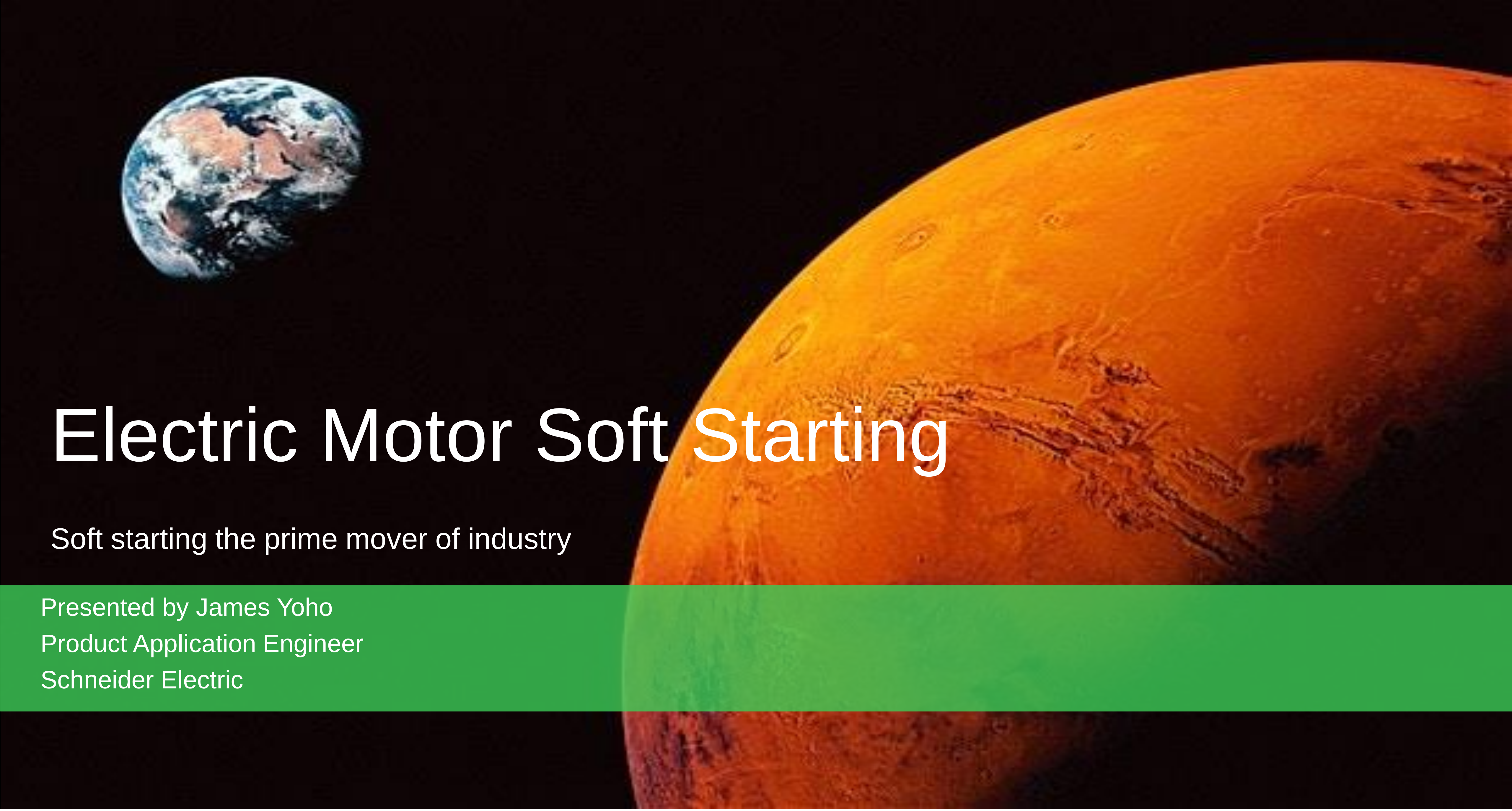


Electric Motor Soft Starting

Soft starting the prime mover of industry

Presented by James Yoho
Product Application Engineer
Schneider Electric

References

- **NEMA Standards Publication ICS 7.2-2015**
- *Application Guide for AC Adjustable Speed Drive Systems*

- *Published by*
- **National Electrical Manufacturers Association**1300 North 17th Street, Suite 900Rosslyn, VA 22209
- www.nema.org

NEMA Standards

- MG1- Motors and Generators
- Part 30 *Application Considerations For **Constant Speed Motors Used On A Sinusoidal Bus** With Harmonic Content **And General Purpose Motors Used With Adjustable—Voltage Or Adjustable—Frequency Controls Or Both*** provides information for **NEMA Design A and B** motors that are covered in MG1 Part 12 *Test and Performance—AC and DC Motors*, when used with adjustable voltage or frequency controls, as indicated in the Scope of Part 30. It also defines terms, performance considerations, and sets limits for which these general-purpose motors are suitable for operation.

