in the delta.

5.2.2 Torque Calculation of Motor

Starting torque is proportional to the square of the voltage applied to the winding per phase

$$T \propto (V)^2$$

Ratio of Torque in star (T_S) and Torque in delta (T_D) configuration of motor winding is given as,

$$\frac{T_S}{T_D} = \frac{\left(V_L/\sqrt{3}\right)^2}{V_L{}^2} = \frac{1}{3}$$

The above relationship shows that the **star delta starter** reduces the starting torque to one-third of that produced by the DOL starter. The star-delta starter is equivalent to an auto-transformer with a 57.7% tapping.

5.2.3 Toque – Speed Characteristic

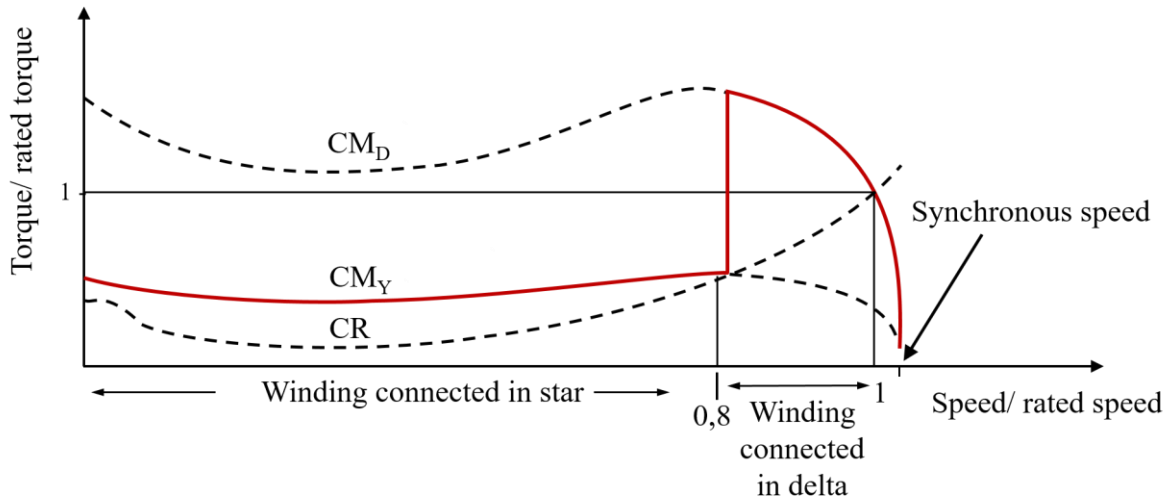


Figure 30: Typical Torque during a Star-delta Starter

Where,

CM_D : Motor Toque in Delta connection,
CM_y: Motor Toque in Star connection and
CR: Load torque

5.2.4 Current – Speed Characteristic

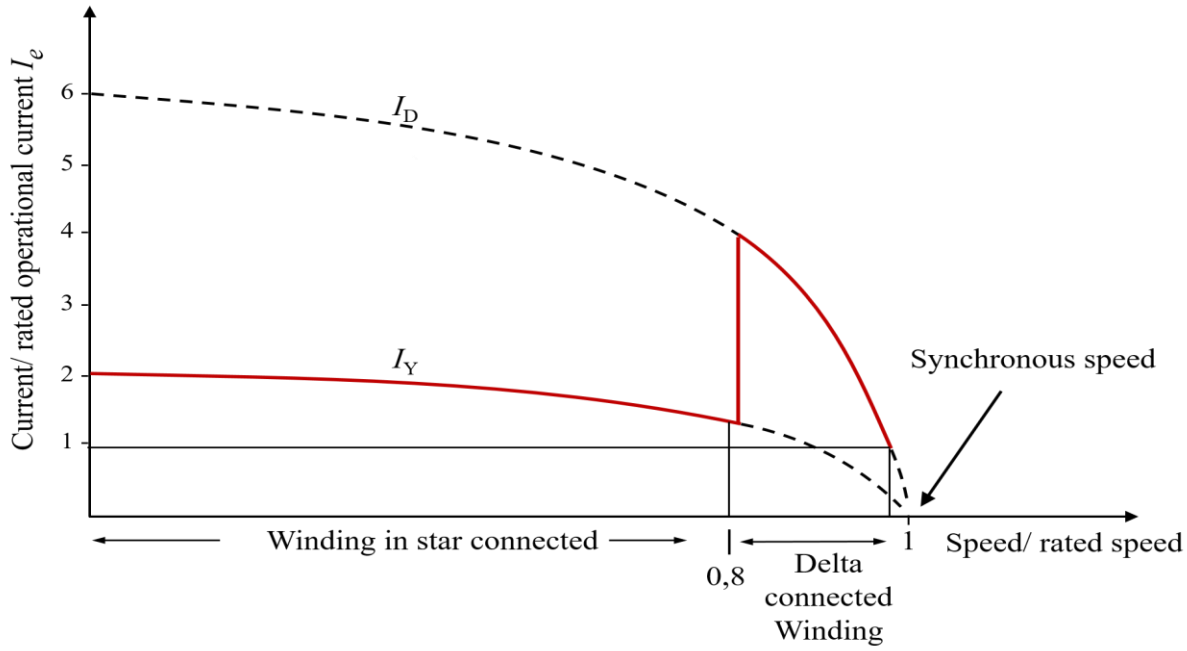


Figure 31: Typical Current during a Star-delta Starter

Where,

I_D: Motor Current in Delta connection and

I_y: Motor Current in Star connection

5.3 ADVANTAGES, DISADVANTAGES AND APPLICATIONS

5.3.1 Advantages

- Simple design and operation.
- Comparatively cheaper than other voltage controlling methods, such as autotransformer, soft starter, VFD starter.
- The torque and current performance of the Y-Δ starter is good.
- It reduces the starting current to approximately one-third compared to a DOL that means it is economical in terms of electricity consumption.
- Overload relay size can be reduced to about 50% because it operates under low starting voltage and currents.
- Other voltage reduction devices are not required.

5.3.2 Disadvantages

- Starting Torque is also reduced to one-third because the starter reduces the starting current to one-third of the rated current [as Line voltage is also reduced to 57% (1/√3)].
- It requires six leads or terminals for a Delta-connected motor.
- For Delta connection, the supply voltage must be the same as the rated motor voltage.

- At switching time (from Star to Delta), if the motor does not reach enough speed, then the current peak may be equally high as in a DOL starter, thus causing harmful effects on the contactor's contacts, making it unreliable.
- We should not use a star-delta starter if the required (application or load) torque is high.

5.3.3 Applications

Star-Delta starter can only be used for low to medium voltage and light starting torque induction motors which means suitable for motors rated 40 HP to 100 HP where load torque is low during startup. This starter is used in pumps, lathes, machine tools, and air compressors and Industries with light mechanical load applications.

CHAPTER 6

SOFT STARTER

A soft starter is used to gradually start or stop an electric motor by controlling the applied voltage. It reduces the inrush current and mechanical stress on the motor & ensure a smooth acceleration and deceleration process. This helps to prevent sudden torque surges, minimize wear & tear on mechanical components, and avoid large voltage drops in the electrical system. They are energy-efficient, customizable, and ideal for systems requiring controlled starting and stopping, although they can be more expensive compared to traditional starters.



Figure 32: Block Diagram of Typical Soft Starter

6.1 CIRCUITS OF SOFT STARTER

There are mainly two circuits. One circuit deliver the power to the motor is power circuit and second circuit controls the operation or on/off of the motor, is control circuit.

