Evolution of Motor Control

ISA Los Angeles County Section
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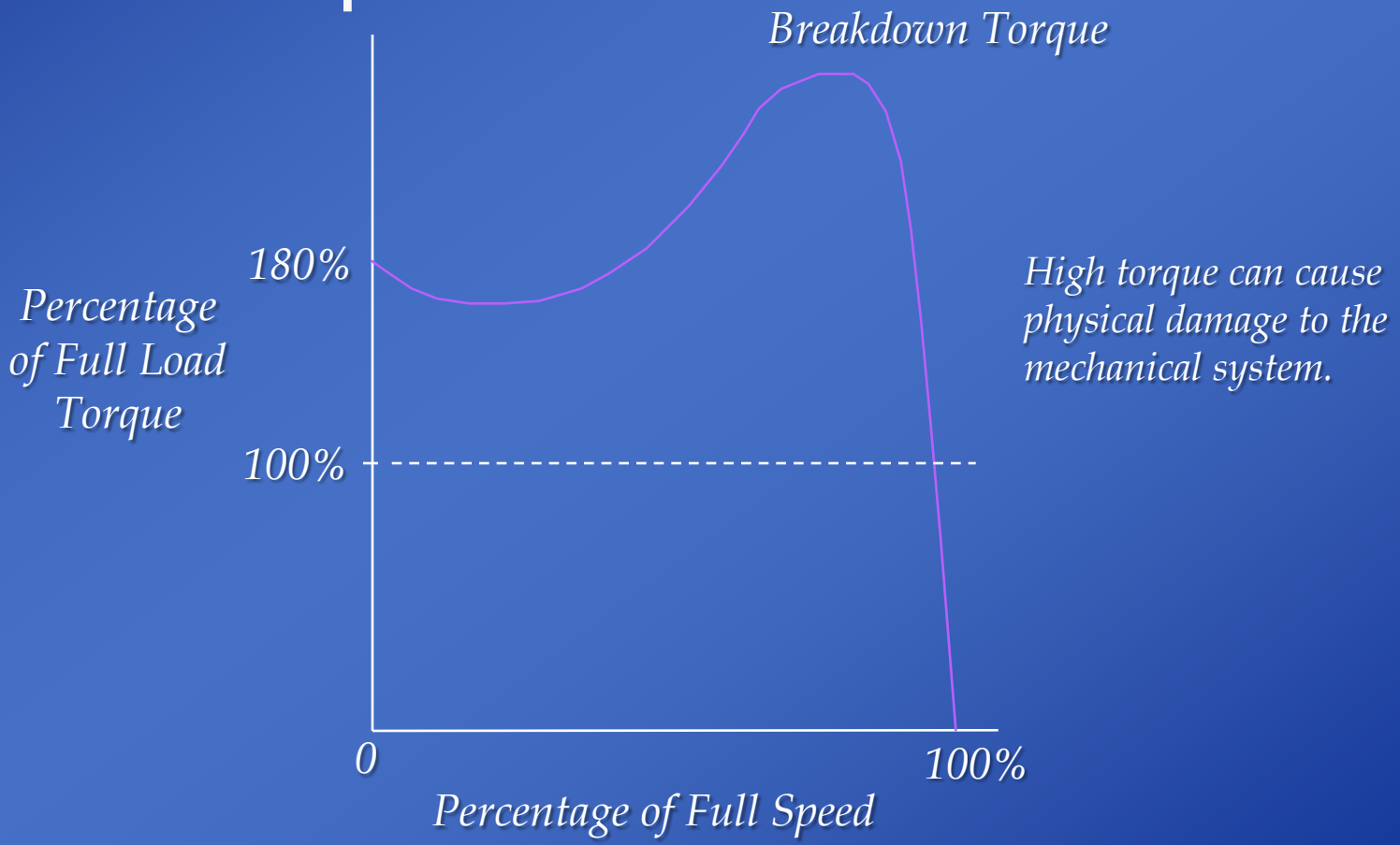
Motor Control

- A device or group of devices that serves to govern in some predetermined manner the performance of an electric motor.
- This may include manual or automatic means of starting, stopping, reversing, speed regulating, torque limiting, and overload/fault protection.

Motor Characteristics

Motor Torque Curve



Motor Characteristics

Motor Properties

- Starting torque can be controlled by changing the applied voltage. The torque is proportional to the square of the applied voltage.

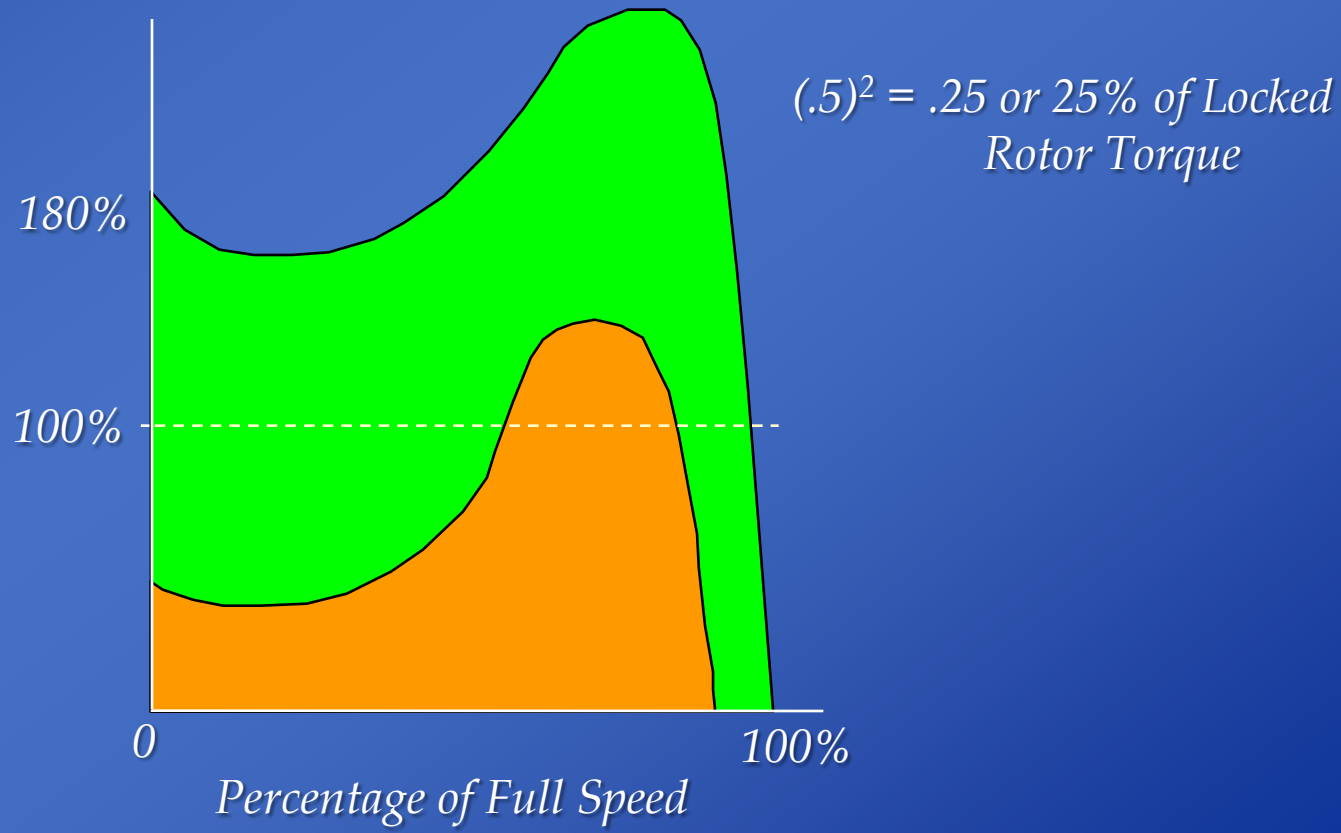
$$\%\ Torque \propto \%\ Voltage^2$$

- During start, current is directly related to the voltage applied to the motor.