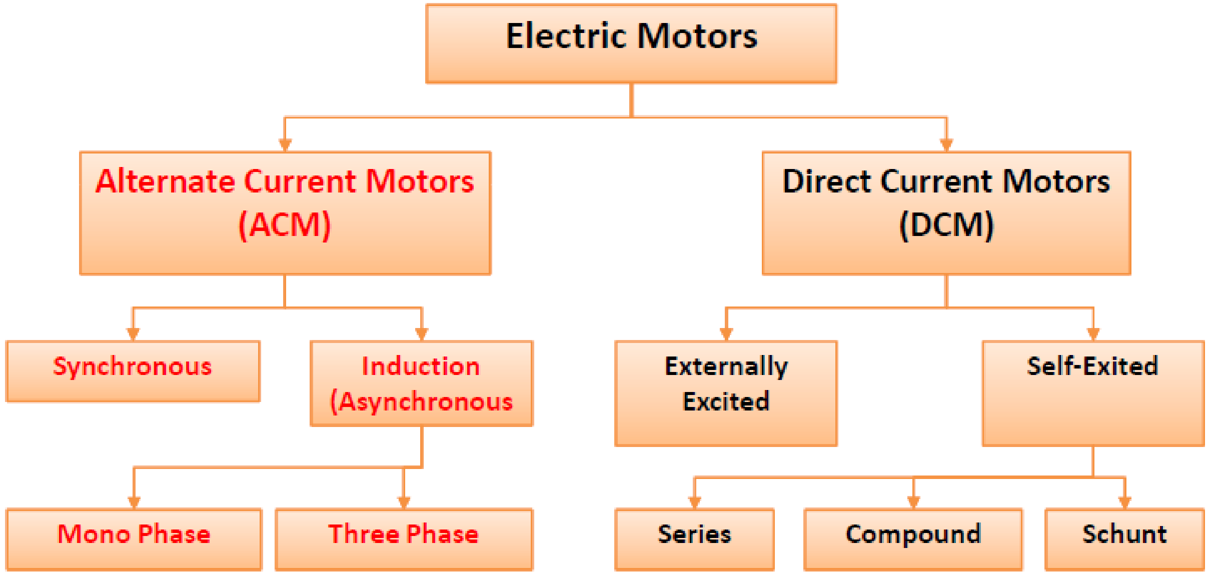
- Part 31 *Definite-Purpose Inverter-Fed Motors* defines a **definite-purpose motor specifically designed for operation with adjustable frequency controls**. Part 31 gives the minimum performance standards that apply to this type of motor.

- **drive:** The equipment used for converting available electrical power into mechanical power suitable for the operation of a machine. **A drive is a combination of a power control, motor, and any motor-mounted auxiliary devices.**

