MOTOR STARTERS

Contents to be covered:

1. Motor Control Centers.
2. DOL Starter.
3. Star / Delta Starter.
4. Soft Starter.
5. Variable Frequency Starter.

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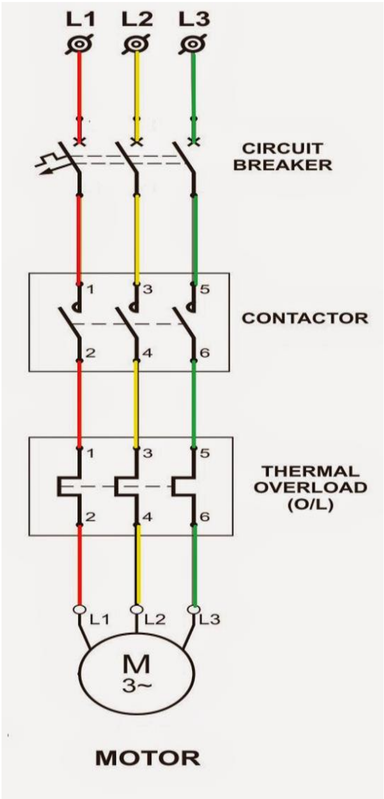
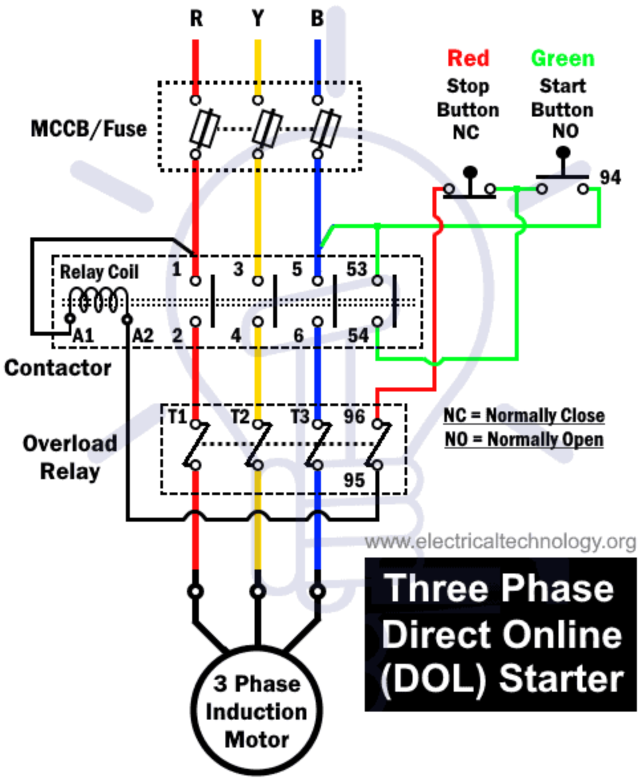
TYPES OF TECHNIQUES USED FOR THE MOTOR STARTERS

1. Full Voltage or Across the Line Starters.
2. Full Voltage Reversing Starters.
3. Multi-speed Starter.
4. Reduced Voltage Starter.

FULL VOLTAGE / ACROSS THE LINE STARTERS

1. This type of starters directly connect the motors with the power lines providing the full voltage.
2. The motors connected through such starters have low power ratings so that they do not create a huge voltage drop in the power lines.
3. They are used in applications where motors have low ratings & need to run in one direction.
4. This is called as *DOL starter* in the Industry.





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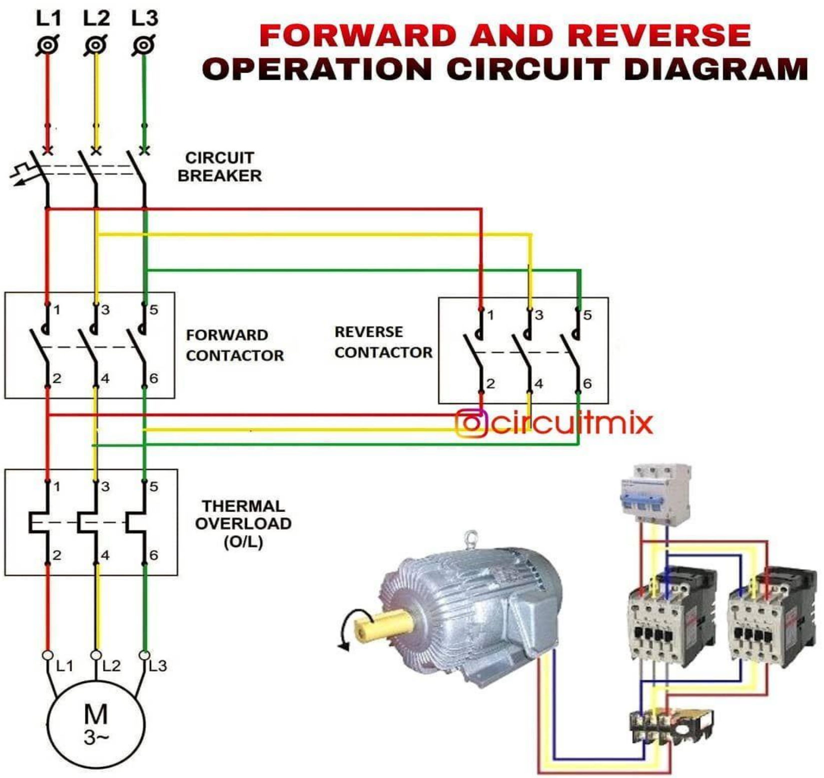
FULL VOLTAGE REVERSING STARTERS

1. Three phase induction motors can be reversed by swapping any two phases.

2. Such as starter incorporates two mechanically and electrically interlocked magnetic contactors with swapped phases for forward and reverse operation.

3. It is used in applications where the motor needs to run in both directions.



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MULTI-SPEED STARTERS

1. These starters are used to vary the speed of an AC motor.

2. Strategies for varying the speed of an AC motors:

   (a) Vary the AC supply frequency.

   (b) Vary the number of poles by reconnecting the windings.

$$\textbf{Speed} = \frac{\textbf{60f}}{\textbf{P}}$$

Where, D

f = frequency of the AC supply.
P = Number of pole pairs.

Example: What is the speed of a 4 poles AC induction motor at a supply frequency of 50 Hz?

Solution: *Use the above formula.*

P = 2 and f = 50 Hz.

*Speed (N) = (60*50) / 2 rpm.*

N = 1500 rpm.

REDUCED VOLTAGE STARTERS

1. This starter is used to reduce the voltage at the starting of the motor to reduce the inrush current that could damage the windings of the motor and also cause a huge dip in the voltage.

2. These starters are used for high rated motors.

3. The following starters are the example of "reduced voltage starters". Those are

   (a) *"Start-Delta" or "Wye-Delta" Starter.*

   (b) *"Autotransformer" Starter.*

   (c) *"Electronic Soft" Starter.*

TYPES OF MOTOR STARTERS

Based on the techniques learned in the previous slides, the following types of motor starters are used in the industry. Those are

- Direct Online Starters (DOL).
- Stator Resistance Starters.
- Rotor Resistance or Slip Ring Motor Starters.
- Autotransformer Starters.
- Start - Delta Starters.
- Soft Starters.
- Variable Frequency Driver (VFD) Starters.

DIRECR ONLINE (DOL) STARTERS

1 This is the simplest form of motor starter that connects the motor directly to the power supply.

2. This consists of a *magnetic contactor* that connects the motor with the power supply.

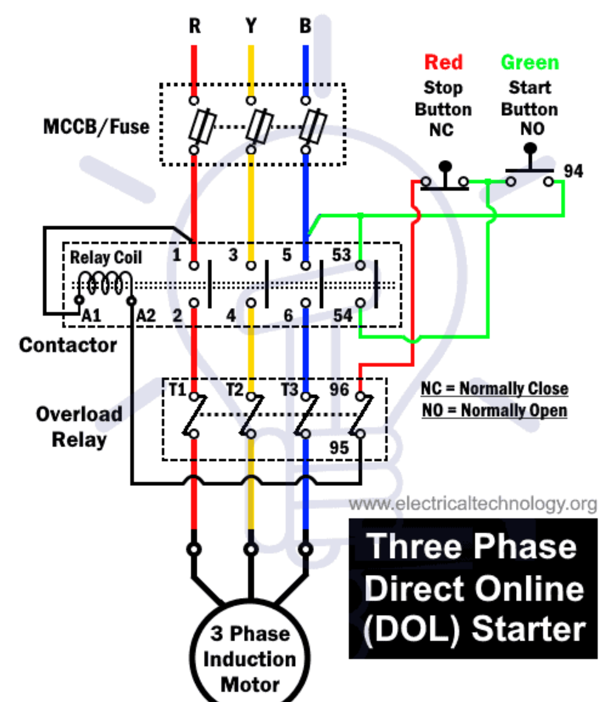
3. This consists of an "*overload relay*" for the protection against overcurrent.