6.1.1 Power Circuit

The power circuit is delivering the required electrical power to the motor. It has components (Like MCB/MCCB/Fuse, overload thermal relay, Thyristor in back-to-back configuration, bypass power contactor, Heat Sink) that connect the motor to the controlled three-phase power supply.

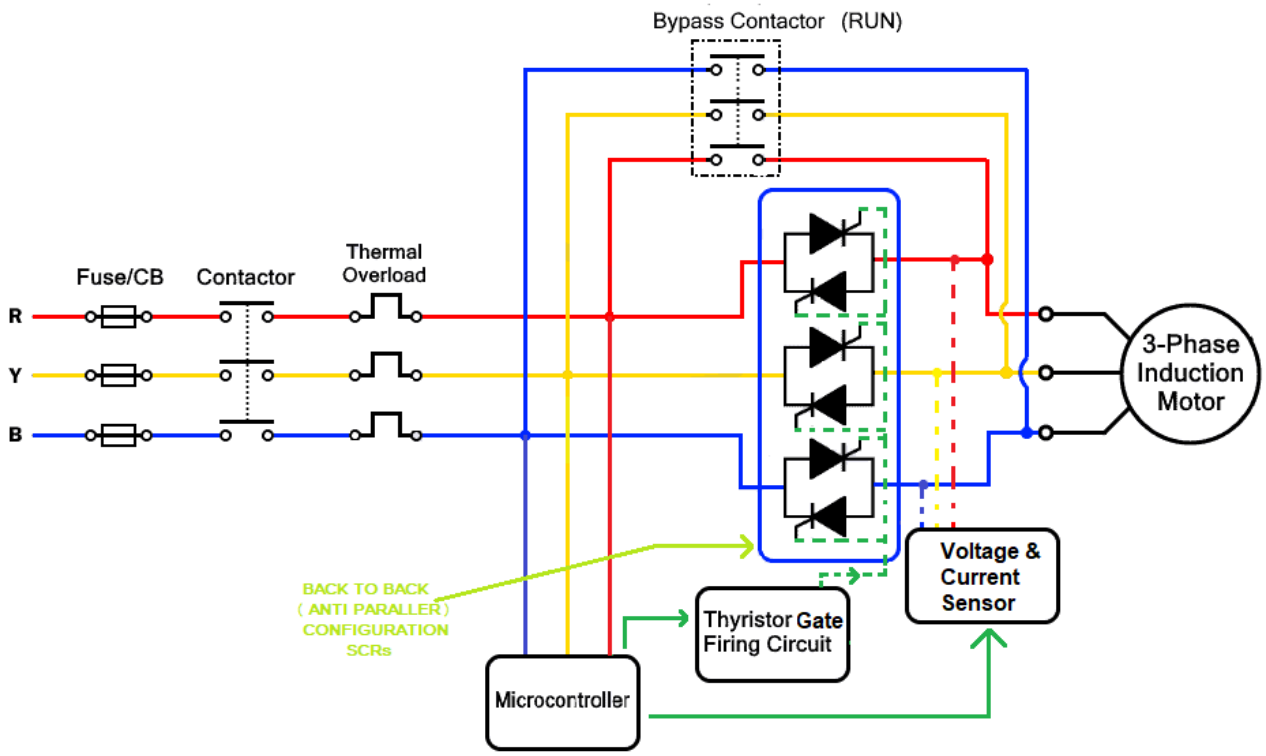


Figure 33: Typical Circuit of Soft Starter

6.1.2 Control Circuit

This circuit controls, monitors and protects the components of a power supply circuit. This circuit have push buttons, various protections, auxiliary contacts, microcontroller, SCR firing circuit, feedback circuit (voltage, current sensing elements) etc.

6.1.3 Operation of Motor in Soft Starter

The starting voltage of an electric motor is reduced depending on the angle of conduction of the thyristors, thus decreasing the peaks in the current, one of the duties of a soft-starter is to control the power of a motor without changing its frequency.

In a soft starter, a thyristor is the main component necessary for voltage control. This is a controlled rectifier. It starts current flow conduction in one direction when there is an applied gate pulse known as a firing pulse.

When carrying out the soft start, an electric signal is passed through the SCRs such that only the last sinus curve half period passes through. During this start, the electric signal is passed earlier, allowing bigger voltage parts to cross through the SCRs. Eventually, after passing a zero, the firing signal is passed, allowing all the voltage to pass across the thyristor too.

During the process of soft stop, the process is the opposite of the soft start. At the start, full voltage passes through the SCRs, and as the process of stopping proceeds, the firing signal is sent in a delayed mode allowing less voltage to go through the SCR until it gets to zero. After that, the motor receives zero voltage and comes to a stop.

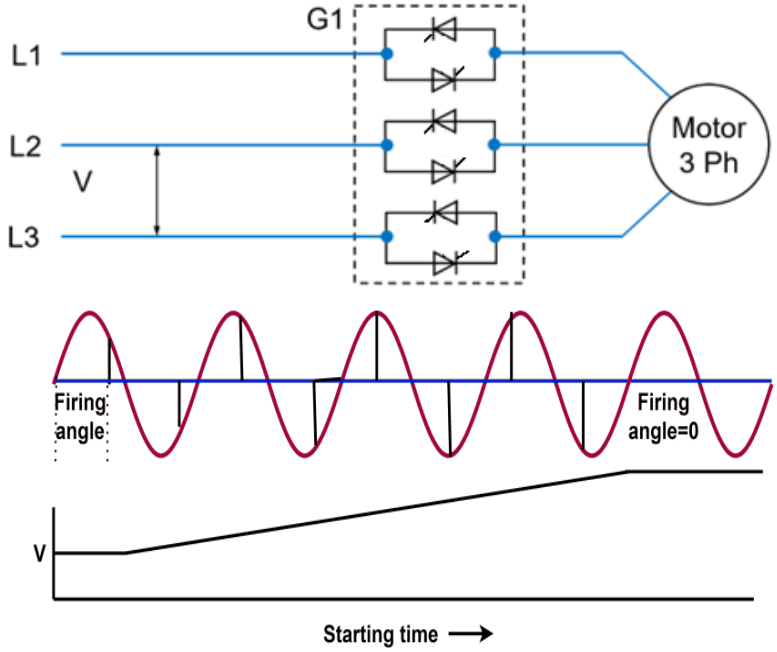


Figure 34: Starting Principle of Soft Starter

From the figure above, it is very clear the at the time of starting of motor the voltage applied to motor (V) is minimum by using the gate pulse with firing angle (α) near to 180° and which increases as the speed of the motor increases i.e. voltage is stepping up upto full line voltage with firing zero angle. It means, voltage applied to motor can be controlled by the adjusting the firing angle. Larger the firing angle lesser the voltage applied and lesser the firing angle larger the voltage applied.

Note:

Starter controls the voltage applied to motor at the starting time, which reduces the starting current and starting torque as compared to DOL starter and smoothen the starting of the motor.