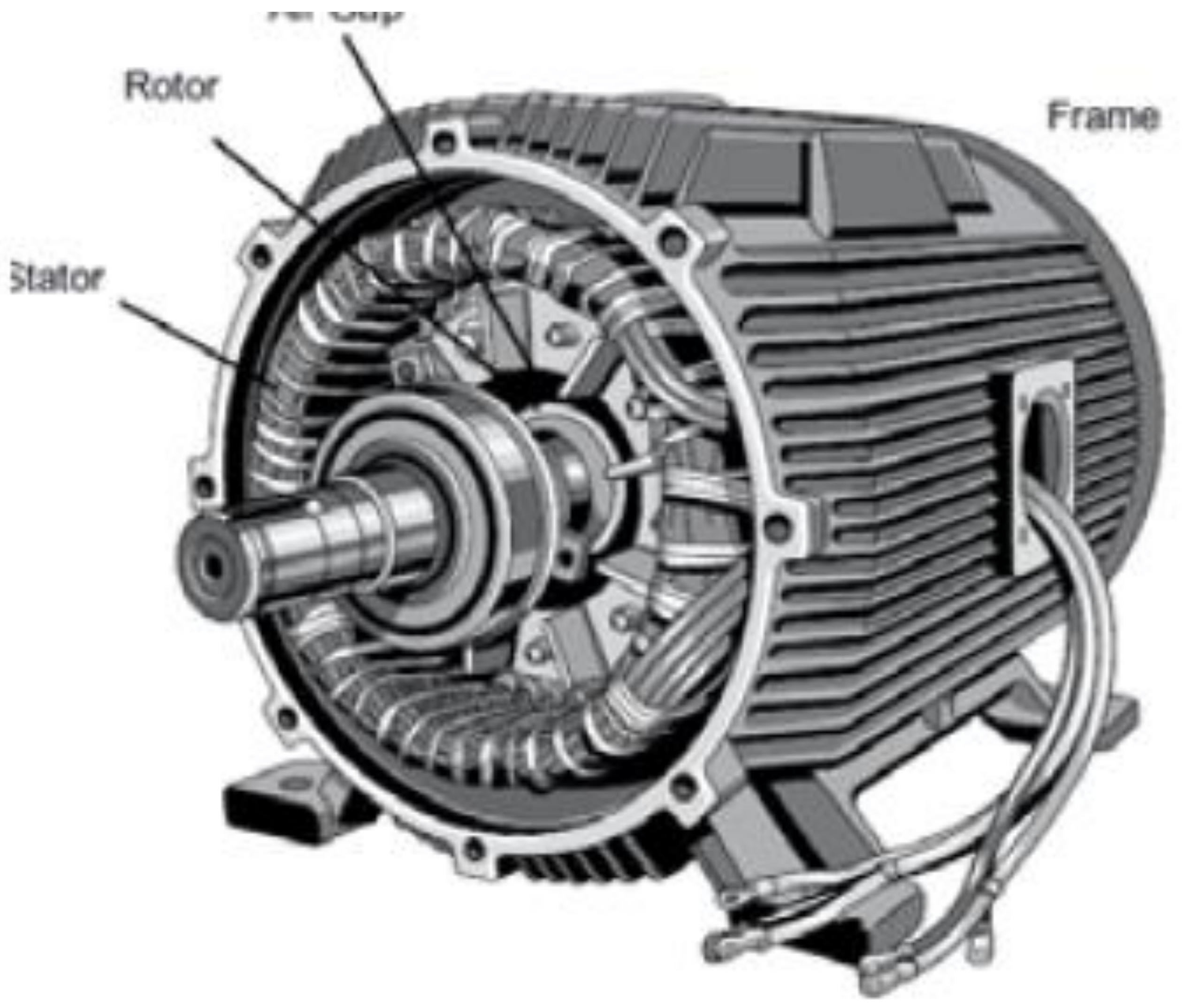
Terminology

- **5.2.1.6 Voltage**
- AC motors are rated by NEMA standards to operate at 100 percent output torque when the **voltage applied to the motor terminals is within ±10 percent of the rated voltage.** Although some control designs may operate when the supply voltage is beyond these limits, their **output voltage may vary more than ±10 percent under these conditions and could result in damage to the motor**.

Motor
AC or DC Motor



- The ACM's are simplier in structure and more economic
- Generate more power comparing with a DC motor that has the same weight.
- Maintenance of AC-motor is easier.
- AC-Motor speed control is harder