4. There is no voltage reduction for safe starting of the motor.

5. Therefore, the motor used with DOL starter has below *5 hp* ratings. In some Countries, the Authorities allow the usage of DOL starters for higher rated motors also. For example,
   Sri Lanka – DOL can be used up to 5.5kW.
   U.A.E – DOL can be used up to 7.5kW.

Advantages:

- *It has very simple and cost-effective design.*
- *It very easy to understand and operate.*
- *It provides high starting torque due to high starting current.*



Disadvantages:

- *The high inrush current can damage the windings.*
- *The high inrush current causes voltage dip in the power line.*
- *It is not suitable for heavy motors.*
- *It can decrease the life span of the motor.*

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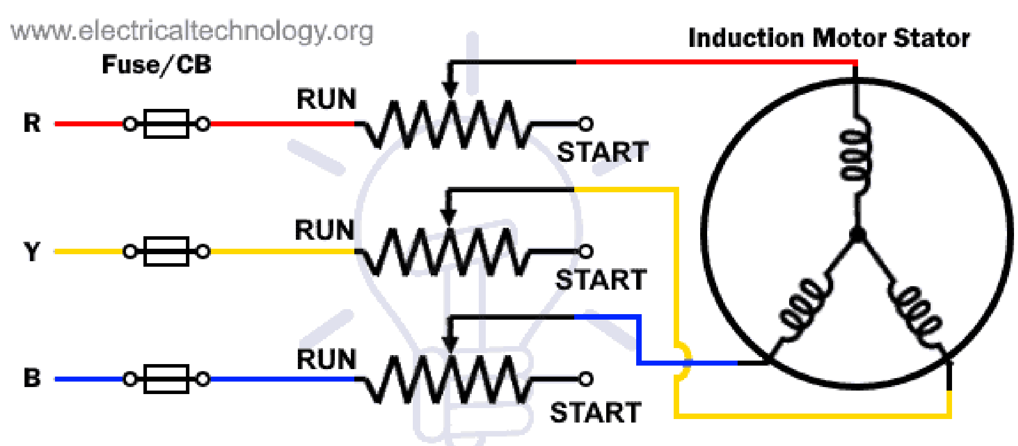
STATOR RESISTANCE STARTERS

1. External resistance is added in series with each phase of a 3-phase induction motor's stator.
2. The resistor's job is to reduce the line voltage (subsequently reducing the initial current) applied to the motor.
3. Initially, the variable resistor is kept at maximum position offering maximum resistance. Therefore, the voltage across the motor is minimum (in safe level) due to the voltage drop across the resistor.
4. The low stator voltage limits the starting inrush current that can damage the motor windings. As the motor picks up the speed, the resistance is reduced & the stator phase is directly connected to the power lines.
5. The initial starting torque is very low.



Stator Resistance starter

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ROTOR RESISTANCE OR SLIP RING STARTERS

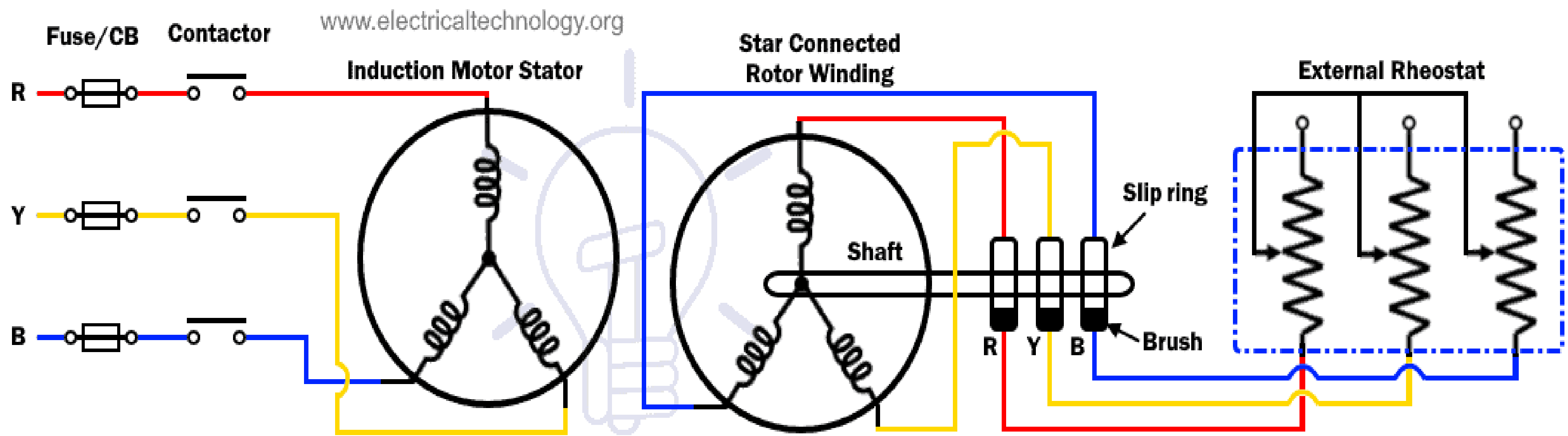
1. This type of motor starter works on a full voltage motor starting technique.

2. It works only on slip ring induction motor and that's why it is known as a slip ring motor starter.

3. External resistances are connected with the rotor in star combination through the slip ring.

4. These resistors limit the rotor current & increase the torque.

5. This, in turn, reduces the starting stator current. It also helps in improving the power factor.



Rotor Resistance or Slip Ring Motor Starter

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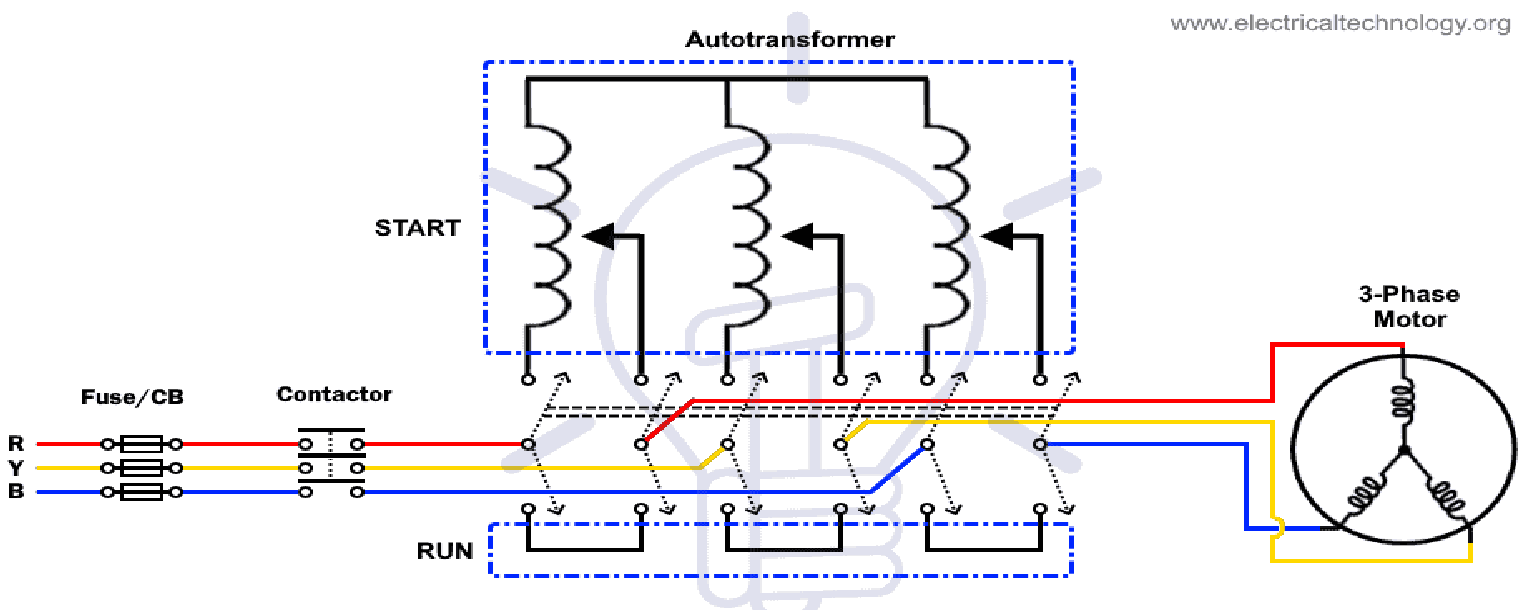
AUTOTRANSFORMER STARTERS

1. This type of motor starter uses an Autotransformer as a step-down transformer to reduce the voltage applied to the stator during the starting stage. It can be connected to both star & delta connected motors.