$$\frac{Voltage\ (applied)}{Line\ Voltage} = \frac{Current\ (drawn)}{Current\ (maximum)}$$

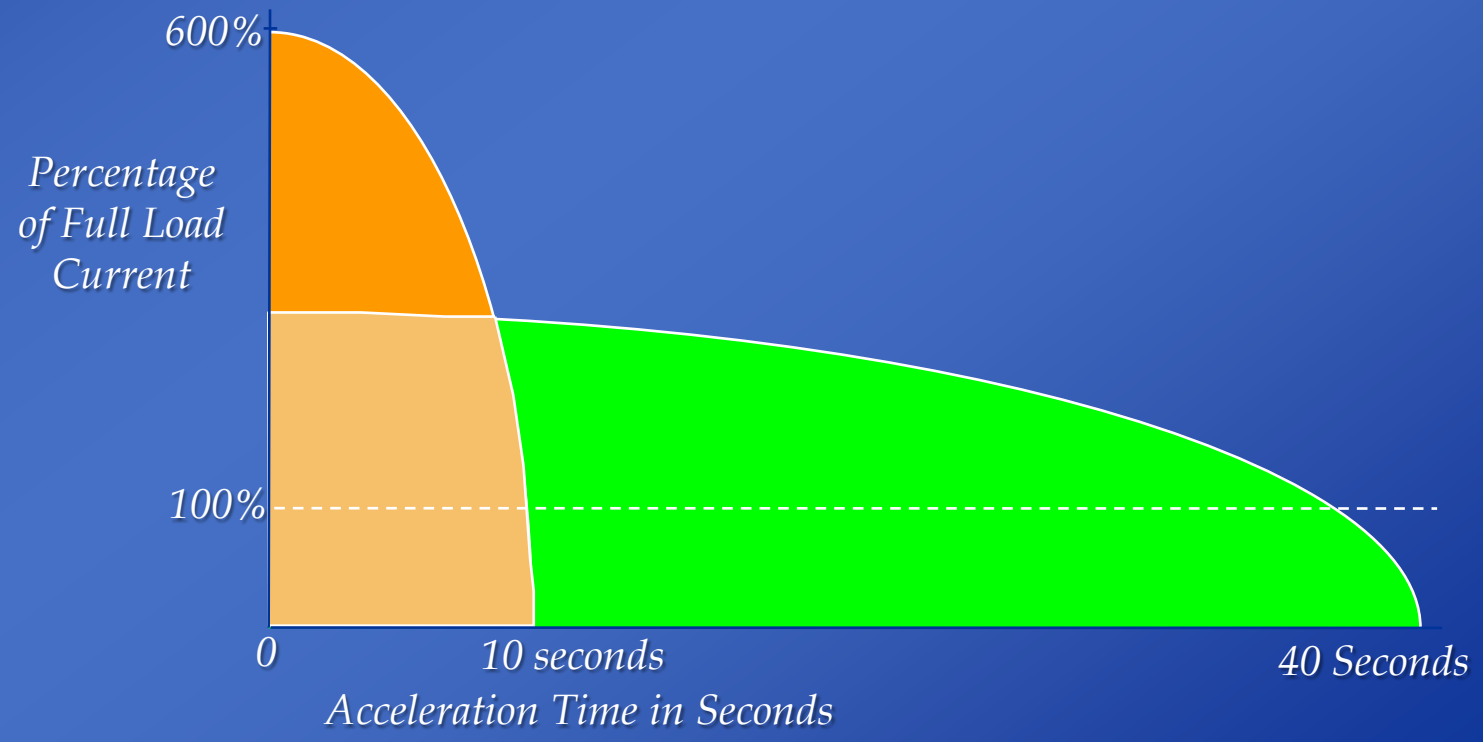
Motor Characteristics

A 50% reduction in applied voltage = 75% reduction in generated torque



Motor Characteristics

A 50% reduction in applied voltage = 50% reduction in starting current



Reasons for Reduced Voltage Start

- Electric Utilities limit full voltage starting of large motors
- Voltage fluctuations due to full voltage start of large motors
- High inrush currents result from full voltage start of large motors
- Starting torque requirements of driven loads

Starting Methods

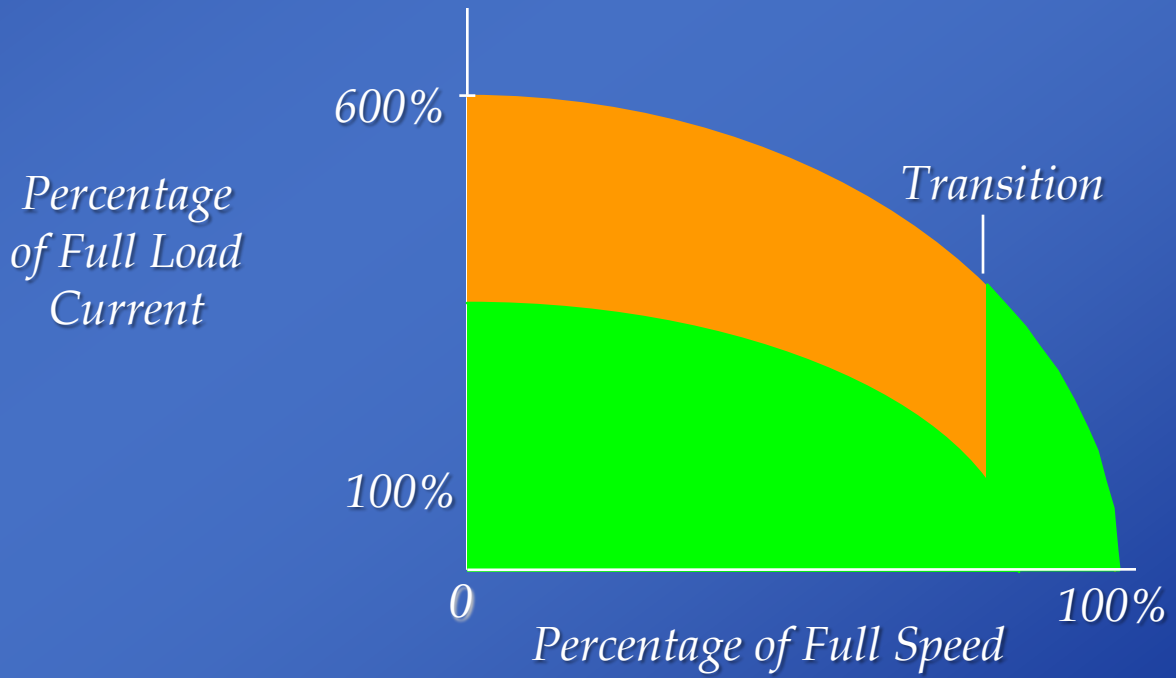
The key to controlling the motor is controlling the applied voltage.