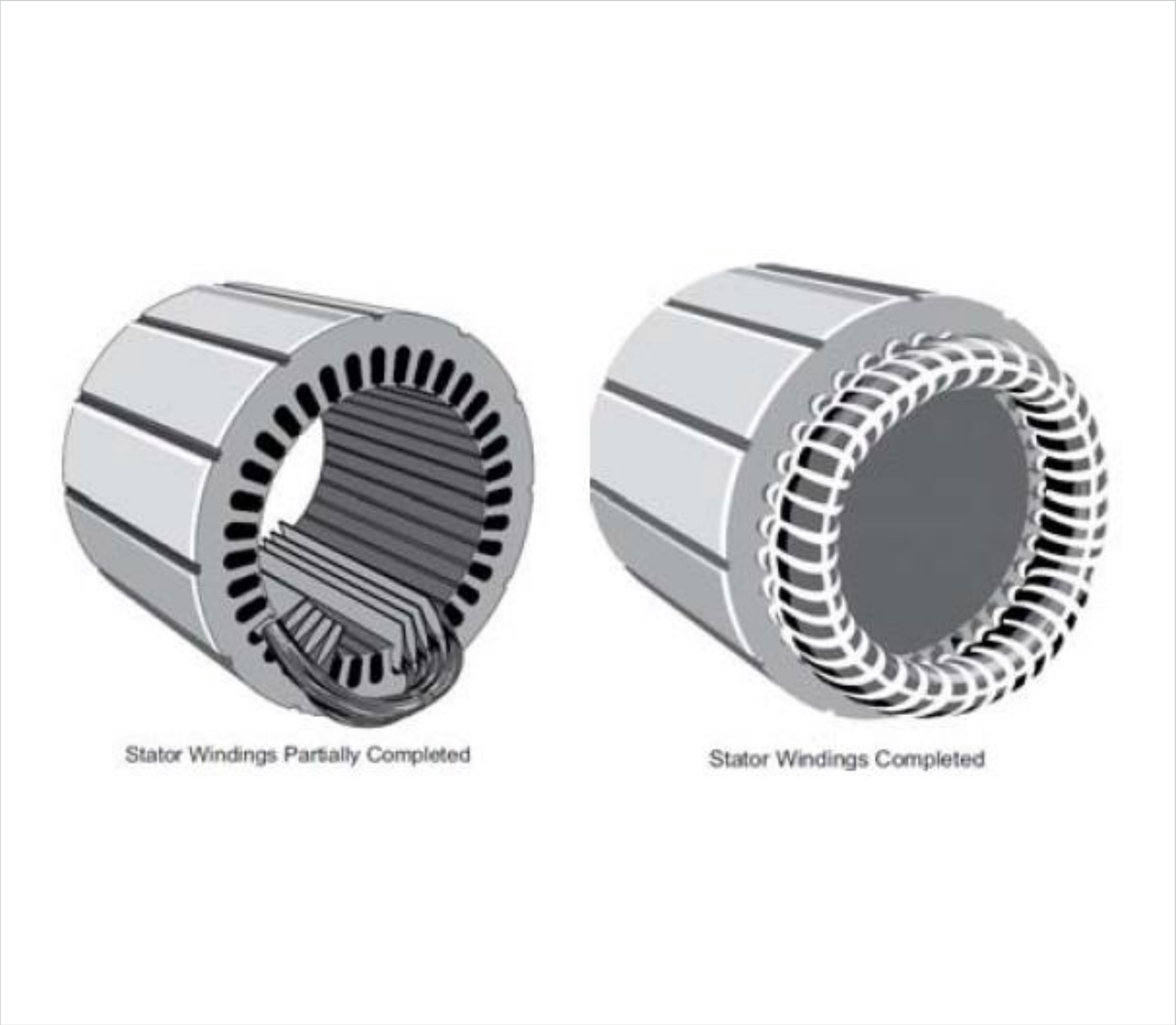
Partially Assembled Motor

Motor
Main parts - Enclosure

- The Enclosure
  - …protects the internal parts from water and other environmental elements. The degree of protection depends upon the type of enclosure
  - …consists of a frame and two end brackets (or bearing housings).
  - The stator is mounted inside the frame.
  - The rotor fits inside the stator with a slight air gap separating it from the stator.
  - There is no direct physical connection between the rotor and the stator.

Motor
Main parts - Stator

- The Stator
  - … is the stationary part of the motor's electromagnetic circuit.
  - … core is made up of many thin metal sheets, called laminations.
    Laminations are used to reduce energy loses that would result if a solid core were used.
    Stator laminations are stacked together forming a hollow cylinder.
  - Coils of insulated wire are inserted into slots of the stator core.
  - When motor is in operation
    - the stator windings are connected directly to the power source.
    - Each grouping of coils, together with the steel core it surrounds, becomes an electromagnet