2. The autotransformer's secondary is connected with each phase of the motor.

3. During starting, the relay is at the start position i.e., the tap point provides a reduced voltage for the startup. The relay switches between the tap points to increase the voltage with the speed of the motor. At last, it connects it with the full rated voltage.



Autotransformer Motor Starter

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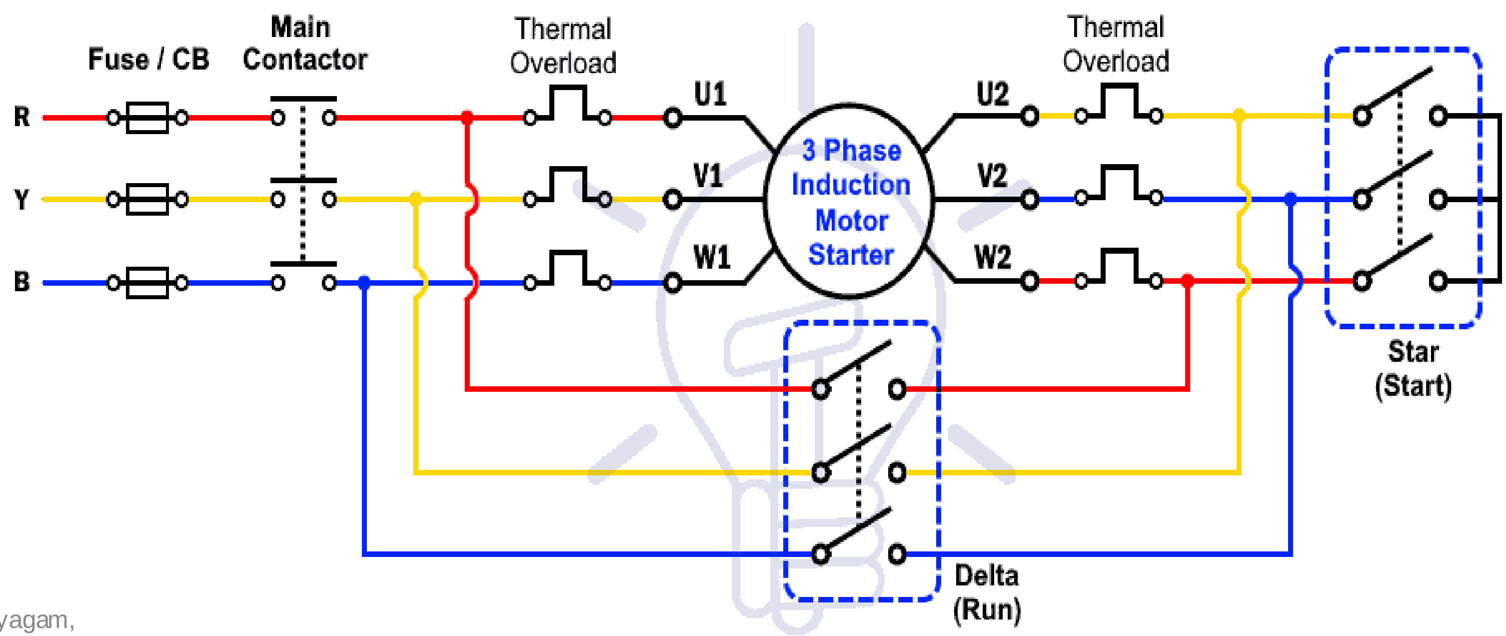
STAR – DELTA STARTERS

1. This is another common starting method used in industries for large motors. The windings of 3 phase induction motor are switched between star and delta connections to start the motor.

2. During the start of an induction motor, it is connected in star using a triple pole contactor. The phase voltage in star connection is reduced by the factor of $1/\sqrt{3}$ and it reduces the starting current as well as the starting torque by 1/3 of the normal rated value.

3. When the motor accelerates, a timer relay switches the "star connection" of the stator windings into the "delta connection", allowing the full voltage across each winding. The motor runs at rated speed.



Star Delta Starter

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STAR – DELTA STARTERS

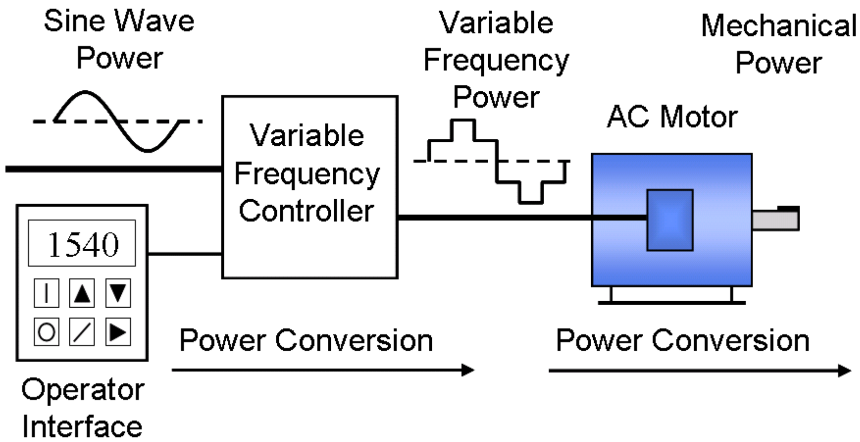
Advantages:

- Its design is simple & cheap.
- It does not require maintenance.
- Provide a low surge current.
- It is used for starting large induction motors.
- It is best for long acceleration time.

Disadvantages:

- It works on delta connected motor.
- There are more wire connections.
- It offers low starting torque.
- There is a mechanical jerk while switching from star to delta.

VARIABLE FREQUENCY DRIVES (VFD)



1. This is also called as follows:
   - Variable Speed Drives (VSD).
   - Adjustable Frequency Drives (AFD).
   - Adjustable Speed Drives (ASD).
   - Inverter Drives.
   - Drives.

2. Generally, VFDs are used for three-phase AC Induction Motors.

3. VFDs are used with fixed speed Induction Motors, which are compatible for VFDs.

4. VFD controller is a solid-state power electronic conversion system consisting of
   - A rectifier bridge converter
   - A direct current (DC) link
   - An inverter

5. VFD controller basically vary the *frequency* and *voltage* of the power supply to the motor.

6. VFD controller uses different technologies for frequency and voltage control. Those are
   - Pulse With Modulation (PWM)
   - Current Source Inverter (CSI)
   - Voltage Source Inverter (VSI)

VARIABLE FREQUENCY DRIVES (VFD)

7. The PWM technique is the most common one.

8. The PWM technique requires

COMPARISON OF THREE PHASE INDUCTION MOTOR STARTERS

Method	Starting current	Starting Torque	Pros	Cons
Direct-on-Line (DOL)	5-10 times the full load current	5-10 times the full load torque	Economical and Higher starting torque.	High in-rush current
Star-Delta Starter	2-3 times the full load current	2-3 times the full load torque	Inrush current can be reduced to one-third when compared to DOL.	Starting torque will reduce
Auto-transformer	2-3 times the full load current	2-3 times the full load torque	Inrush current can be reduced to one-third when compared to DOL.	Starting torque will reduce
Soft starter	3-5 times the full load current	1.5-2.5 times the full load torque	Inrush current can be reduced. Starting torque can be controlled.	Starting torque will be less
Variable Speed drive	1.1-1.5 times full load current	1.5-2.5 times the full load torque	Speed and torque control, communication and Energy saving.	Higher cost