6.1.4 Torque – Speed Characteristic

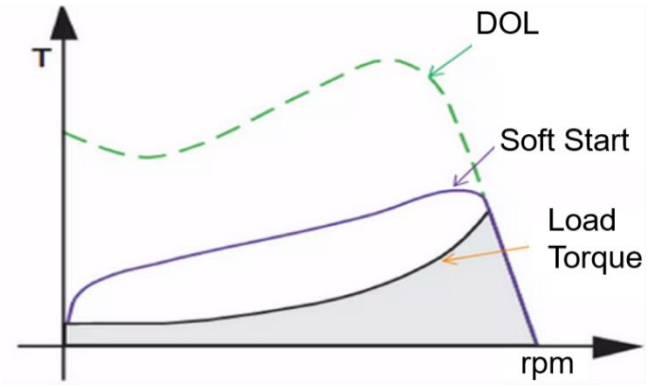


Figure 35: Torque – Speed Characteristic of Motor in Soft Starter

6.1.5 Current – Speed Characteristic

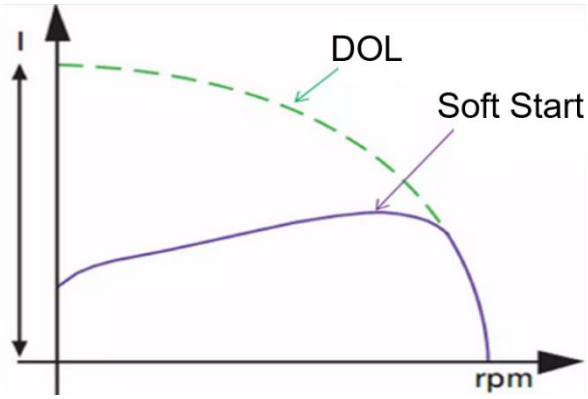


Figure 36: Current – Speed Characteristic of Motor in Soft Starter

6.2 ADVANTAGES, DISADVANTAGES AND APLLICATIONS

6.2.1 Advantages

- Unlike other types of motors, it offers gradual voltage increase hence a very smooth startup.
- Zero power surge since it limits the amount of current passing as a time.
- Motor acceleration and deceleration are adjustable by varying the soft starter firing angle.
- Some motor applications require multiple starts or stops at several intervals, the soft starter can do this without multiple starts and stops.
- Overheating is greatly reduced because it injects greatly low currents during startup.
- Offers an increased lifespan compared to conventional starters due to its smooth operation and lesser mechanical and electrical stresses within the motor windings.
- High and improved efficiency as compared to the conventional motor.

6.2.2 Disadvantages

- Soft starters are usually expensive.
- It does not regulate the speed of motor.
- It has a reduced starting torque.
- A build-up of heat greatly increases the internal temperature of the panel, so ventilation or cooling system should be effective.

6.2.3 Applications

Soft starters are widely used in applications like conveyors, centrifugal pumps (sanitation, irrigation, oil) fans, exhausters and blowers, air and refrigeration compressors, mixers, crushers and grinders where smooth operation and reduced electrical stress are critical.

CHAPTER 7

VARIABLE FREQUENCY DRIVES (VFDs)

A Variable Frequency Drive (VFD) is an advanced motor control device used to regulate the speed and torque of an AC motor by varying the motor's input frequency and voltage. It operates by converting fixed-frequency AC power into variable-frequency AC power. VFDs are widely used with three-phase induction motors to provide precise control over motor speed, improve energy efficiency, and enable smoother acceleration and deceleration.

The VFD consists of three main stages:

1. **Rectifier/ converter**, which converts AC input to DC using diodes or SCRs,
2. **DC Filter**, which filters/ convert the pulsating DC to DC using capacitors and inductors, and
3. I**nverter**, which converts the DC back to variable-frequency AC for the motor using IGBTs and PWM control.

A microcontroller controls the entire process, allowing real-time adjustments based on input parameters and feedback from the motor.



Figure 37: Typical VDF Starter

7.1 CIRCUITS OF VDF STARTER

Two types of circuits are in VDF one circuit deliver the power to the motor is power circuit and another circuit controls the operation or on/off of the motor, is control circuit.

7.1.1 Power Circuit

The power circuit of a Variable Frequency Drive (VFD) delivers the power to the motor. The supply power of fixed-frequency AC power converted into variable-frequency AC to control motor speed.

It consists of component of rectifier, DC filter and Inverter.

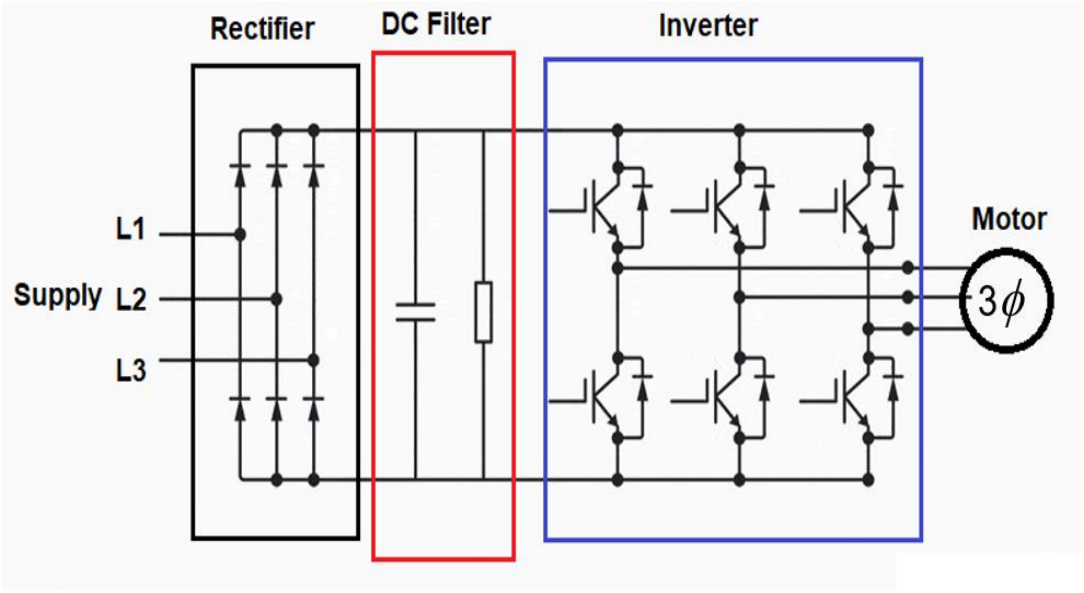


Figure 38: Circuit of Typical VFD Starter

7.1.2 Control Circuit

The control circuit of a VFD manages the motor speed and performance by controlling the power circuit. Controls circuit includes:

Microcontroller/DSP: Executes control algorithms like V/f or vector control and adjusts frequency/voltage.
PWM Generator: Produces signals to switch IGBTs in the inverter for smooth AC output.
Feedback Sensors: Monitor motor speed, current, and voltage for real-time control and protection.

7.1.3 Operation of Motor

A variable frequency drive takes in fixed AC voltage and frequency into a rectifier bridge to convert the voltage to DC, uses a capacitor bank and inductors to filter the DC, then inverts the DC voltage back to AC and sends it out to the motor at the frequency desired.

A microprocessor or digital signal processor (DSP) communicates with the PLC and monitor motor operation. Control circuitry coordinates the switching of power devices to activate the power components in the right sequence. The motor speed varies by changing the voltage and frequency supplied by the output devices.

Basic VFDs maintain motor torque by keeping the volts-to-frequency ratio constant. Advanced units use more intelligent & adaptive algorithms to improve motor performance. In short, a VFD convert one voltage and frequency to another level to change motor speed without losing torque in shown in figure below.

VFD main drive controller using a solid-state power electronics conversion system containing the rectifier bridge converter, a DC link or filter, and a switching or inverter section.