How is voltage reduced during starting?

- Electromechanical devices
- Solid State Devices

Starting Methods

Electromechanical devices include a transition from starting to running that involves a second current and torque spike



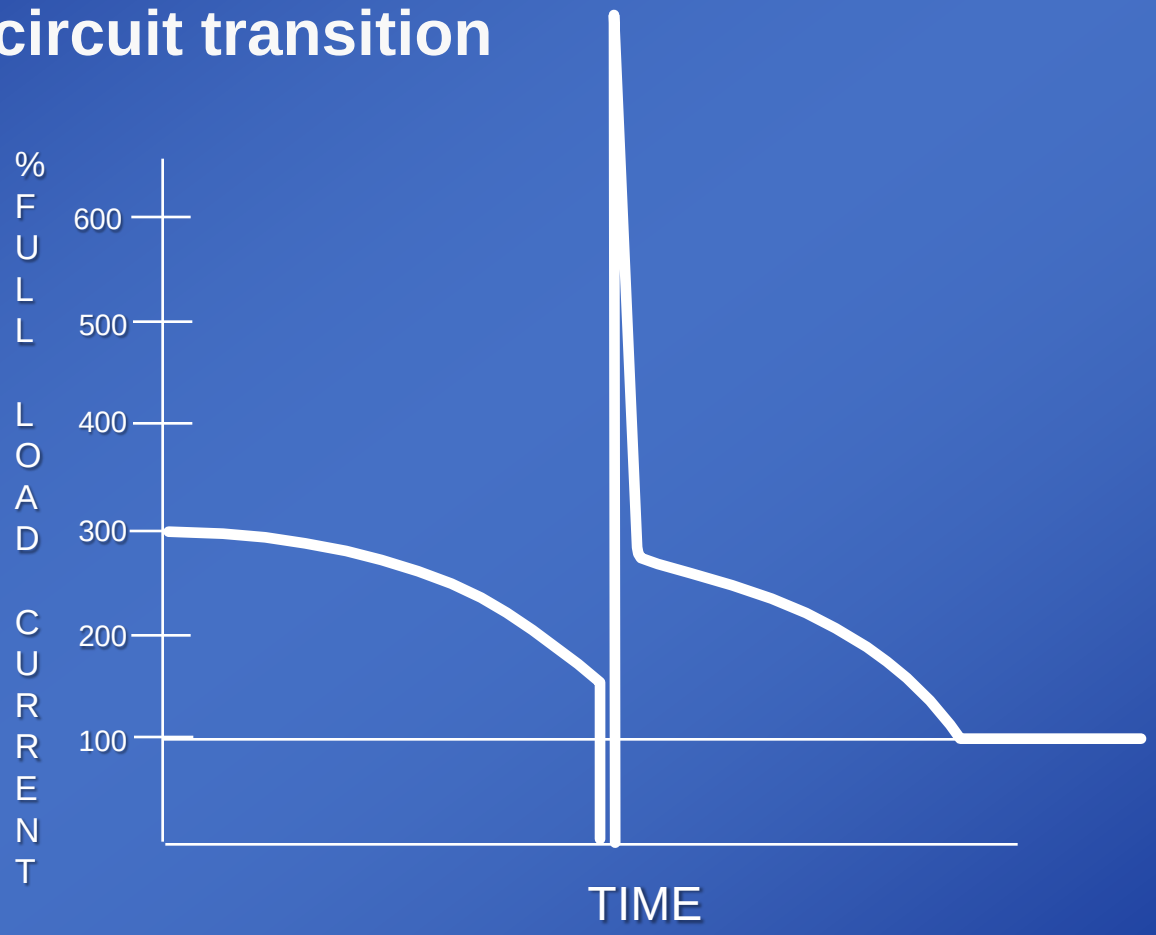
Starting Methods

During transition from reduced voltage start to full voltage run

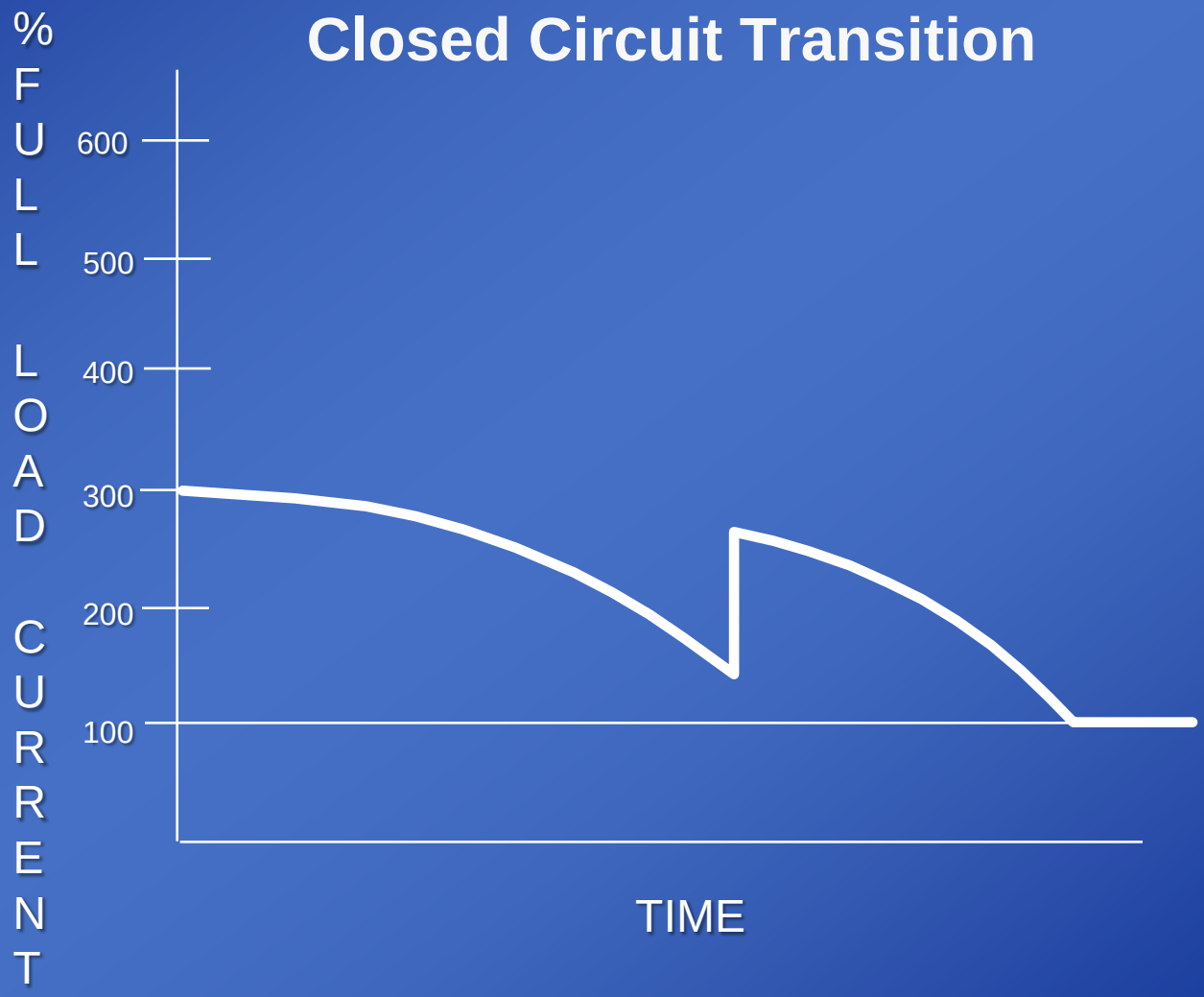
- Open circuit – motor disconnected from line during transition
- Closed circuit – motor remains connected to the line during transition