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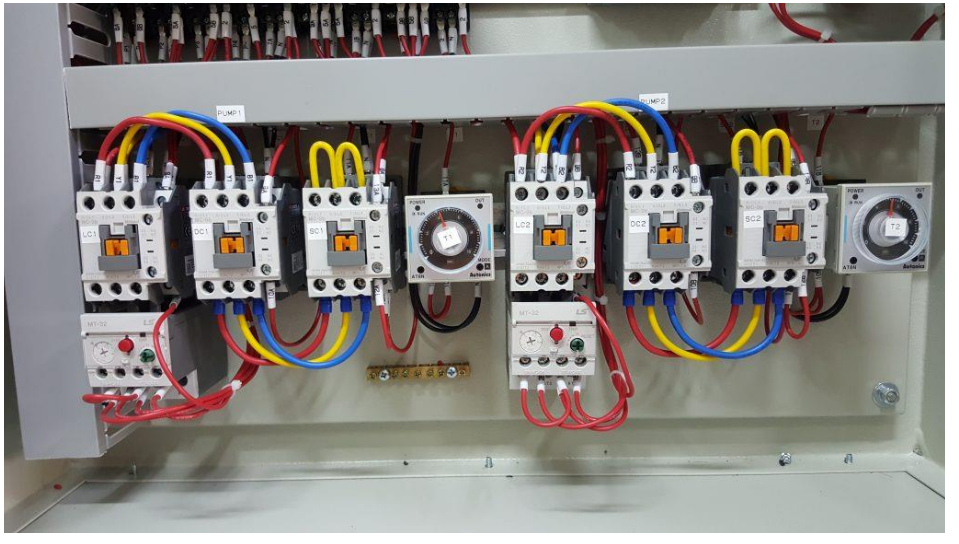
STAR-DELTA STARTERS

1. Most induction motors are started using DOL starters. But, when very large motors are started that way, they cause disturbance of voltage on the supply line due to large starting current surges.

2. To limit the starting current surges, large induction motors are started at reduced voltage and then have the full supply voltage reconnected when they run up near to their full speed.

3. The most famous and simple reduced voltage starter arrangement is the Star-Delta Starter.



4. As you can see from the above photo, one S-D stater consists of the followings:

- Main contactor.
- Delta contactor.
- Start contactor.
- Thermal overload relay
- Timer

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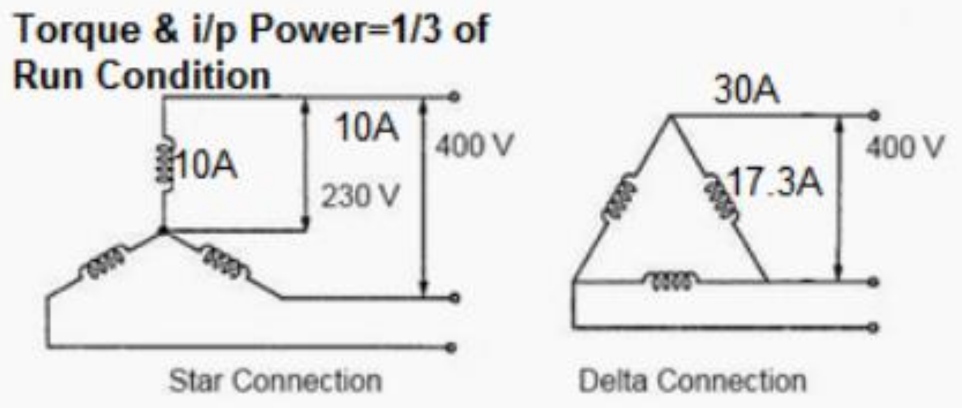
STAR-DELTA STARTERS

5. Working principal of the S/D starter is as follows:



Scheme – Working Principle of Star-Delta Starter

6. Traditionally, there has been a requirement to fit a reduced voltage starter on all the motors greater than 5 hp (4 kW). S/D is one of the lowest cost electromechanical reduced voltage starter.

7. As seen previously, the S/D starter is manufactured from 3 nos. of contactors, a timer and a thermal overload.

8. The contactors are smaller than the single contactor used in DOL starters.

9. Initially, both “Main Contactor” and “Star Contactor” are energized (closed) so that the winding of the motors can be connected in “Stat” arrangement.

STAR-DELTA STARTERS

10. After a pre-set time, the “Star Contactor” is de-energized (opened), and the “Delta Contactor” is energized (closed). This allows the motor windings to be connected in “Delta” arrangement.

11. All the Contactors used in the S/D starter should be AC3 rated contactors.

12. The sizing of the Contactors are done as follows:

    (a) Main contactor – 58% (1/√3) of the rated current of the Motor.

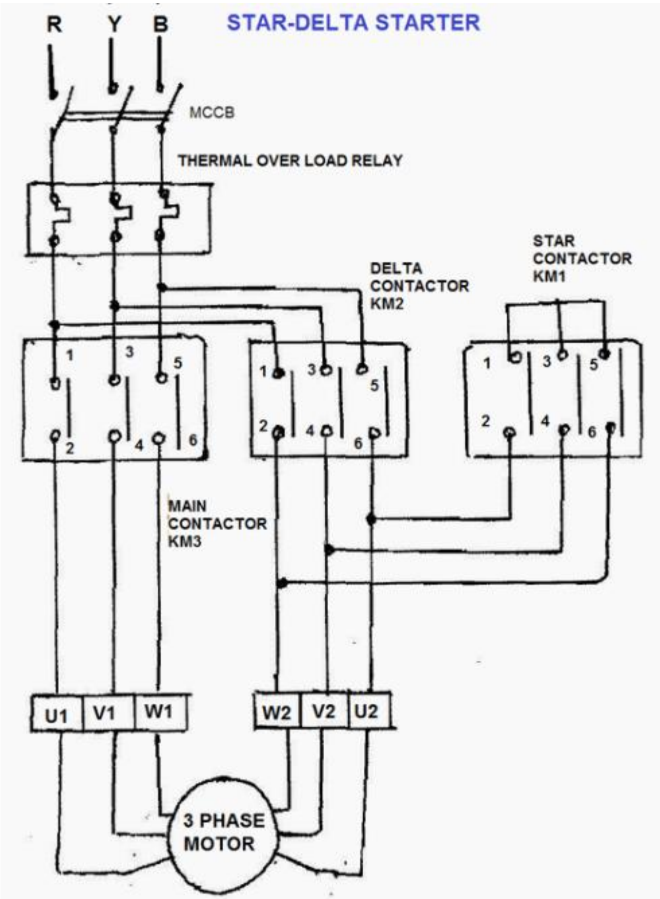
    (b) Delta contactor – 58% (1/√3) of the rated current of the Motor.

    (c) Star contactor – 33% (1/3) of the rated current of the Motor.

    Note: *For starting time exceeding 15 seconds, a bigger star contactor must be selected. If the start contactor rating is equal to that of main contactor, then start time up to approximately 1 minute is permissible.*

13. The power circuit of the S/D starter shall be as shown in the figure.

14. The “Star” and “Delta” contactors are Electrically and Mechanically interlocked in order to avoid accidental activation / energization of both contactors together.



Power circuit of Star-Delta starter

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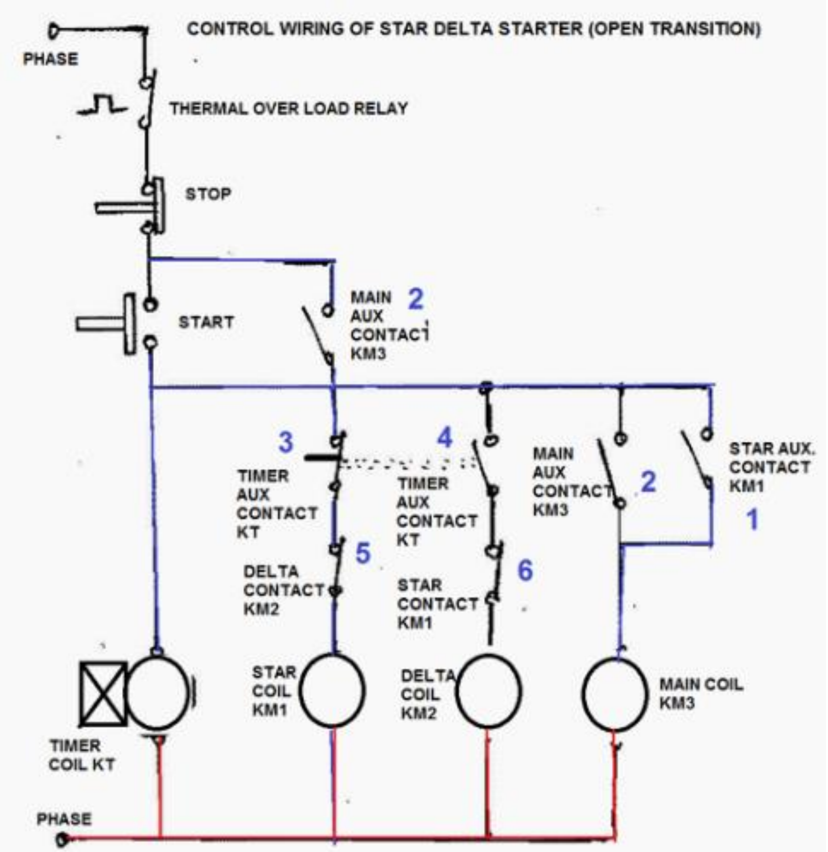
STAR-DELTA STARTERS