A monitoring and control interface, providing the operator or PLC a way to start and stop the motor, adjust the speed, change direction, etc. This interface also provides information about the operation of the motor, health of the drive, etc.

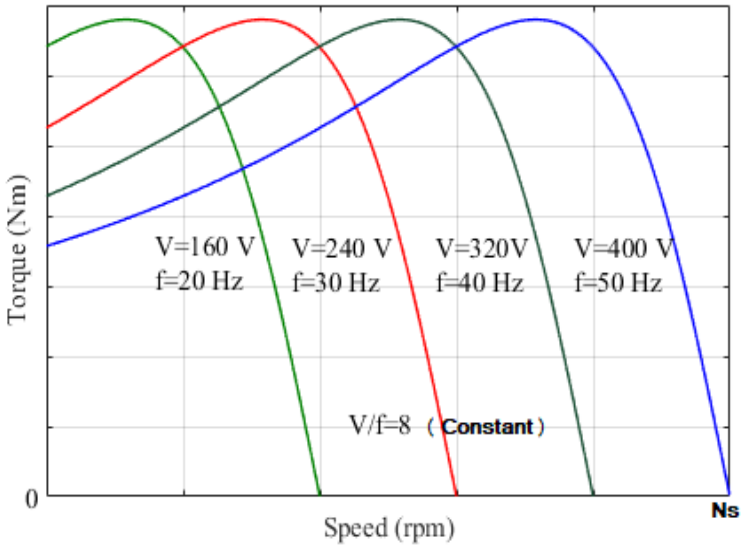


Figure 39: Torque-Speed characteristics in VFD starter with Constant V/f ratio

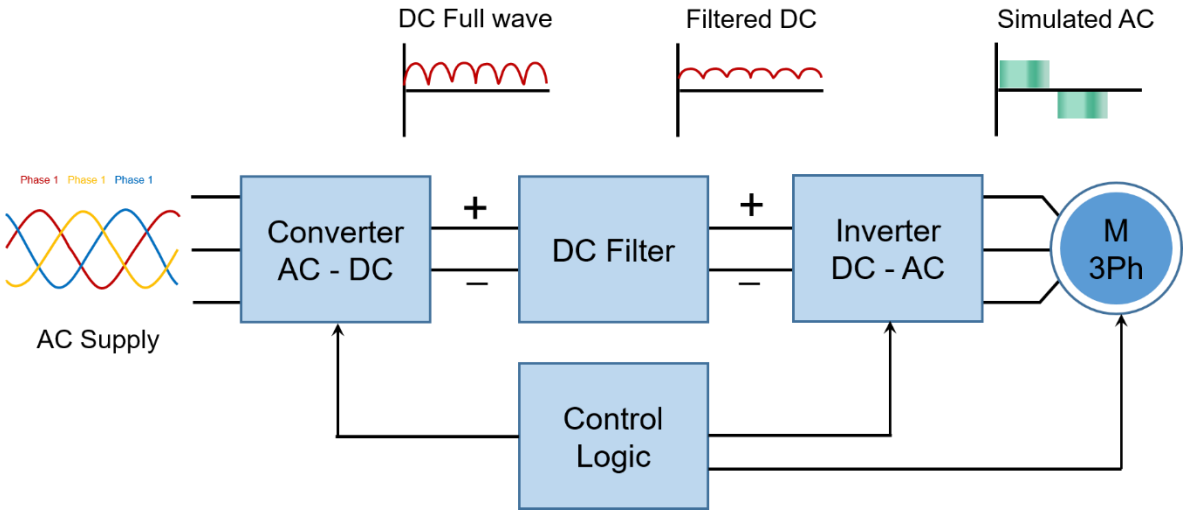


Figure 40: Block Diagram of VDF for Motor Starting

7.1.4 Torque – Speed and Current – Speed Characteristic

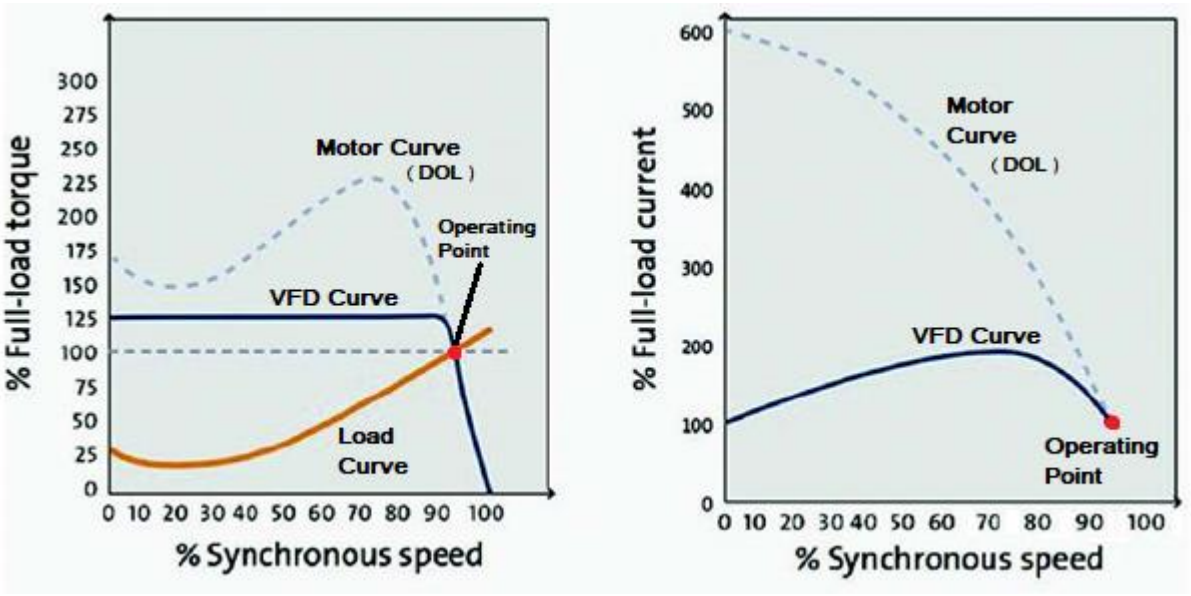


Figure 41: Torque & Current-Speed characteristics in VFD starter

Note:

In the above figures, it is clearly shown that the speed of the motor changes in proportional with frequency of applied voltage and changes in applied voltage adjust the torque (because the torque is proportional to square of voltage). Maintain the V/f ratio constant the torque & speed of the motor can be controlled as per the requirement of application. It is also clear that the starting current of motor can also be reduced significantly by using VFD starters.

7.2 ADVANTAGES, DISADVANTAGES AND APLLICATIONS

7.2.1 Advantages

- VFDs can significantly reduce energy consumption by adjusting the motor speed to match the load on the system.
- VFDs allow for precise control of the motor speed, allowing for better process control and improved product quality.
- Consumes very low motor starting currents.
- Has a relatively high-power factor.
- Enhanced the life by reducing mechanical and thermal stress on belts and motors during starting.

7.2.2 Disadvantages

- VFDs can be more expensive than other methods of motor control.
- It is more complex to install and maintain than other types of motor control systems.
- It can produce electrical harmonics that can interfere with other equipment or power systems.
- It generates heat that may need to be dissipated through the use of cooling fans or other cooling methods.