Starting Methods

Open circuit transition



Starting Methods

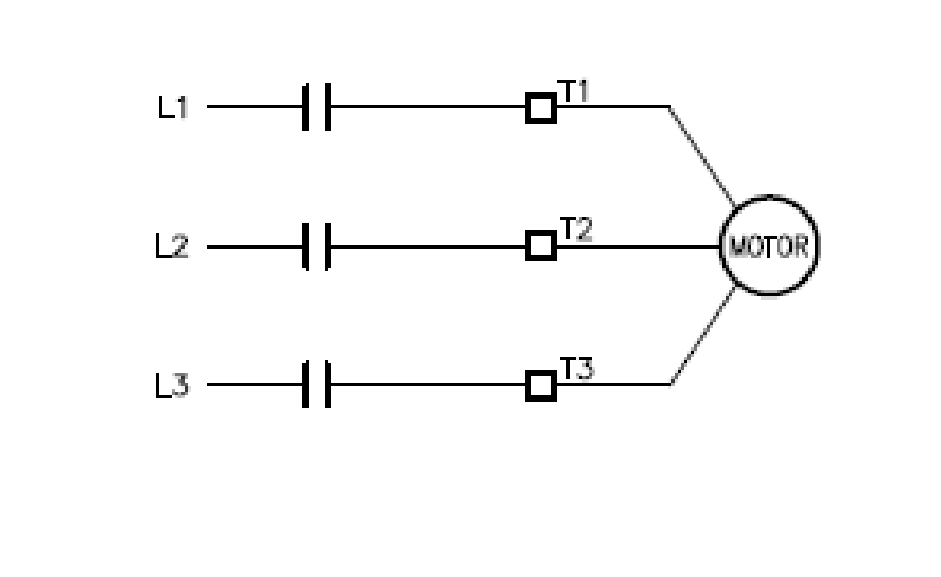


Prior to 1970s Only Electro-Mechanical Starters

- Full Voltage
- Primary Resistance Reduced Voltage
- Primary Reactance Reduced Voltage
- Part Winding Reduced Voltage
- Wye-Delta (Star-Delta) Reduced Voltage
- Auto Transformer Reduced Voltage
- Two-Speed Full Voltage Starter

Full Voltage

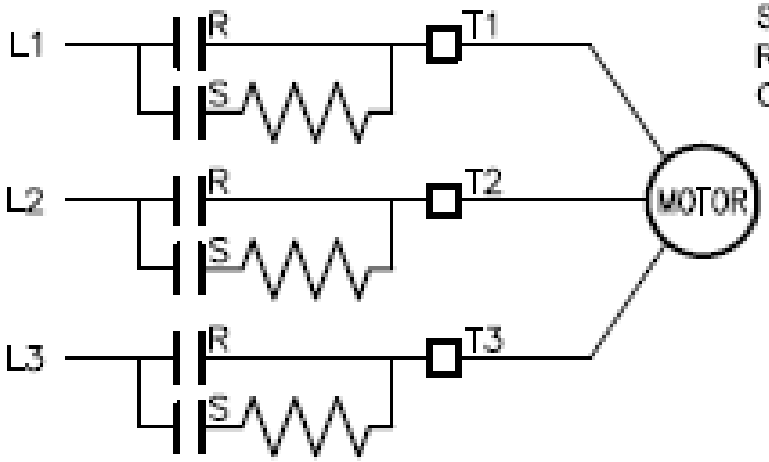
- Motor terminal voltage = line voltage
- Motor current = line current
- Starting torque = rated starting torque



Primary Resistance

- Motor terminal voltage is reduced from line voltage
- Motor current = line current
- Starting torque is reduced by the square of the terminal voltage
- Closed transition
- Used where current reduction needs are low or where load torque during acceleration is minimal

Primary Resistance



START: R OPEN, S CLOSED
RUN: R CLOSED, S OPEN
CLOSED TRANSITION (R CLOSES BEFORE S OPENS)

Primary Reactance

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- Motor current = line current
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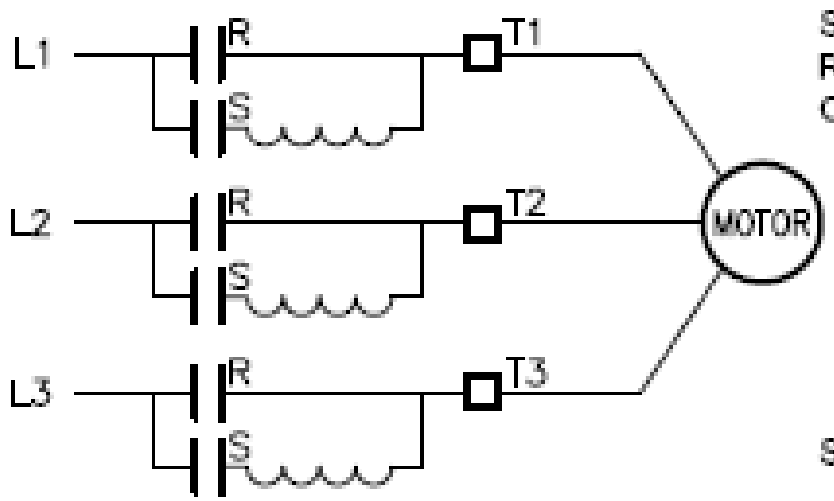
Primary Reactance



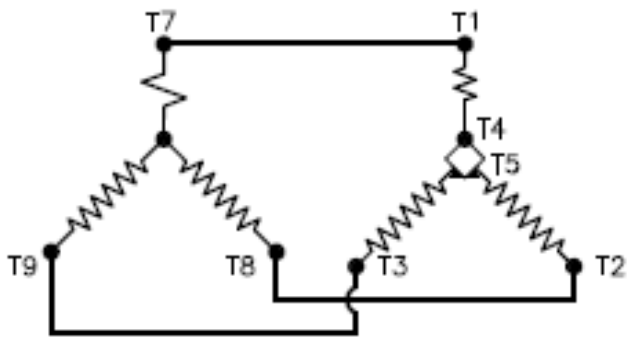
START: R OPEN, S CLOSED
RUN: R CLOSED, S OPEN
CLOSED TRANSITION (R CLOSES BEFORE S OPENS)