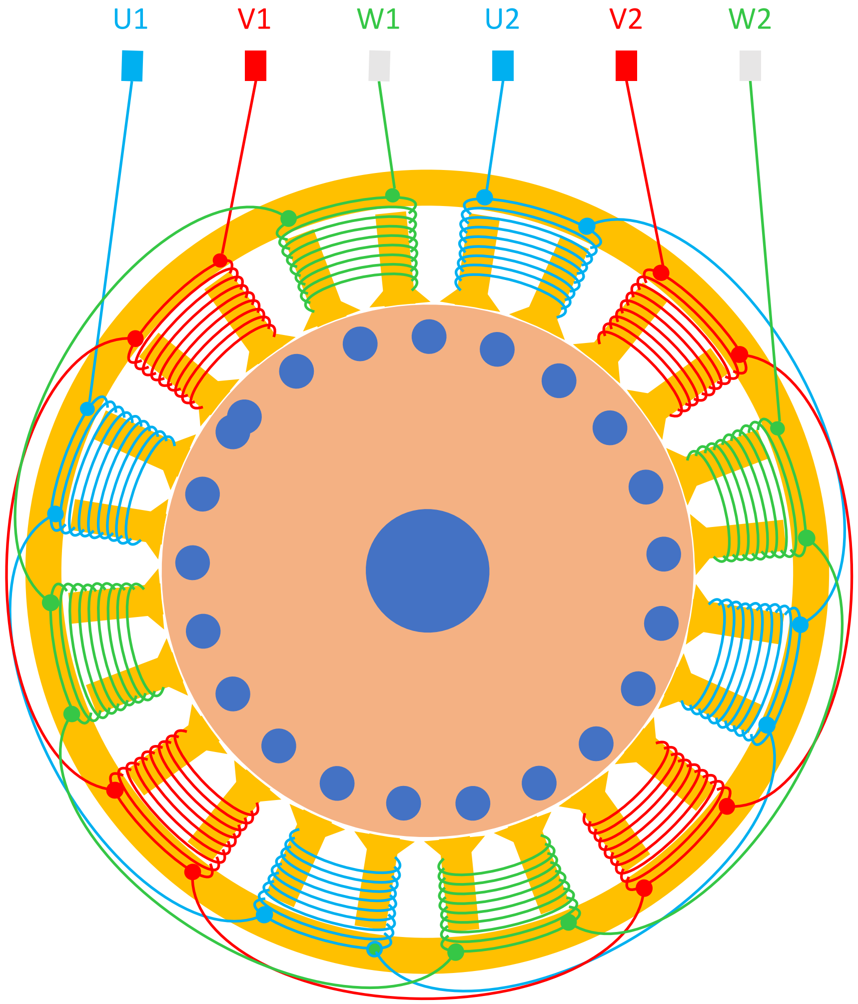
Motor
Main parts - Rotor

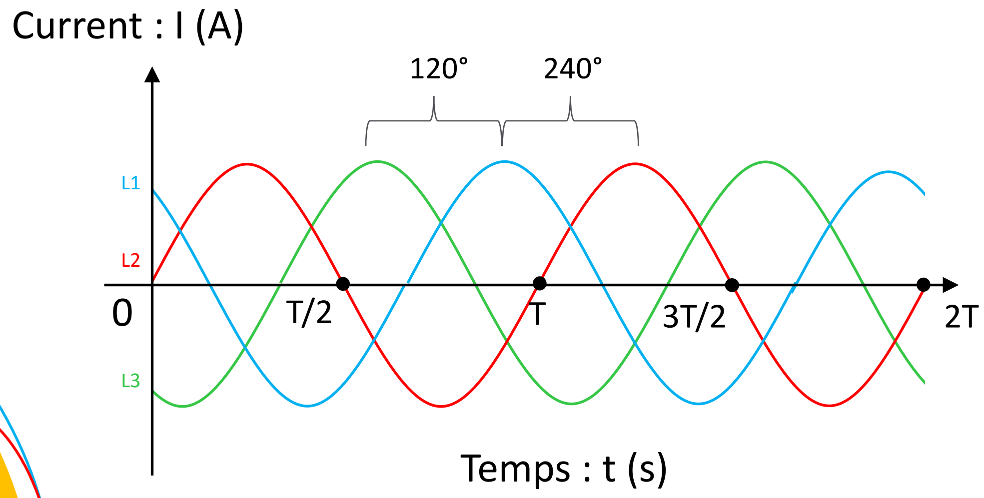
- The Rotor
  - …is the rotating part of the motor's electromagnetic circuit.
  - …is not supplied with electrical power
    Electrical current in rotor flows because of the electromagnetic induction.
  - There two common type of constructions for rotor
    used in an induction motor
    - .) Squirrel cage rotor
  - .) Wound Rotor