7.2.3 Applications

- Material transferring on the conveyor belt because it offers the smoothest starting.
- Automatic systems to open and close the gates since VFD operations have minimal noise.
- Hoist control and lifting of the materials due to reduced power consumption, less maintenance, and longer equipment life.

CHAPTER 8

SELECTION CRITERIA OF STARTING METHOD

The selection of motor starters depends on various factors to ensure optimal performance, reliability, and efficiency. Here is an elaboration on the key criteria:

- Power Capacity of Motor
- Type of Load and torque requirements
- Supply system capacity
- Cost and complexity considerations
- Application specific requirements

8.1 BASED ON POWER CAPACITY OF MOTOR

Selection of motor starter based on power capacity of motor involves matching the motor's starting requirements with an appropriate starting method. The table below summarizes the recommended starters for different Power capacity of motor:

Table 6: Starting Method based on Power Capacity of Motor

Motor Size (Approx.)	Starting Methods
Small (up to 10 HP)	DOL Starter
Medium (10-40 HP)	Star-Delta
Large (40–100 HP)	Star-Delta, Soft Starter, Autotransformer
Very Large (>100 HP)	Autotransformer, VFD

By considering motor size and power, you can select a starting method that ensures efficient, safe, and cost-effective operation.

8.2 BASED ON TYPE OF LOAD AND TORQUE REQUIREMENTS

Selection of motor starter based on type of load and torque requirements involves the characteristics of the load and ensuring the motor starter provides sufficient torque without causing excessive electrical or mechanical stress. The table below summarizes the recommended starters for different type of load and torque requirements:

Table 7: Starting Method based on Starting Torque of Load and torque requirements

Starting Torque of Load	Characteristic	Application	Starting Methods
Low Torque Loads	Load torque increases gradually as speed increases	Fans, centrifugal pumps, and blowers.	DOL Starter, Star-Delta Starter

Starting Torque of Load	Characteristic	Application	Starting Methods
Medium Torque Loads	Require moderate torque at startup.	Compressors, conveyors, and escalators.	Star-Delta Starter, Soft Starter, Autotransformer Starter
High Torque Loads	Require high torque immediately at startup to overcome static friction or load inertia. High mechanical stress during startup	Crushers, mills, hoists, and heavy-duty conveyors.	Autotransformer Starter, Soft Starter
Variable Torque Loads	Torque requirements vary with speed or load conditions.	Variable-speed pumps and fans, HVAC systems.	VFD
Constant Torque Loads	Torque remains constant irrespective of speed.	Conveyors, extruders, and mixers.	Soft Starter, Autotransformer Starter, VFD

By assessing the load type and torque requirements, you can choose a starting method that ensures efficient motor operation, reduces stress, and minimizes energy consumption

8.3 BASED ON SUPPLY SYSTEM CAPACITY

The selection of a motor starting method based on the supply system capacity focuses on the electrical network's ability to handle the motor's starting current without causing significant voltage drops or disturbances.

Key Factors to Consider for Supply System Capacity:

- System Voltage: Ensure the starter matches the system voltage (low voltage, medium voltage, or high voltage).
- Transformer Rating: Determine if the system transformer can handle the motor's starting current.
- Voltage Drop Tolerance: Identify how much voltage drop is permissible during startup to avoid affecting other equipment.
- Connected Load: Assess the sensitivity of other loads to voltage dips caused by motor startup. Supply system may be bifurcated into following parts

8.3.1 Supply System with High Capacity

Supply System with High Capacity can handle high inrush current without significant voltage drops. Minimal concern for system stability during motor startup.

8.3.2 Supply System with Moderate Capacity

Supply System with Moderate capacity can handle moderate inrush currents but may experience voltage dips during high-current startups. Requires a reduction in starting current for larger motors.

8.3.3 Weak Supply System

Weak supply system Common in rural or isolated areas with low power availability. Voltage drops can be critical, impacting connected devices.

The table below summarizes the recommended starters based on supply system capacity

Table 8: Starting Method based on Supply system capacity

Supply System Capacity	Impact of Motor Startup	Starting Methods
High Capacity	Minimal voltage dip	DOL Starter
Moderate Capacity	Considerable voltage dip	Star-Delta Starter, Soft Starter, Autotransformer Starter
Weak System	Critical voltage dip	Soft Starter, VFD

By evaluating the supply system's capacity, you can select a starting method that ensures the motor starts efficiently without compromising the stability of the power network.

8.4 BASED ON COST AND COMPLEXITY CONSIDERATIONS

The selection of a motor starting method based on cost and complexity requires balancing the initial investment, operational efficiency, and maintenance requirements. Factors to Consider in Cost and Complexity are as below:

- Initial Cost of starters
- Installation Complexity: Skilled personnel for installation and configuration are required or not.
- Maintenance Costs
- Operational Efficiency

Cost and solution/ maintenance requirements are bifurcated in three categories

8.4.1 Low-Cost and Simple Solution

Low-budget setups, non-critical systems, small-to-medium motors.

8.4.2 Moderate Cost and Complexity Solutions

Systems with medium budgets requiring reduced mechanical and electrical stress.

8.4.3 High-Cost and Advanced Solutions

Critical systems, large motors, or high-tech industrial applications requiring precise control.

Table 9 Starting Method based on cost and complexity considerations

Cost Category	Starting Methods	Advantages	Applications
Low Cost & Simple	DOL Starter, Star-Delta Starter	Affordable, easy to use, minimal maintenance	Small to medium motors, non-critical systems
Moderate Cost & Complexity	Soft Starter, Autotransformer	Smoother starts, reduced stress	Medium to large motors, moderate budgets
High Cost & Advanced	VFD	Precise control, energy-efficient	Large motors, critical applications

By considering cost and complexity, you can select a starting method that balances affordability with performance, ensuring efficient operation and long-term reliability.

8.5 BASED ON APPLICATION SPECIFIC REQUIREMENTS

The selection of a motor starting method based on application-specific requirements involves tailoring the starting method to the unique demands of the application, including torque, speed control, system stability, and operational constraints. The table below summarizes the recommended starters based on application specific requirement

Table 10: Based on application specific requirements

Application Type	Requirements	Application	Starting Methods
High Starting Torque	High torque at startup	Crushers, mills, hoists, heavy-duty conveyors.	Autotransformer Starter, Soft Starter
Precise Speed Control	Adjustable speed, precise control	HVAC systems, conveyors, mixers, variable-speed pumps.	VFD
High Inertia Loads	Controlled acceleration	Large fans, centrifuges, flywheels.	Soft Starter, VFD
Frequent Starts and Stops	Durable, frequent cycling	Elevators, cranes, hoists.	Soft Starter, VFD
Limited Power Supply	Minimize starting current	Rural or isolated industrial setups, backup generator-powered systems.	Star-Delta Starter, Soft Starter, VFD
Low Starting Torque	Simple and economical	Centrifugal pumps, fans, blowers.	DOL Starter, Star-Delta Starter
Critical and Sensitive Applications	Smooth, reliable, and protective startup	Process industries, power plants, data centers.	VFD, Soft Starter

By analyzing the specific requirements of an application, you can select a starting method that optimally meets performance, reliability, and operational goals.

CHAPTER 9

MANITENANCE & TROUBLESHOOTING FOR COMMON FAILURES

9.1 MAINTENANCE

Starters controls the high electrical currents, and poorly maintained starters can lead to electrical hazards such as short circuits, sparks, or overheating. Regular maintenance ensures these protective devices functioning correctly. Maintenance also minimizes the risk of sudden breakdowns, minimize wear and tear of components and ensure smooth & continuous operation. Regular checks and timely repairs eliminate potential safety risks to personnel and equipment.