Series Reactor Reduced Voltage Starting

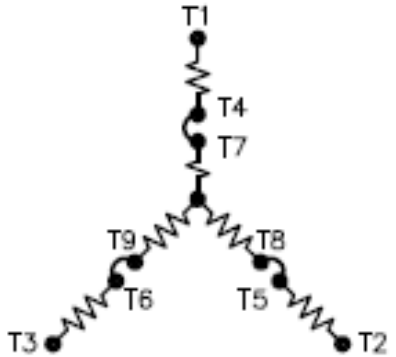
Part Winding

- Starting current is ~60-75% of normal
- Starting torque is very low
- Winding heating is very high on start connection
- Closed transition
- Should not stay on start connection more than 2-3 seconds

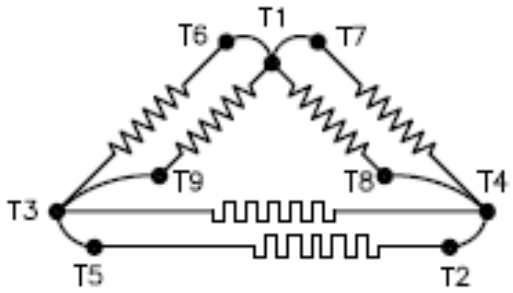
Motor Windings



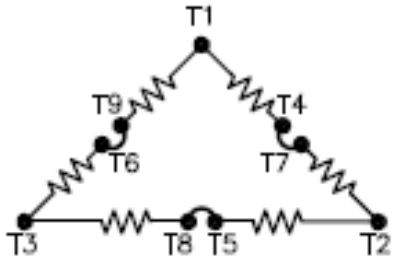
230 V (Wye)



460 V (Wye)

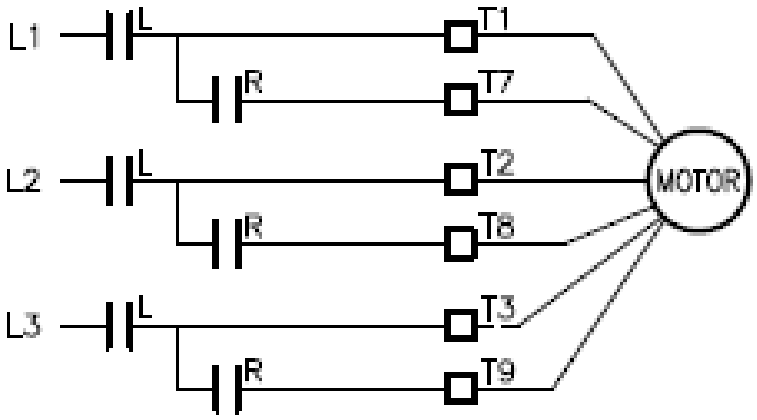


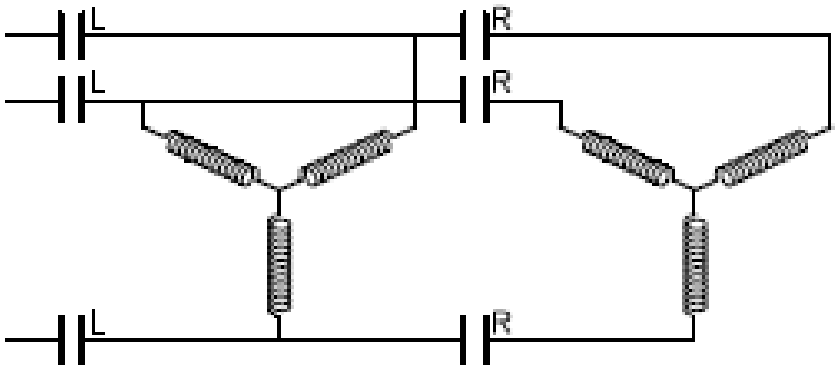
230 V (Delta)



460 V (Delta)

Part Winding





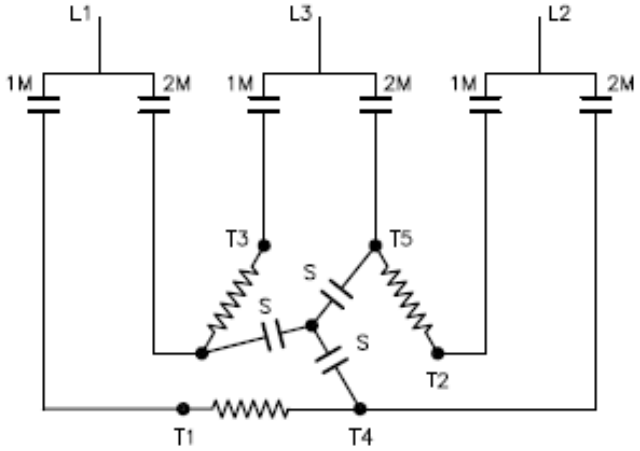
START: L Closed, R OPEN
RUN: L & R CLOSED

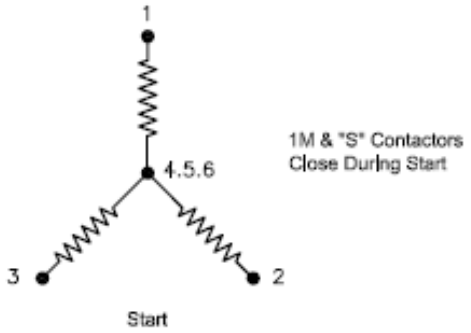
Part Winding Start

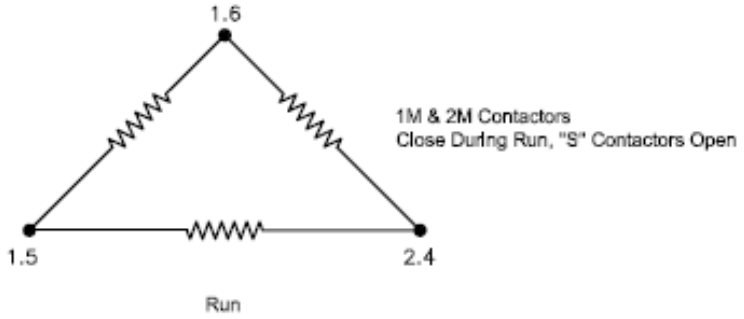
Wye Start Delta Run

- Starting current is ~ 30% of normal
- Starting torque is ~ 25-30% of normal
- Used where load torque during acceleration is very low
- Open transition, but can be closed transition with additional step
- Used more often on European motors