15. The control circuit of the S/D starter can be seen in the figure provided below:

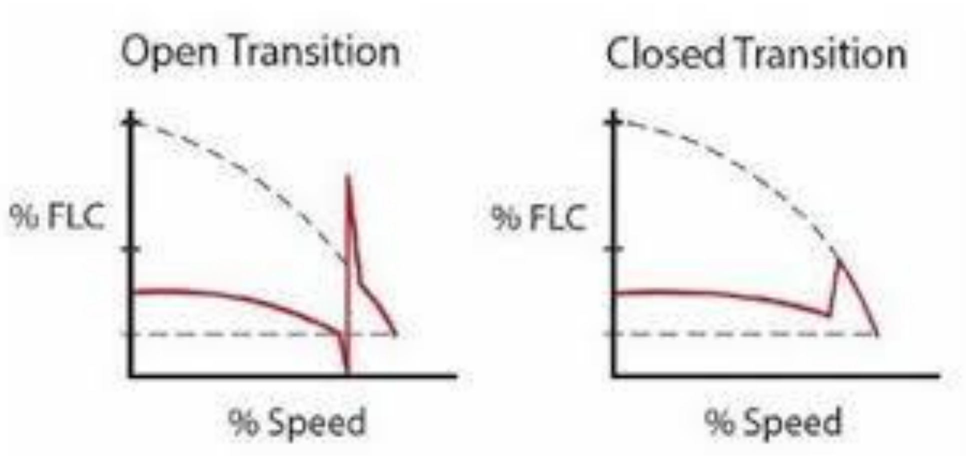


Scheme – Control Circuit of Star-Delta Starter (Open Transition)

STAR-DELTA STARTERS

16. There are two types of S/D Starters. Those are as follows:
    (a) Open Transition Starters (OTS).
    (b) Close Transition Starters (CTS).

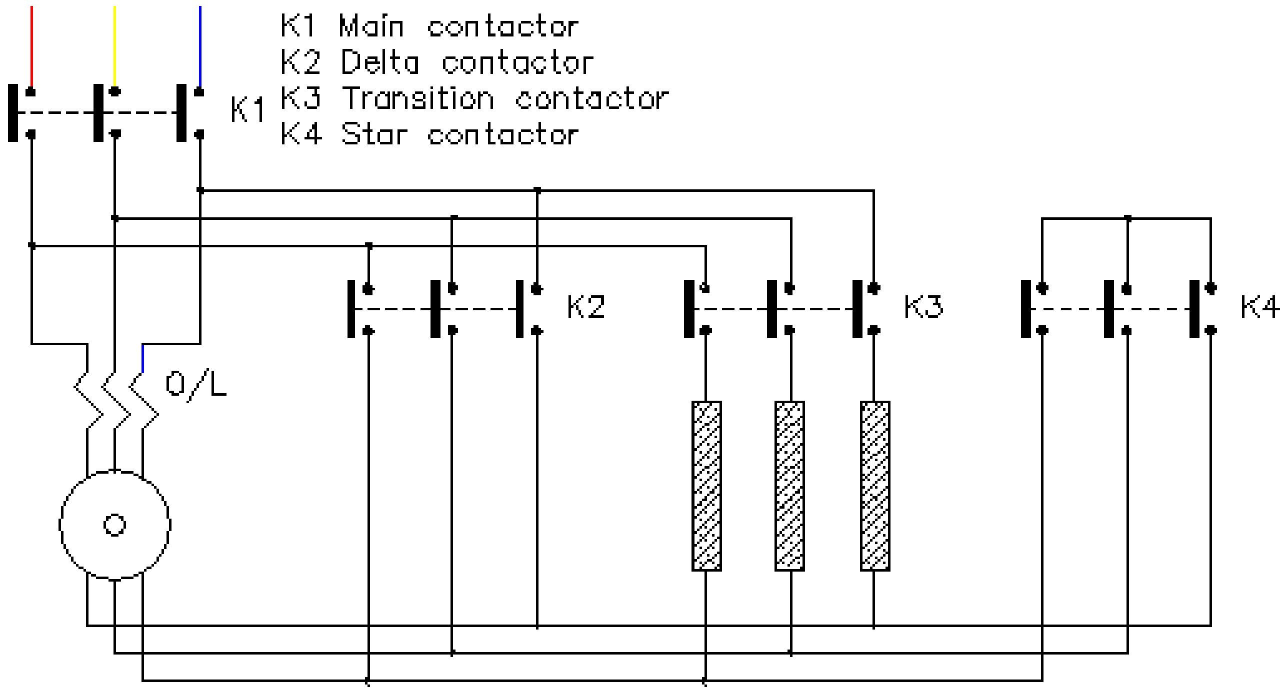
17. In an OTS, the power is disconnected from the motor while the windings are reconfigured via external switching. And then, the power supply is suddenly re-connected one the reconfiguration is done. This type of external switching leads to a transient situation as you can see in the figure provided below.



18. The resulting surge in current and torque in the OTS could electrical and mechanical shocks on the system.

STAR-DELTA STARTERS

19. The CTS uses a technique to reduce the magnitude of the switching transients. This requires the use of 4th contactor and a set of three resistors.



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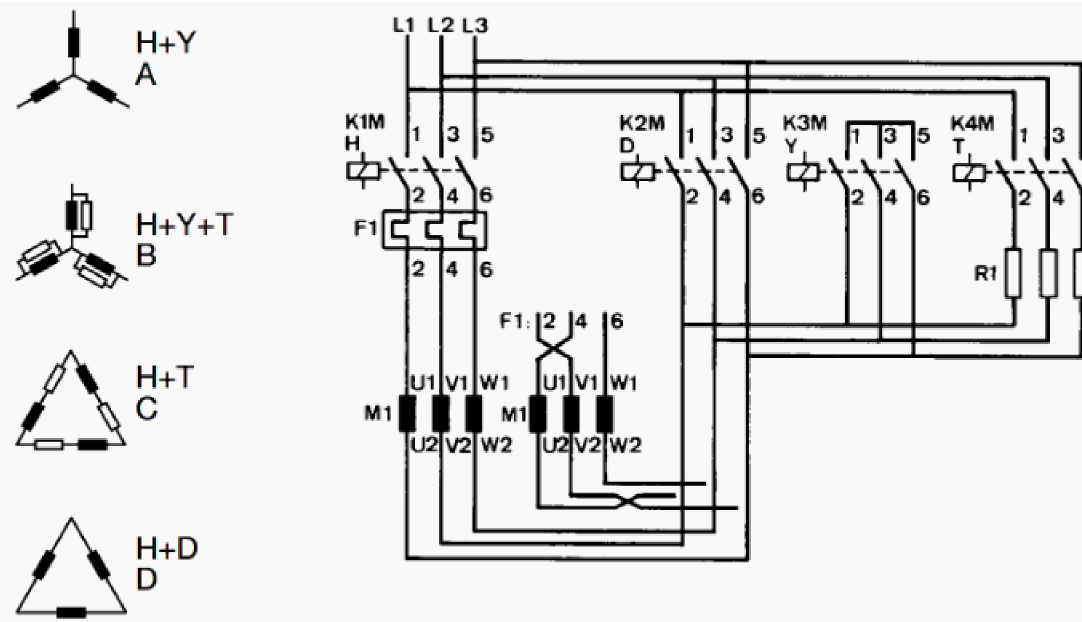
STAR-DELTA STARTERS

20. Before the star contactor opens, a fourth (transition contactor) K4M closes the motor circuits via resistors in delta. This prevents an interruption of the motor current during switch over and the motor speed remains practically constant.
21. Afterwards, the delta contactor K2M creates the final switching status and throws off transition contactor K4M.