9.1.1 General Check Points of Maintenance for Each type of Starter

- ✓ **Environmental Control**: Keep the starter enclosure clean, dry, and free from dust and moisture.
- ✓ **Connection Tightness**: Regularly check and tighten all electrical connections to avoid sparking and overheating.
- ✓ **Contactor:** Clean the contact points of contacts for dust & carbon deposits and also check the physical condition, replace if worn out.
- ✓ **Thermal Imaging**: Use thermal imaging to detect hotspots in electrical components (if possible).
- ✓ **Lubrication**: For starters with moving parts, apply appropriate lubrication where necessary.
- ✓ **Visual Inspection**: Look for signs of overheating or insulation damage.
- ✓ **Periodic Testing**: Perform functional tests under no-load and load conditions to ensure all components operate correctly.
- ✓ **Documentation**: Maintain a detailed maintenance log, recording inspections, replacements, and adjustments.

Note:

Don't open the relays for maintenance purpose.

9.1.2 Specific Maintenance Activities for Each Type of Starter

9.1.2.1 Direct-On-Line (DOL) Starter

DOL starters are simple and commonly used for small motors. They require regular inspection and cleaning to ensure proper functionality.

Some of major maintenance activities are as given below:

- ➢ **Overload Relay Testing**: Verify the overload relay settings to match motor ratings and ensure it trips during load conditions.
- ➢ **Push Buttons**: Check the functionality of the start and stop push buttons. Replace if faulty.
- ➢ **Indication lamps**: Check all the indication lamps are working. Replace if found faulty.

9.1.2.2 Star-Delta Starter

Star-delta starters have more components compared to DOL, requiring additional attention to ensure smooth transition from star to delta mode.

Following maintenance activities to be done:

- **Timer Adjustment:** Check the timer settings to ensure proper delay for star-to-delta transition.
- **Transition Smoothness:** Monitor the transition between star and delta modes for any jerks or delays.
- **Overload Relay:** Test the thermal overload relay for proper operation.
- **Mechanical Components:** Ensure the mechanical interlocking between star and delta contactors is functional.

9.1.2.3 Auto-Transformer Starter

Auto-transformer starters involve additional components, such as transformers, which require specific checks.

Typical checks/ inspection/ check points during maintenance:

- **Transformer Inspection:** Check for winding overheating, humming noise & insulation damage and insulation resistance testing.
- **Tap Settings:** Verify the tap connections and settings for correct voltage ratios.
- **Overload Relay:** Test the thermal overload relay for proper operation.
- **Cooling System:** Ensure proper ventilation or cooling of the transformer.

9.1.2.4 Soft Starter

Soft starters use electronic circuitry to control motor starting, requiring minimal physical components to maintain.

Some of the main activities are given below:

- **Cooling System:** Check cooling fans and heat sinks for dust or blockage.
- **Power Modules:** Inspect thyristors or SCRs for damage or overheating.
- **Control Parameters:** Verify and recalibrate control settings, such as acceleration and deceleration time.
- **Firmware Updates:** Update the firmware to the latest version, if applicable.

9.1.2.5 Variable Frequency Drive (VFD) Starter

VFDs involve advanced electronics, and their maintenance requires specialized knowledge.

Various inspection points are:

- **Cooling System:** Clean air filters and ensure cooling fans are operational for cooling & ventilation.
- **Power Components:** Inspect IGBT modules for signs of wear or overheating.
- **Control Parameters:** Verify and recalibrate control settings as per the application.
- **Harmonics Check:** Monitor and mitigate harmonics in the system using appropriate filters.
- **Capacitor Health:** Test DC bus capacitors for leakage or deterioration.

Note:

(1) Activities mentioned in para 9.1.2 (Specific Maintenance Activities for Each Type) of Starter are in addition to activities mentioned in para 9.1.1 (General Check Points of Maintenance for Each type of Starter).

(2) These are typical activities for maintenance but before the maintenance please check the recommendation of OEMs form the same and do accordingly.

9.2 TROUBLESHOOTING

Troubleshooting is the approach to identifying, diagnosing, and resolving issues in electrical or mechanical systems. In motor starters, such as DOL, Auto-transformer, Star-Delta, Soft Starters, and VFDs, troubleshooting involves examining the symptoms, checking electrical components, verifying settings, and inspecting mechanical loads. This ensures the reliable operation of the motor while minimizing downtime.

Troubleshooting of different type of starters are given under:

9.2.1 DOL Starter

Table 11: A troubleshooting for most common possible issues in a Direct-On-Line (DOL) starter

Common Problem	Possible Cause	Troubleshooting Steps
Motor fails to start	– Power supply issue: No voltage, phase loss, or imbalance. – Faulty main contactor or control circuit. – Blown fuses or tripped MCB.	1. Verify power supply and phase balance. 2. Inspect the main contactor and control wiring for faults. 3. Check and replace blown fuses.
Excessive starting current	– Short circuit in motor windings or cables. – Overloaded motor. – Mechanical jamming of the load.	1. Test motor winding resistance. 2. Verify motor rating against the load. 3. Inspect the load for mechanical obstructions.
Frequent tripping	– Overload relay settings too low. – Motor drawing high current due to overload or fault. – Phase imbalance or loss.	1. Check and recalibrate overload relay settings. 2. Test motor winding insulation. 3. Inspect and correct phase imbalance.
Motor runs but stops abruptly	– Undervoltage or supply fluctuations. – Loose wiring in the control circuit. – Overload relay activation.	1. Measure and stabilize supply voltage. 2. Tighten control circuit connections. 3. Inspect and adjust overload relay settings.
Motor hums but does not start	– Low voltage or single-phasing. – Faulty or stuck main contactor. – High load torque at start-up.	1. Measure voltage across all phases. 2. Inspect and clean or replace the main contactor. 3. Reduce load or start without load.
Overheating of motor	– Continuous overloading of motor. – Prolonged starting duration. – Faulty bearings or insufficient cooling.	1. Verify the motor is not overloaded. 2. Check for smooth motor start. 3. Inspect cooling fan and motor bearings.

Common Problem	Possible Cause	Troubleshooting Steps
Contactor chatter or noise	– Low control voltage – Loose contactor mounting – Damaged coil.	1. Check and stabilize control voltage. 2. Tighten contactor mounting. 3. Replace defective contactor components.
Starter does not energize	– Control circuit wiring fault. – Faulty pushbutton or relay. – Coil of contactor is open or damaged.	1. Inspect wiring and connections in the control circuit. 2. Test pushbuttons and relays for proper operation. 3. Measure coil resistance and replace if faulty.
Motor starts but runs at low speed	– Voltage drop or weak supply. – Motor winding damage or incorrect connections. – High load resistance.	1. Measure voltage at motor terminals. 2. Test motor winding continuity and connections. 3. Reduce load and retest.
Starter overheating	– Prolonged duty cycle or overload conditions. – Loose or corroded electrical connections. – Faulty contactor contacts.	1. Ensure the starter is not exceeding its duty cycle. 2. Tighten or clean all electrical connections. 3. Replace worn contactor contacts.