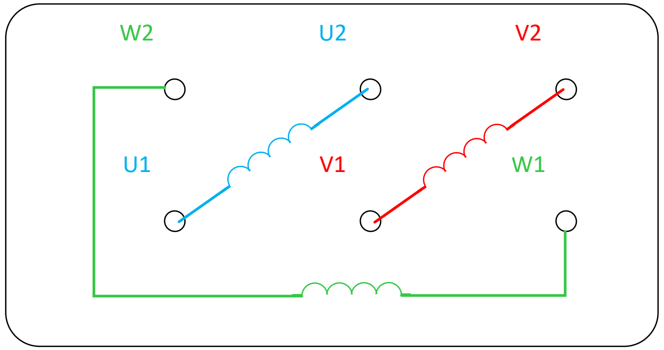
Electrical motor

Motor winding

- 3 phase motor has independent coils for each phase.
- Shift phase of 120° in each line.
- Internal connection as
  - U1,V1,W1 (start)
  - U2,V2,W2 (end)



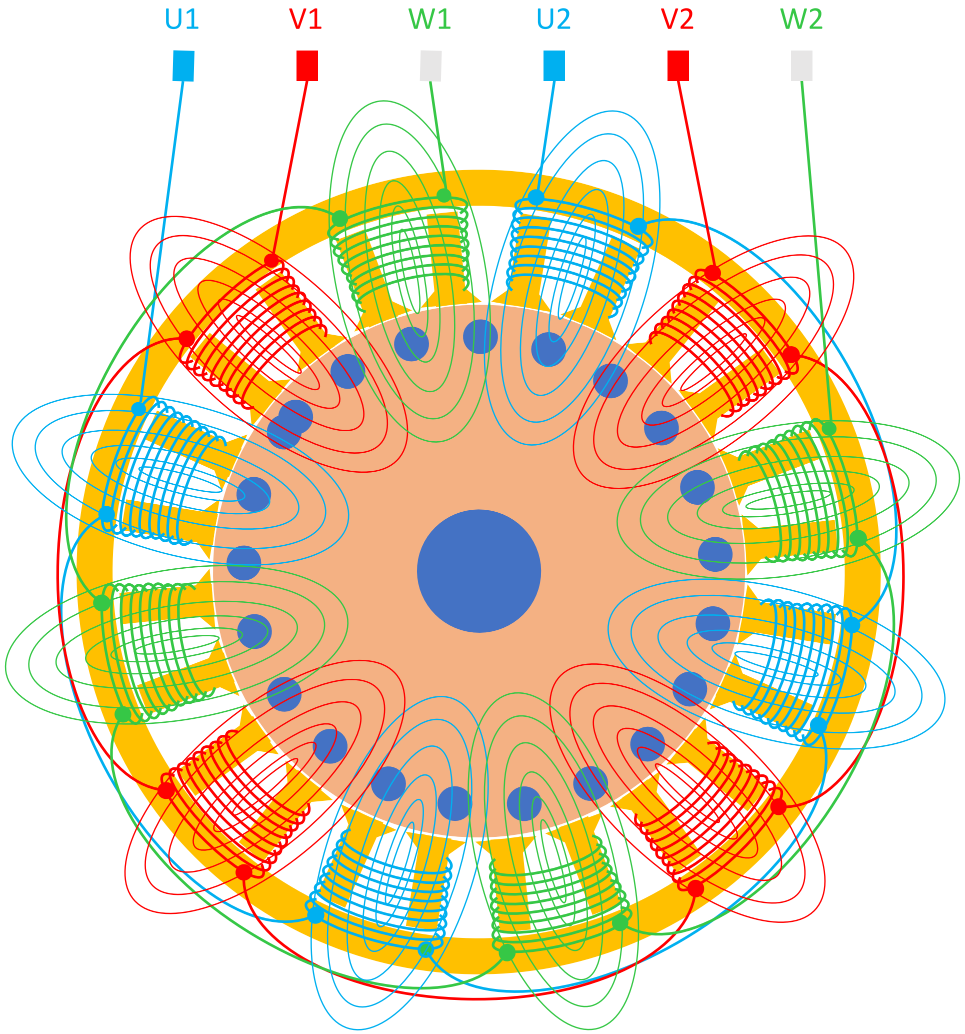


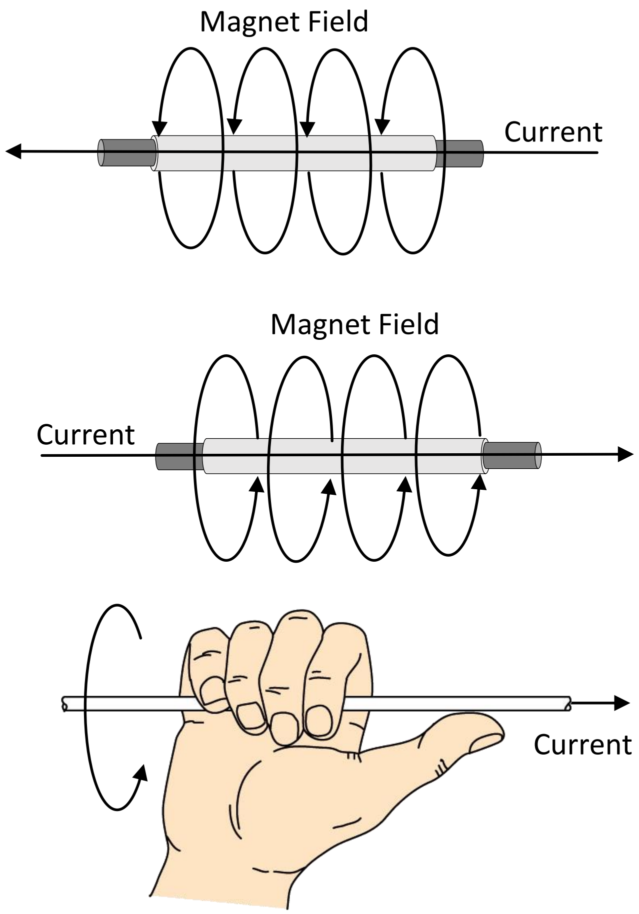


Electrical motor

Magnet Field

- Magnet fields are created by current flowing through wires.