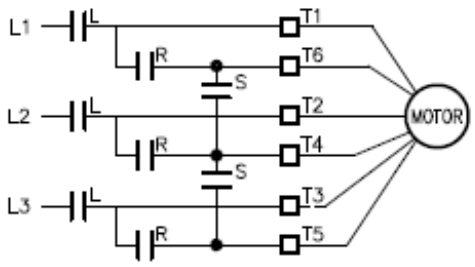
Wye Start Delta Run

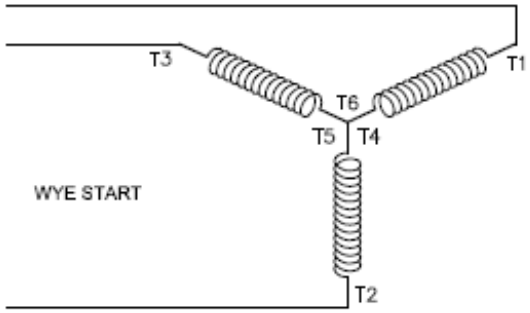


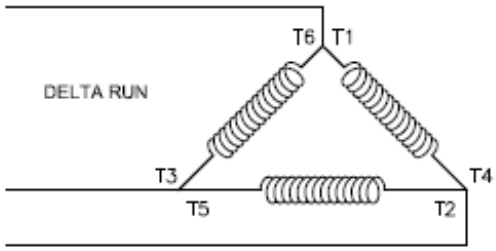




Wye Start Delta Run







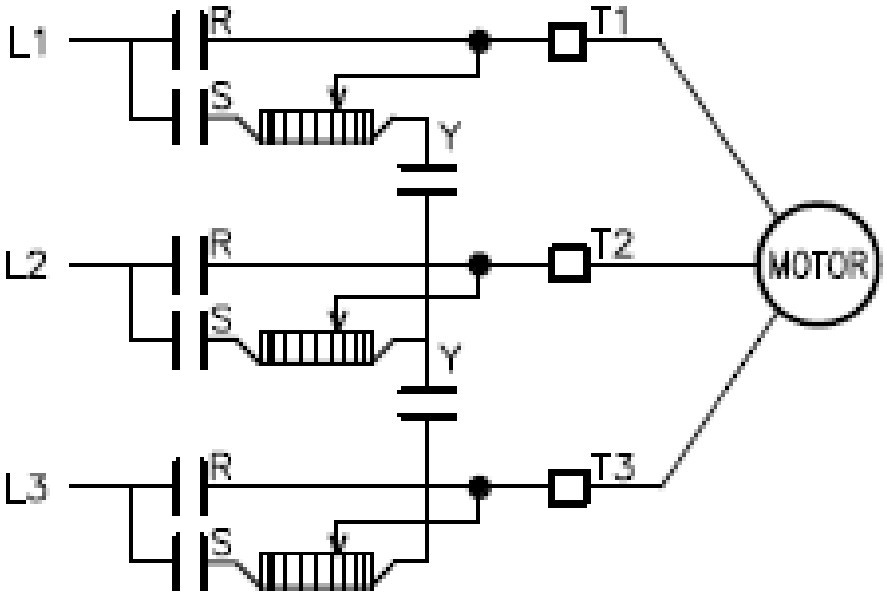
START: R OPEN, L & S CLOSED
RUN: R & L CLOSED, S OPEN

Wye Start, Delta Run

Auto-Transformer

- Motor terminal voltage less than line voltage (by transformer ratio)
- Motor current exceeds line current (by inverse of transformer ratio)
- Starting torque is reduced by the square of the terminal voltage
- Used where complete acceleration at reduced voltage is needed
- Where line amp reduction need is severe and load torque is not minimal
- Closed transition (with Korndorfer circuit)