Uninterrupted Star-Delta Starting

Sizing of Controlgear:

- Main contactor **K1M 0.58 Ie**
- Delta contactor **K2M 0.58 Ie**
- Star contactor **K3M 0.58 Ie**
- Transition contactor **K4M typ. 0.27 Ie (depending on transition current)**
- Transition resistors typ. **0.35...0.4 Ue/Ie**

ENHANCED STAR-DELTA STARTERS

1. The enhanced S/D starting is used when the torque during the normal S/D is not sufficient.

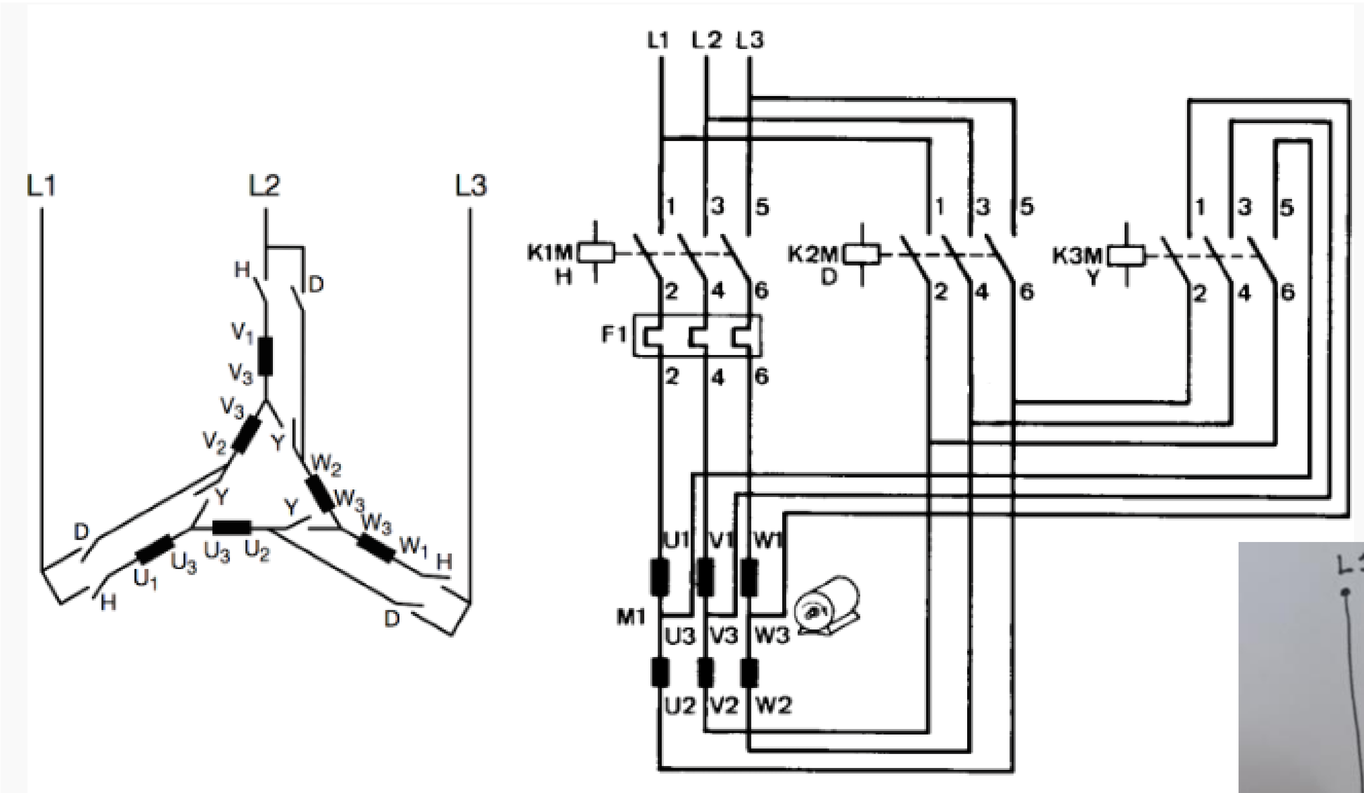
2. The following enhanced S/D staring methods are available in practice:

   (a) Combined Star-Delta Starting (CSD).

   (b) Partially wound Star-Delta Starting (PWSD).

COMBINED STAR-DELTA STARTERS

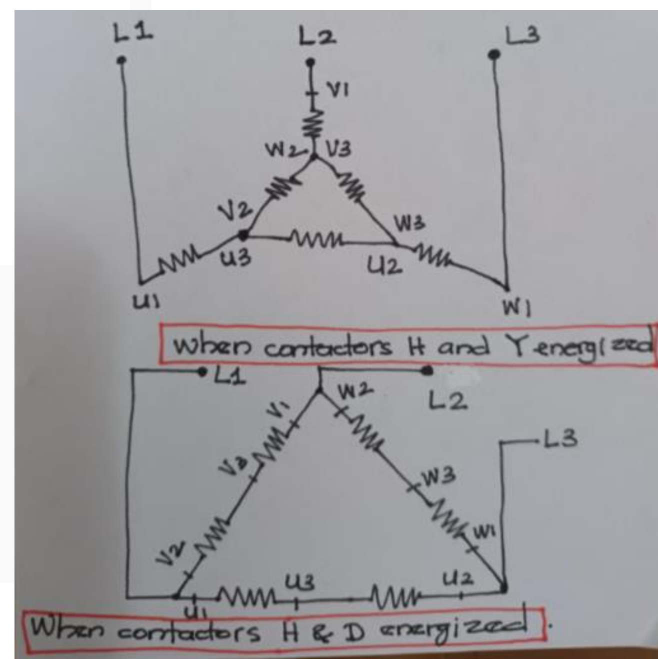
The motor windings are usually divided into two equally halves. During start, half a winding is switched in delta and the other half in star. This results in correspondingly higher starting torque.



Combined Star-Delta-Starting

Sizing of controlgear:

- Main contactor **K1M 0.58 Ie**
- Delta contactor **K2M 0.58 Ie**
- Star contactor **K3M 0.34 Ie**