9.2.2 Auto Transformer Starter

Table 12: A troubleshooting for most common possible issues in an Auto Transformer starter

Common Problem	Possible Cause	Troubleshooting
Motor Fails to Start	– Power Supply Issues: Incoming power is absent, unbalanced, or low. – Faulty Contactors: Main or start contactor not engaging. – Control Circuit Faults: Defective control relay, timer, or wiring.	1. Check the power supply voltage and ensure all phases are present and balanced. 2. Test the continuity and coil resistance of contactors using a multimeter. 3. Inspect the control circuit for loose wires or faulty components. Verify timer operation. 4. Bypass the control circuit temporarily to test direct starting.
Excessive Starting Current	– Incorrect Tapping Selection: Auto-transformer tapping set too high. – Short Circuits: Fault in the motor windings or cables. – Mechanical Load Issue: The motor is overloaded or jammed.	1. Verify the auto-transformer tapping setting and adjust it to a lower voltage ratio. 2. Check motor winding resistance to detect short circuits or imbalances. 3. Inspect the mechanical load for obstructions or excessive friction.

Common Problem	Possible Cause	Troubleshooting
Auto-transformer Overheating	– Continuous Duty: Auto-transformer is not switching out after starting. – Overload Conditions: The motor is drawing higher current than rated. – Improper Ventilation: Poor airflow around the starter.	1. Check the timer and transition contactor operation to ensure the auto-transformer switches out post-startup. 2. Measure motor current with a clamp meter and compare it to the nameplate rating. 3. Ensure the auto-transformer has adequate ventilation. Clean any accumulated dust.
Motor Runs with Reduced Performance	– Auto-transformer Stuck in Start Position: Contactors fail to transition to full voltage. – Voltage Drop: Excessive drop in supply voltage. – Winding Damage: Motor windings partially damaged.	1. Check transition contactor operation and timer settings. Ensure a smooth transition to full voltage. 2. Measure voltage at the motor terminals during running and starting phases. 3. Perform an insulation resistance test on motor windings.
Starter Does Not Transition to Full Voltage	– Timer Failure: Timer not initiating the transition sequence. – Transition Contactor Fault: Contactor coil or contacts are defective. – Control Circuit Issue: Faulty wiring or auxiliary relays.	1. Inspect the timer and test its operation with a multimeter. 2. Test the continuity and operation of the transition contactor. 3. Check control circuit connections and test auxiliary relays.
Unusual Noise or Vibrations	– Loose Components: Vibrations due to loose connections or parts. – Faulty Contactor: Buzzing noise from a defective or poorly seated contactor. – Mechanical Load Issues: Misalignment or imbalance in the load.	1. Tighten all electrical connections and mounting screws. 2. Inspect contactors for buzzing; replace worn-out components. 3. Check for load alignment and balance. Inspect for any mechanical damage.
Frequent Tripping	– Overload Relay Set Too Low: Overload relay setting incorrectly calibrated. – Phase Imbalance or Loss: Motor drawing uneven current. – Motor or Cable Fault: Insulation breakdown or winding failure.	1. Verify and adjust overload relay settings according to the motor nameplate data. 2. Check for phase imbalance using a multimeter or clamp meter. 3. Test the motor and cable insulation resistance with a megger.

Common Problem	Possible Cause	Troubleshooting
Motor Starts but Stops Abruptly	– Undervoltage or Voltage Fluctuations: Inconsistent supply voltage. – Loose Control Connections: Intermittent control circuit faults. – Overload Relay Activation: Motor drawing excessive current due to overload.	1. Monitor supply voltage for fluctuations. Stabilize the power supply if needed. 2. Inspect all control wiring and tighten loose connections. 3. Verify overload relay settings and check for mechanical overload.

9.2.3 Star Delta Starter

Table 13: A troubleshooting for most common possible issues in a Star-Delta starter

Common Problem	Possible Cause	Troubleshooting
Motor fails to start	– Power supply issue: No voltage, phase loss, or imbalance. – Faulty contactors (star or main). – Control circuit fault or timer malfunction.	1. Check the power supply and ensure phase balance. 2. Test the continuity of contactors and inspect control wiring. 3. Verify timer operation.
Excessive starting current	– Incorrect star-delta transition timing. – Short circuit in motor windings. – Load is too heavy.	1. Adjust the timer for proper star-to-delta transition. 1. Test motor winding resistance for faults. 2. Reduce load or start the motor without a load.
Motor runs but stops abruptly	– Overload relay activation. – Undervoltage or supply fluctuations. – Loose connections in the control or power circuits.	1. Check and adjust overload relay settings. 2. Stabilize the power supply voltage. 3. Inspect and tighten all connections.
Motor hums but does not start	– Stuck contactor (star or main). – Low voltage or single-phasing. – High load torque preventing start-up.	1. Inspect and replace faulty contactors. 2. Measure voltage across all phases. 3. Reduce the load and retest.
Motor does not switch to delta	– Faulty delta contactor. – Timer not functioning properly. – Control circuit wiring issue.	1. Test the delta contactor coil and contacts. 2. Verify and adjust the timer.

Common Problem	Possible Cause	Troubleshooting
		3. Inspect and repair control circuit connections.
Motor overheats	– Incorrect star-to-delta timing. – Prolonged operation in star mode. – Overload or poor cooling.	1. Adjust the timer for proper timing. 2. Ensure a quick and smooth transition to delta mode. 3. Inspect cooling fans and verify motor is not overloaded.
Contactors chatter or buzz	– Low control voltage. – Loose or misaligned contactor components. – Faulty contactor coil.	1. Check and stabilize control voltage. 2. Tighten contactor mounting and clean contacts. 3. Replace defective contactor components.
Motor runs at reduced speed	– Star-delta transition failure (motor stuck in star mode). – High load resistance. – Voltage drop at motor terminals.	1. Test the delta contactor and control circuit. 2. Reduce mechanical load and retest. 3. Measure and stabilize voltage at motor terminals.
Starter does not energize	– Control circuit fault. – Faulty pushbuttons, timer, or relays. – Open or damaged contactor coil.	1. Inspect control circuit wiring. 2. Test pushbuttons, timer, and relays. 3. Measure and replace defective contactor coils.
Frequent tripping	– Overload relay set too low. – Motor drawing high current due to overload or fault. – Phase imbalance or supply issues.	1. Verify and recalibrate overload relay settings. 2. Test motor insulation and winding resistance. 3. Check and correct phase imbalance.

9.2.4 Soft Starter

Table 14: A troubleshooting for most common possible issues in a Soft starter

Common Problem	Possible Cause	Troubleshooting
Motor fails to start	– Power supply issue: No voltage, phase loss, or imbalance. – Faulty soft starter power circuit. – Control signal not received by the soft starter.	1. Check incoming power supply and ensure all phases are present. 2. Inspect power circuit components (SCRs, fuses, etc.). 3. Verify control signal from the PLC or pushbuttons.