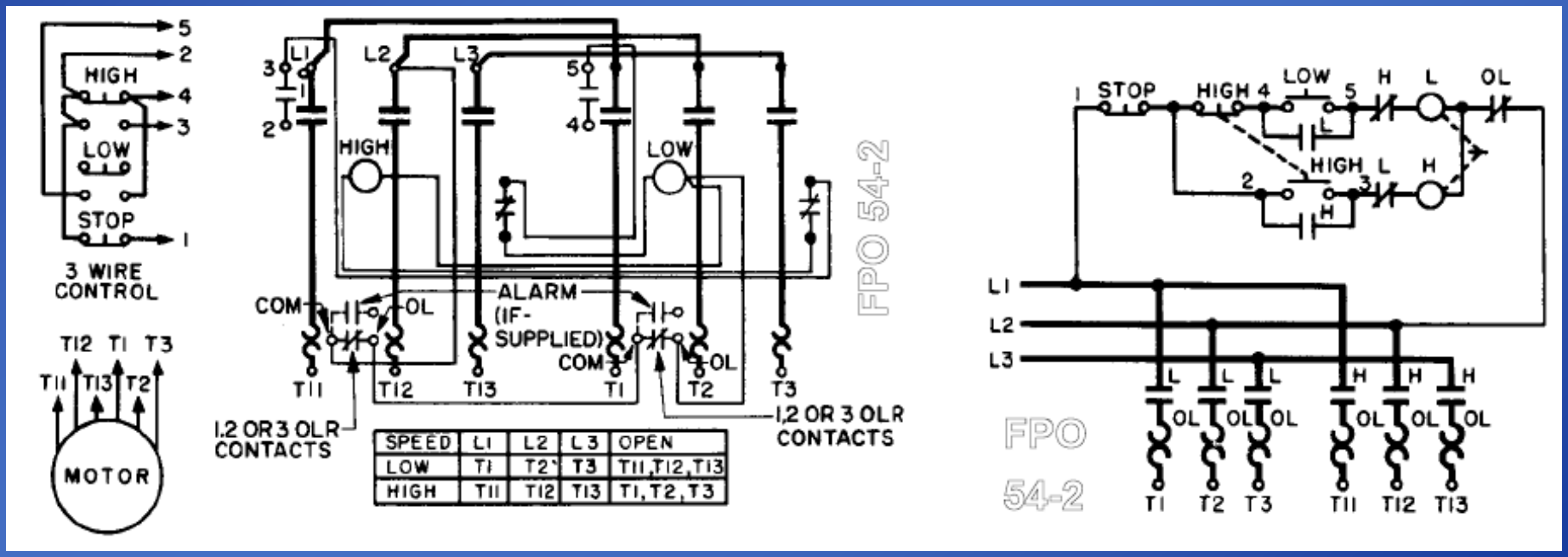
Auto-Transformer



START: R OPEN, S & Y CLOSED
RUN: R CLOSED, S & Y OPEN

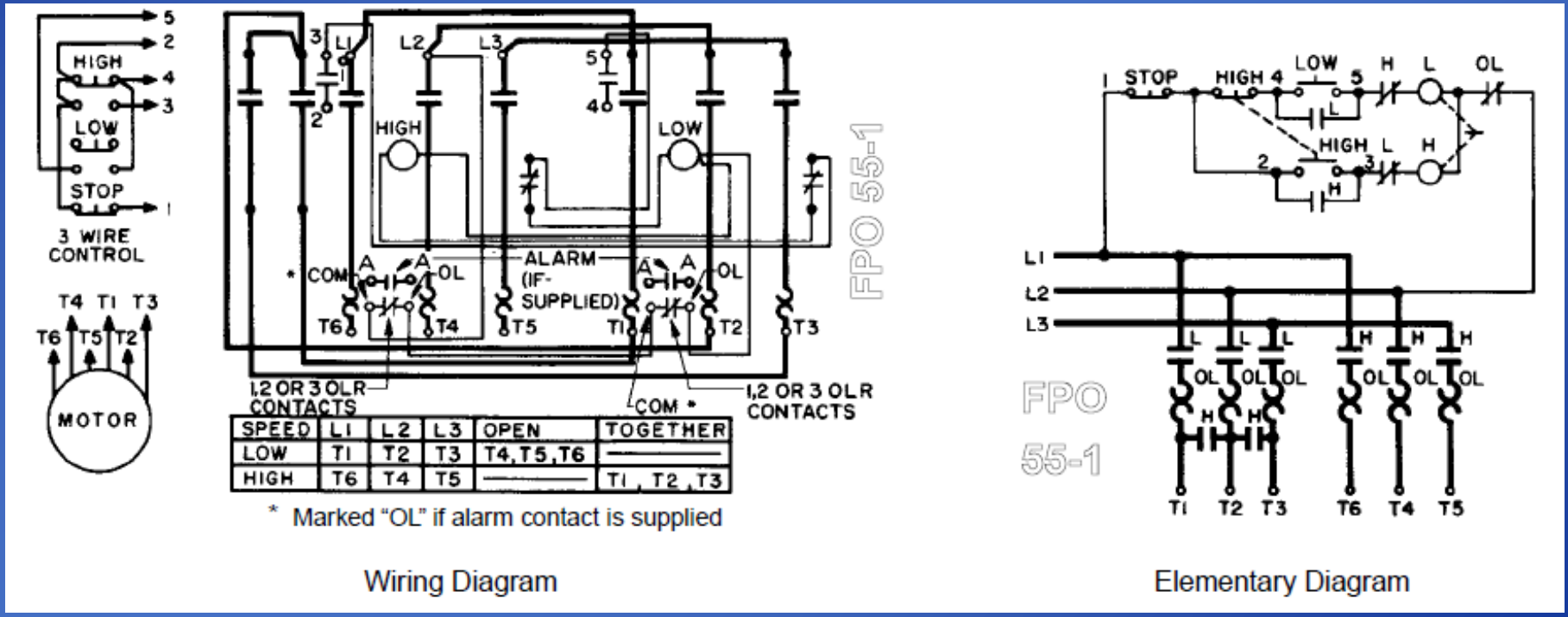
Auto-Transformer Reduced Voltage Starting

Two-Speed Two-Winding (Separate Winding)



SPEED	L1	L2	L3	OPEN
LOW	T1	T2	T3	T11,T12,T13
HIGH	T11	T12	T13	T1,T2,T3

Two-Speed One-Winding (Consequent Pole)



SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	T4, T5, T6	——
HIGH	T6	T4	T5	——	T1 , T2 , T3

* Marked "OL" if alarm contact is supplied

Wiring Diagram

Elementary Diagram

After 1970s use of Electronic circuits in motor control

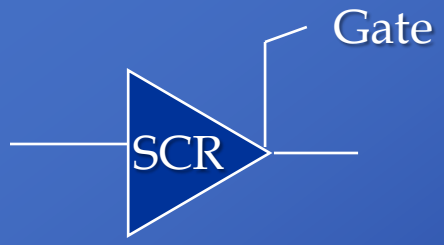
- Solid State Reduced Voltage (SSRV)
- Variable Frequency Drive (VFD)

Solid State Reduced Voltage (SSRV)

- Motor terminal voltage is reduced from line voltage
- Motor current = line current
- Starting torque is reduced by the square of the terminal voltage
- Closed transition
- Used where rate of acceleration/deceleration needs to be controlled
- Where need for current limit exists but load torque is high

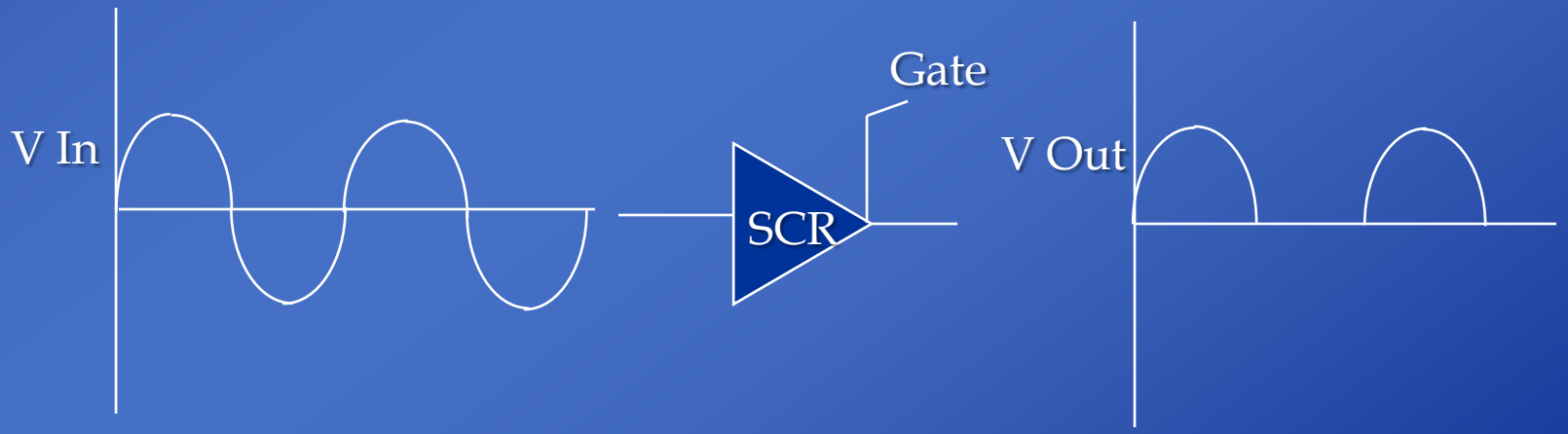
Solid State Reduced Voltage (SSRV)

The solid-state starter is by far the most flexible of all the reduced voltage starting methods. This method utilizes Silicon Controlled Rectifiers (SCR's) for switching power to the connected motor. The SCR is triggered "on" by energizing the gate.