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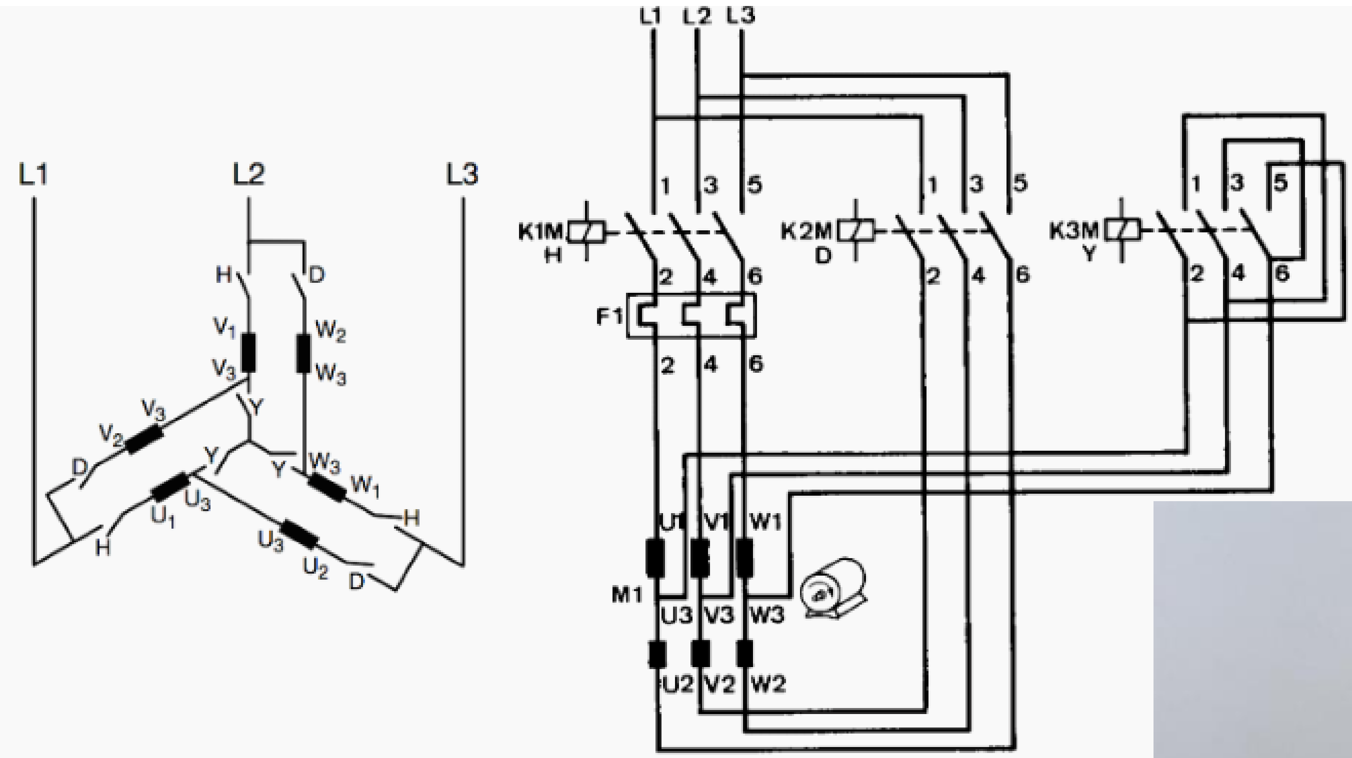
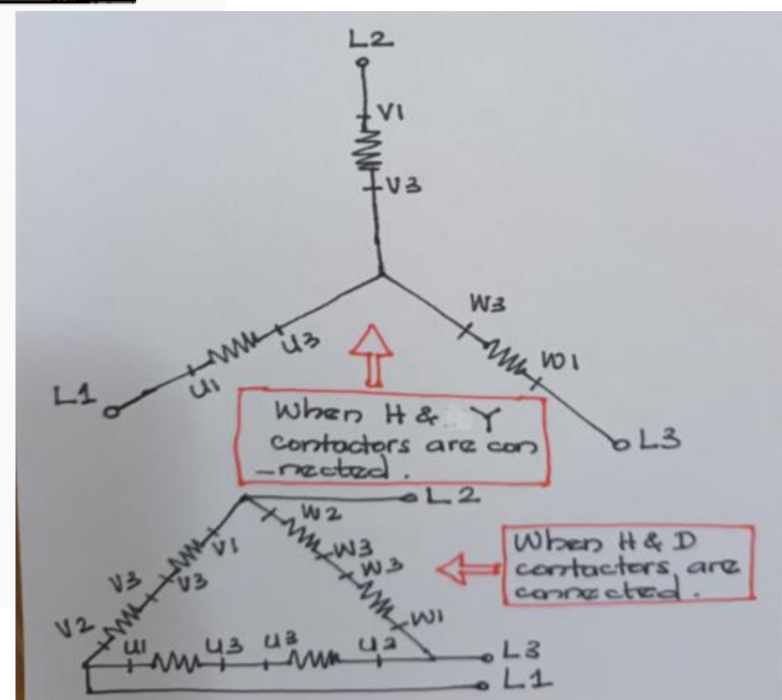
PARTIALLY WOUND STAR-DELTA STARTERS

The motor windings are subdivided. During start star connection, only the main winding (part of the entire winding) is used. This results in correspondingly higher starting torque.



Partially Wound Star-Delta Starting



Sizing of Controlgear:

- Main contactor **K1M 0.58 Ie**
- Delta contactor **K2M 0.58 Ie**
- Star contactor **K3M 0.5 – 0.58 Ie (depending on starting current)**

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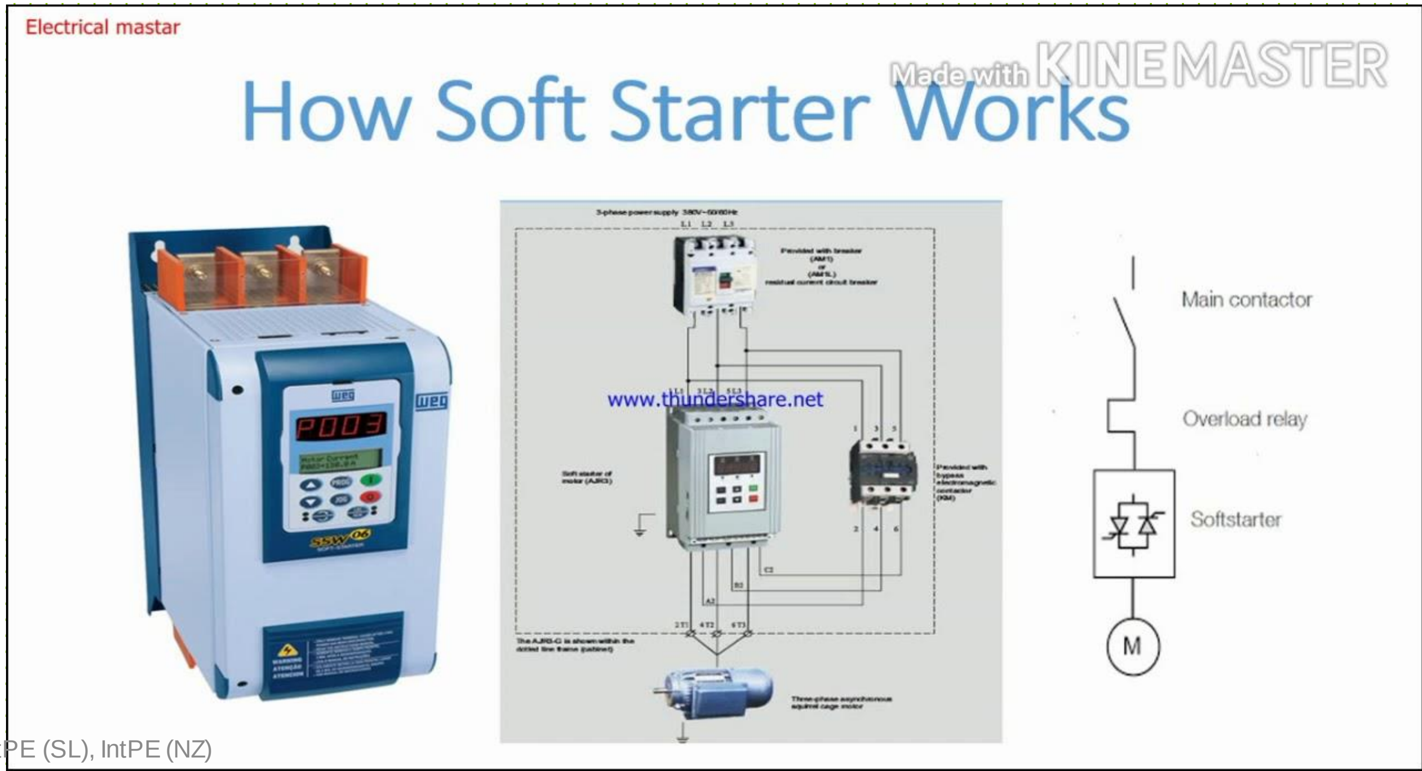
SOFT STARTERS

1. A soft-starter is a solid-state system or device that protects AC electrical motors from damages caused by sudden influxes of power by limiting the large initial inrush of current associated with star up.

2. Both soft-starters and VFDs look like the same from the outset. But the main difference between those is the VFD can vary the speed of the motor while a soft-starter only controls starting and stopping of the motor.

3. As the name implies, the soft-starter ramps up the voltage applied to the motor terminals over time, thereby limiting the inrush current and power, which significantly reduces heat build up.



SOFT STARTERS

1. A by-pass contactor is required to by-pass the soft-starter once the motor reached its rated speed.

2. However, some of the soft-starter has the by-pass starter built-in and thus, a separate by-pass contactor is not required.