- In each direction that current is applied creates the direction of magnet field.
- The easiest way to know the right direction is the “right hand rule”.



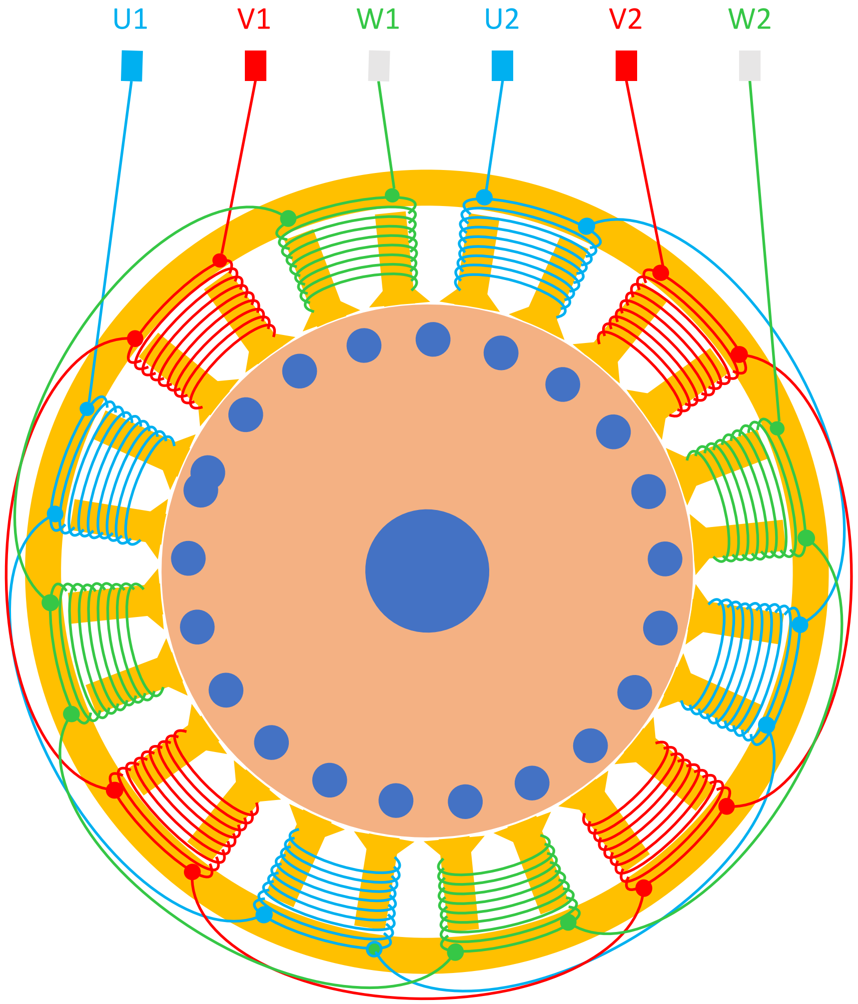


Electrical motor

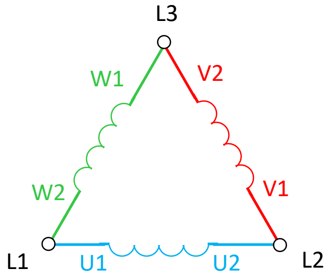
Delta △ / Star Y connections

- **Delta connection △**
- Lower voltage
- High starting Torque
- Insulation level is high