Solid State Reduced Voltage (SSRV)

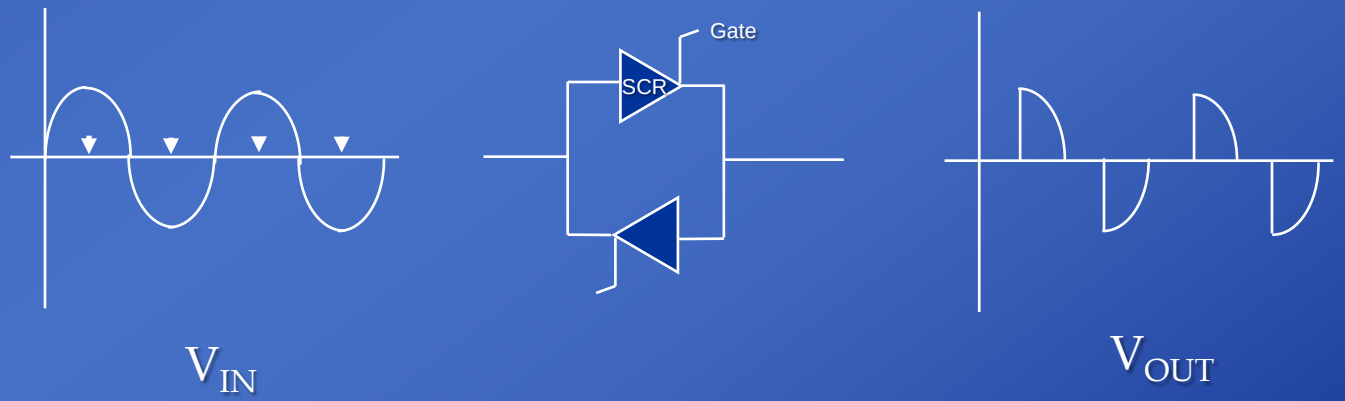
The SCR will allow current to flow in only one direction. Once the AC voltage changes from positive to negative, the SCR will not conduct again until the voltage is positive *and* the gate is triggered.



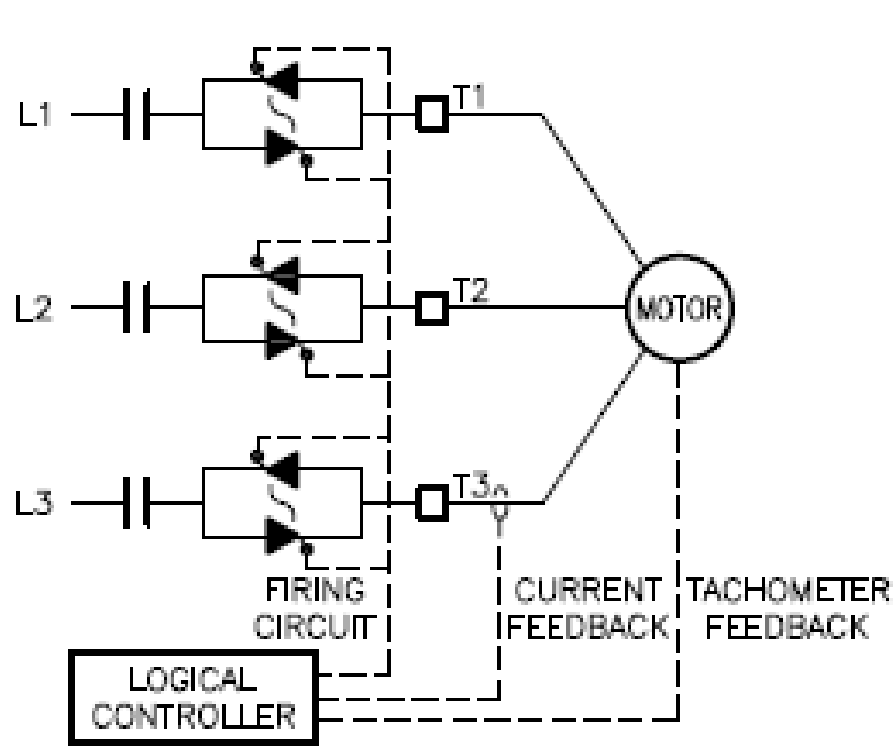
Solid State Reduced Voltage (SSRV)

By controlling when an SCR is fired in the cycle, the output voltage can be controlled. Also, by using SCR's in an "opposed" (back to back) configuration, the full sine wave of the AC power can be controlled.

- Gate Signal



Solid State Reduced Voltage (SSRV)

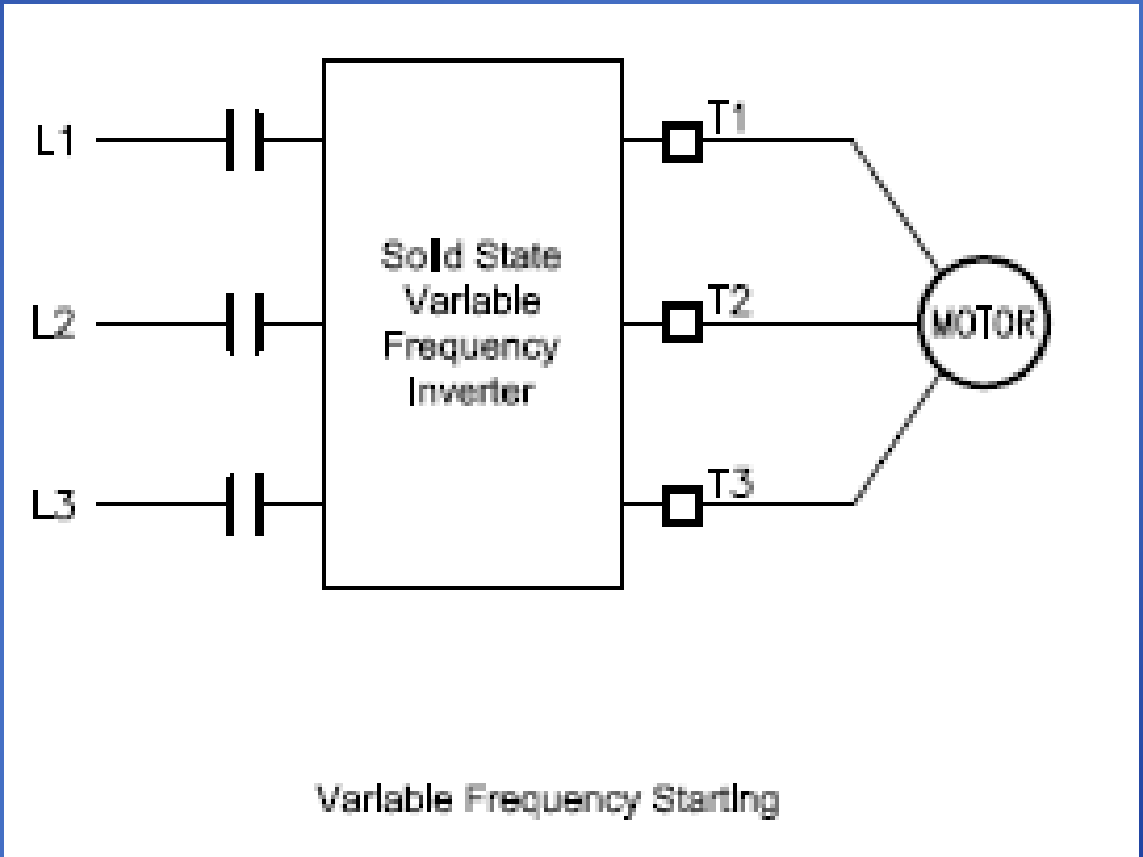


Solid State Reduced Voltage Starting

Solid State Variable Frequency Drive (VFD)

- Can be programmed for current limits, speed control, internal ramp functions.
- Current and torque are a function of the programming
- Closed transition
- Used primarily for efficient speed control
- Can generate high harmonic content

Solid State Variable Frequency Drive (VFD)



Variable Frequency Starting

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