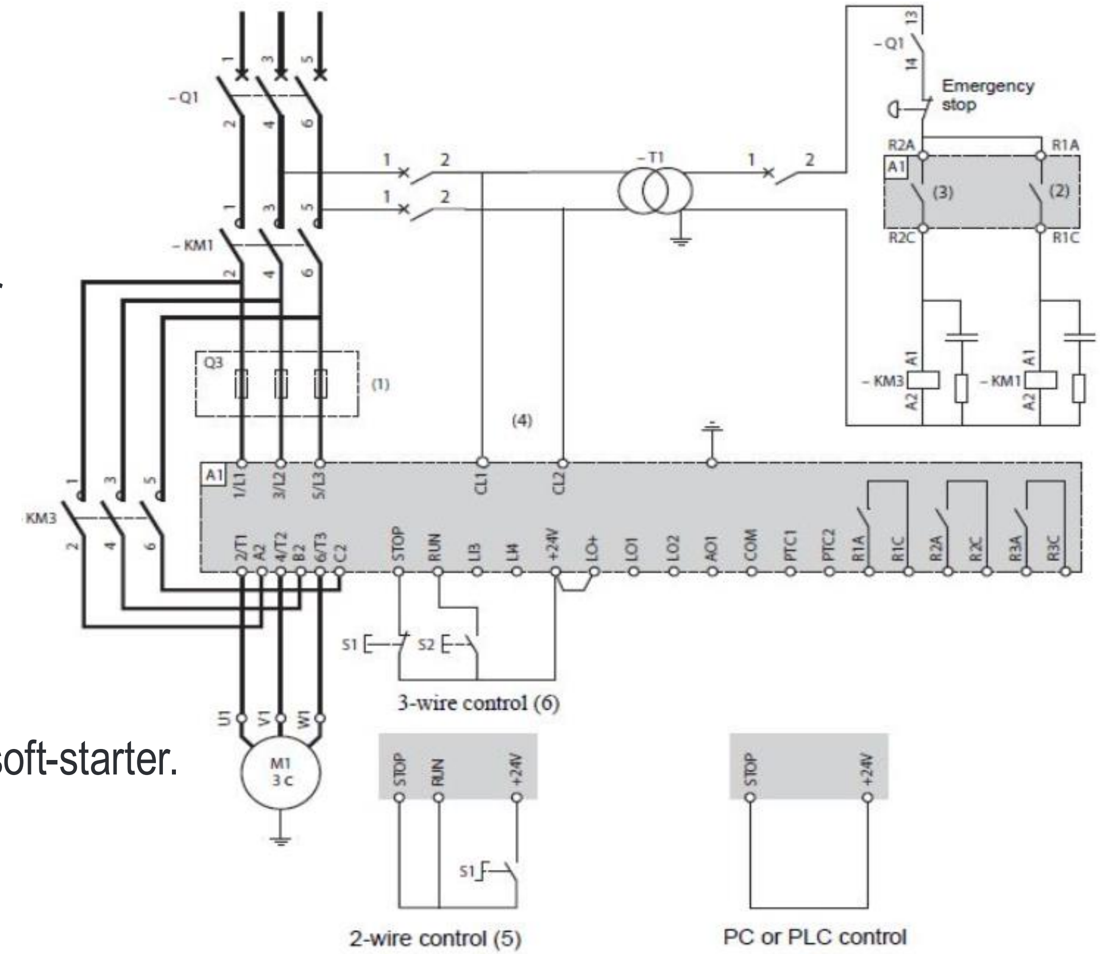
3. The by-pass contactor is required to avoid the energy losses in the power electronic components of the soft-starter.

4. As you can see from the power & control diagram of a soft-starter, there are two contactors: KM1 and KM2.

5. The KM1 is main contactor and is used for switching purpose.

6. The KM2 is the by-pass contactor and used for by-pass the power line direct to the motor without the power part of the soft-starter. However, the protection parts of the soft-starter are still connected.

7. This is to reduce the energy losing in the soft-starter.



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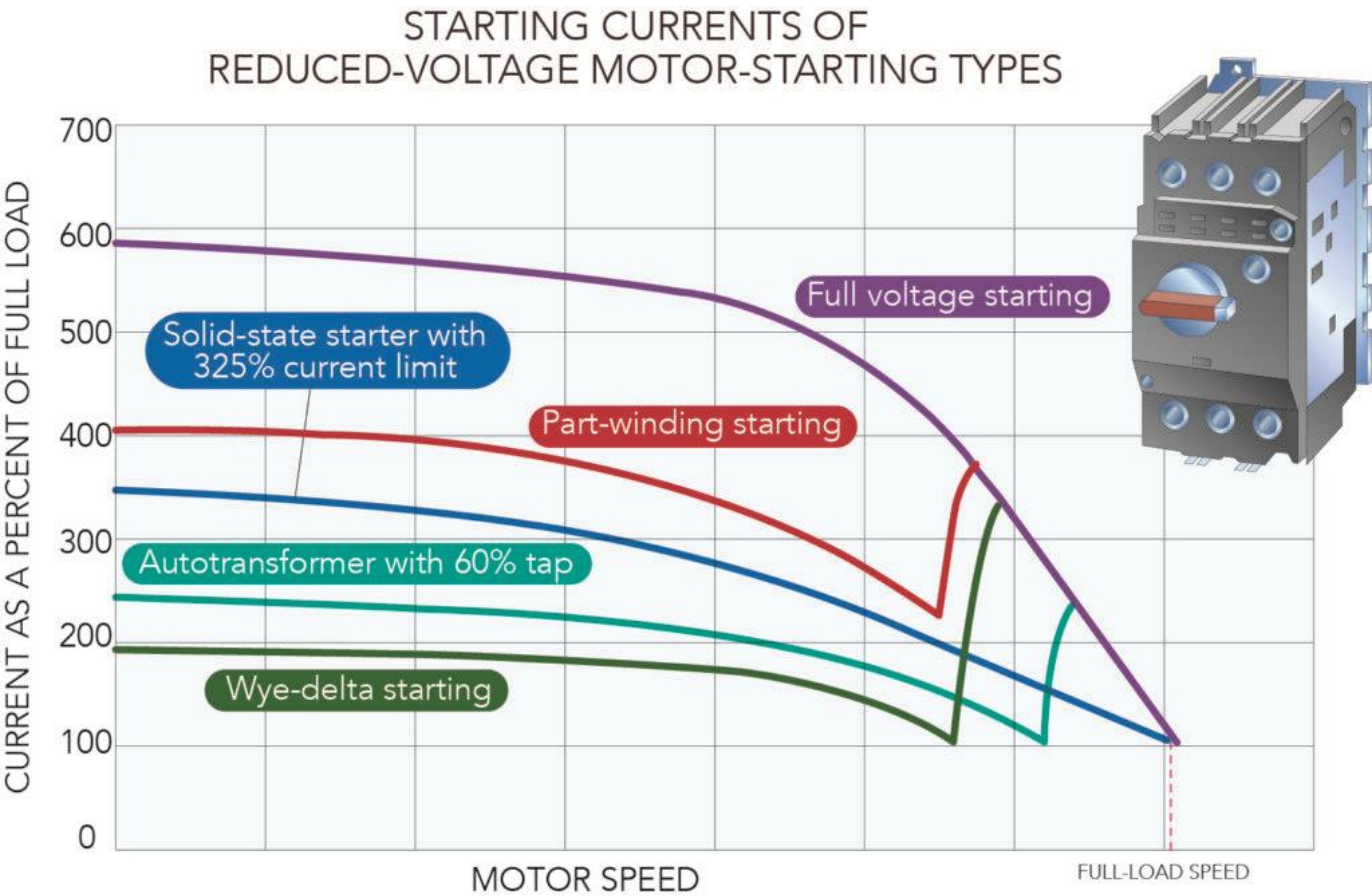

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OVERLOAD PROTECTION OF MOTORS

1. An over current exists when the normal load current for circuit is exceeded.

2. It can be in the form of overload or short circuit.

3. As far as a motor is concerned, the overload is any current, following within the normal circuit path, that is higher than the motor's normal full load ampere (FLA).

4. A short circuit is an overcurrent which greatly exceeds the normal full load current of the circuit.

5. The overload protection for a motor is generally achieved through "Thermal Overload Relay".

6. The short circuit protection for a motor is generally achieved through MCBs or MCCBs, which are slightly oversized to avoid nuisances tripping during the staring of the motor.

7. Type-C or Type-D MCBs are preferred. MCCBs can also be used.

- LRA – Locked Rotor Ampere. This is the current you can except under starting conditions when you apply full voltage. It occurs instantly during the start-up.

- RLA – Rated Load Ampere. The maximum current a motor should draw under any operating conditions.