Common Problem	Possible Cause	Troubleshooting
Motor starts but trips immediately	– Overcurrent protection activated. – Incorrect soft starter settings. – Motor fault or mechanical overload.	1. Measure starting current and adjust ramp-up settings. 2. Verify soft starter overload protection settings. 3. Inspect motor and mechanical load for faults.
Excessive starting current	– Ramp-up time set too short. – SCRs malfunctioning and not limiting current properly. – Motor starting under heavy load.	1. Increase ramp-up time in soft starter settings. 2. Test SCRs for proper operation. 3. Start the motor with a reduced load if possible.
Motor does not reach full speed	– Soft starter stuck in current-limiting mode. – Faulty bypass contactor. – Low supply voltage or high load torque.	1. Verify ramp-up settings and ensure bypass contactor engages. 2. Measure supply voltage at the motor terminals. 3. Inspect the load for mechanical resistance.
Motor overheats	– Ramp-up or ramp-down times too long. – Motor running under overload conditions. – Improper cooling or poor ventilation.	1. Reduce ramp-up and ramp-down times. 2. Verify motor load and ensure it matches the rated capacity. 3. Check motor cooling system and ventilation.
Soft starter does not respond	– No control signal or incorrect wiring. – Faulty control circuit or damaged soft starter components. – Blown internal fuse or power supply fault.	1. Verify control circuit wiring and test signal inputs. 2. Inspect internal fuses and power components. 3. Reset or replace the soft starter if necessary.
Unusual noise during startup	– SCRs switching improperly. – Excessive mechanical load on the motor. – Loose or damaged motor mounts.	1. Test SCRs and inspect the soft starter for harmonic issues. 2. Reduce the load during startup. 3. Inspect motor mounts and connections.
Frequent tripping	– Overload or overcurrent settings too sensitive. – Supply voltage fluctuations or phase imbalance. – Faulty motor or wiring.	1. Recalibrate overload and overcurrent settings. 2. Check and stabilize supply voltage. 3. Test motor windings and insulation resistance.

Common Problem	Possible Cause	Troubleshooting
Bypass contactor does not engage	– Faulty bypass contactor coil or wiring. – Control circuit fault or delayed signal. – Insufficient voltage to operate the contactor.	1. Test bypass contactor operation and wiring. 2. Verify control circuit timing and settings. 3. Measure voltage at the contactor coil terminals.
Soft starter overheating	– Excessive duty cycle or prolonged ramp times. – Faulty SCRs generating excessive heat. – Inadequate cooling or blocked ventilation.	1. Reduce the duty cycle or adjust ramp-up/down times. 2. Test SCRs for proper operation. 3. Ensure soft starter cooling fans and vents are clean and functional.

9.2.5 Variable Frequency Drives Starter

Table 15: A troubleshooting for most common possible issues in a VFD starter

Common Problem	Possible Cause	Troubleshooting
Motor fails to start	– No input power to the VFD. – Faulty start command signal. – Incorrect VFD parameter settings.	1. Verify the VFD power supply and check for blown fuses or tripped breakers. 2. Check control wiring and ensure the start command is being sent. 3. Review and adjust VFD settings (eg., frequency, acceleration).
Motor starts but trips immediately	– Overcurrent or overload protection activated. – Motor acceleration time set too short. – Incorrect motor parameter settings.	1. Measure current and verify load against motor and VFD ratings. 2. Increase acceleration time in the VFD settings. 3. Configure motor parameters correctly (e.g., voltage, frequency, poles).
Motor does not reach desired speed	– Maximum frequency or speed limit set too low. – Load is too heavy for the motor. – Input voltage or current imbalance.	1. Check and increase maximum frequency and speed settings in the VFD. 2. Inspect the load and reduce if necessary. 3. Verify input voltage and ensure proper phase balance.
Motor runs but overheats	– Motor running at low speed for prolonged periods without proper cooling. – Excessive load on the motor.	1. Ensure motor cooling is adequate at low speeds. 2. Reduce load or adjust motor operation parameters.

Common Problem	Possible Cause	Troubleshooting
	– VFD carrier frequency set too high.	3. Lower the carrier frequency setting to reduce heat.
VFD does not respond to commands	– Faulty control wiring or communication failure. – Incorrect control mode selection (e.g., local/remote). – VFD locked out due to previous fault.	1. Inspect and test control wiring and communication ports. 2. Verify and set the correct control mode (local or remote). 3. Reset the VFD and clear fault logs.
Frequent tripping of VFD	– Overvoltage or undervoltage issues. – Motor overload or stalling. – Harmonic interference or noise.	1. Monitor input voltage and stabilize if necessary. 2. Inspect load conditions and reduce if required. 3. Install line reactors or filters to mitigate harmonics.
Unusual noise during operation	– High carrier frequency causing noise. – Loose or faulty motor connections. – Motor bearings or mechanical issues.	1. Reduce the VFD carrier frequency setting. 2. Tighten motor connections and inspect wiring. 3. Check motor bearings for wear or damage.
Motor speed fluctuates	– Input voltage or frequency instability. – Incorrect PID control settings. – Faulty feedback sensor (if applicable).	1. Stabilize the input power supply. 2. Tune PID control parameters in the VFD. 3. Test and replace faulty sensors.
VFD overheating	– Prolonged operation at high load. – Inadequate cooling or blocked ventilation. – VFD ambient temperature too high.	1. Reduce load or adjust duty cycle. 2. Clean and unblock cooling vents or fans. 3. Ensure VFD is installed in a suitable environment.
Display shows fault codes	– Fault conditions such as overcurrent, overvoltage, or under voltage. – External fault triggers (eg., motor thermal protection).	1. Refer to the VFD manual for fault code descriptions. 2. Address the underlying issues (eg., check voltage, load conditions, or motor temperature).

Note:

These are the typical troubleshooting, please refer the recommendations of OEM for troubleshooting of respective starters.

REFERENCE

1. Bureau of Indian Standard “Low-Voltage Switchgear and Controlgear, Part 4 Contactors and Motor-Starters, Section 1 Electromechanical Contactors and Motor-Starters” IS/IEC 60947 Part 4 Sec 1: 2020 RE 2023.

2. Bureau of Indian Standard ““Low-Voltage Switchgear and Controlgear, Part 4 Contactors and Motor-Starters, Section 2 Semiconductor Motor Controllers, Starters and Soft Starters” IS/IEC 60947 Part 4 Sec 2: 2020.

3. Book **Electrical Technology Vol-II,** AC & DC Machine by BL Thareja

4. M/s ABB HandBook on Soft Starters.

5. M/s Nidec Handbook “**An engineering guide to soft starters.**

6. M/s Schneider Electric Handbook on Motor Starters.

7. Various documents received from M/s Lauritz Knudsen Electrical & Automation.

8. Some of the content from Internet.

NOTES

CONTACT US

CAMTECH is continuing its efforts in the documentation and up-gradation of information on maintenance practices of electrical assets. Over the years a large number of publications on electrical assets have been prepared in the form of handbooks, pockets books, pamphlets and video films, etc. These publications have been uploaded on the internet as well as rail net.

Link for downloading CAMTECH publications:

On internet visit: https://indianrailways.gov.in/

Or

On Railnet visit Railway Board website at http://10.1.2.21/

Go to Indian Railways → Directorates → Efficiency & Research → CAMTECH, Gwalior → Publications for download

Or

Link for directly download the Publications:

https://indianrailways.gov.in/railwayboard/view_section.jsp?lang=0&id=0,1,304,366,538,2713,2718,2722

For any further information, regarding publications please contact:

Jt. Director (Elect.) BSNL	:	0751- 2470740 (O)
Rly.	:	03747202
SSE/ Electrical	:	8957022145 (CUG)
E-mail	:	direlcamtech@gmail.com
Fax	:	0751- 2470841
Write at	:	Director (Electrical)

Indian Railways, Centre for Advanced Maintenance Technology
In front of Hotel Adityaz, Airport Road, Maharajpura, Gwalior, Pin Code-474005.



Government of India - Ministry of Railways

INDIAN RAILWAYS

CENTRE FOR ADVANCED MAINTENANCE TECHNOLOGY

Maharajpura, Gwalior, M.P. 474 005