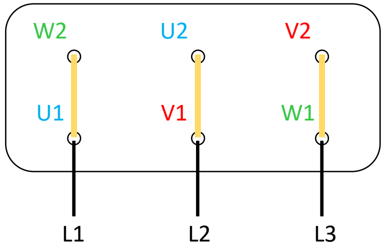
- **Star Connection Y**
- Higher voltage
- Less starting current
- Less insulation level



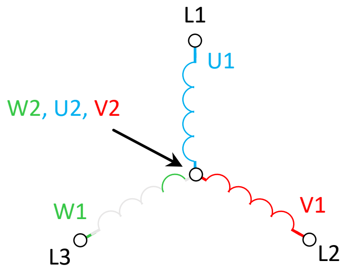
Delta Connection



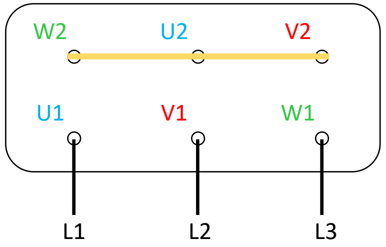
Terminal Connections



Star Connection



Terminal Connections

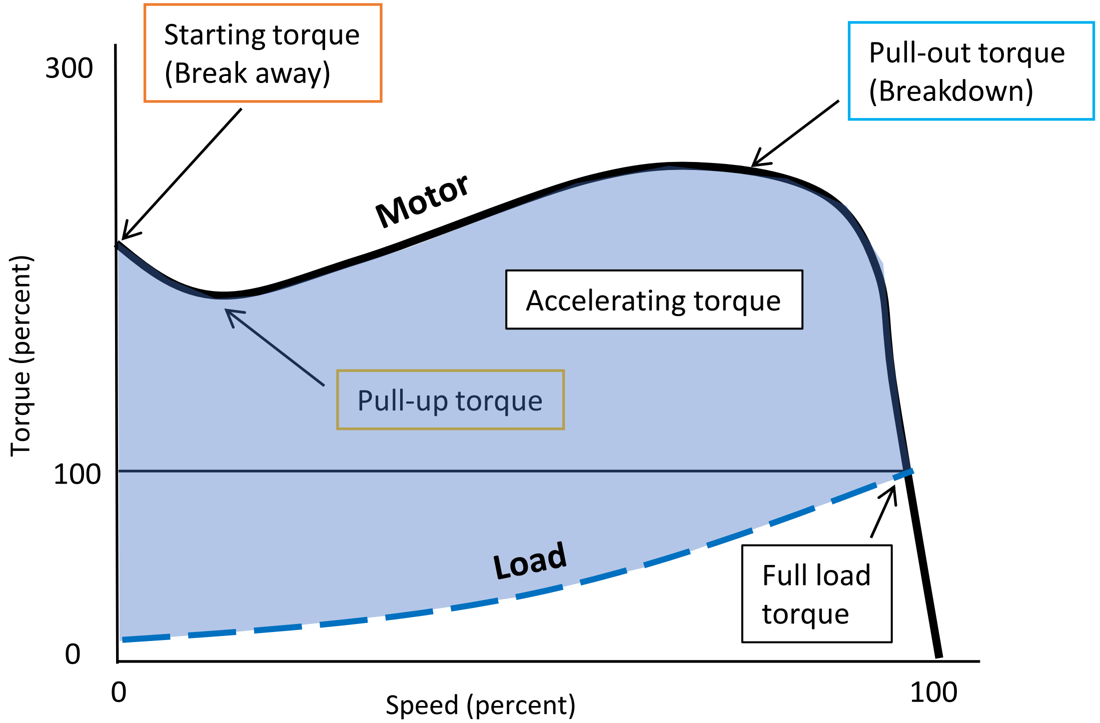


Motor

General information

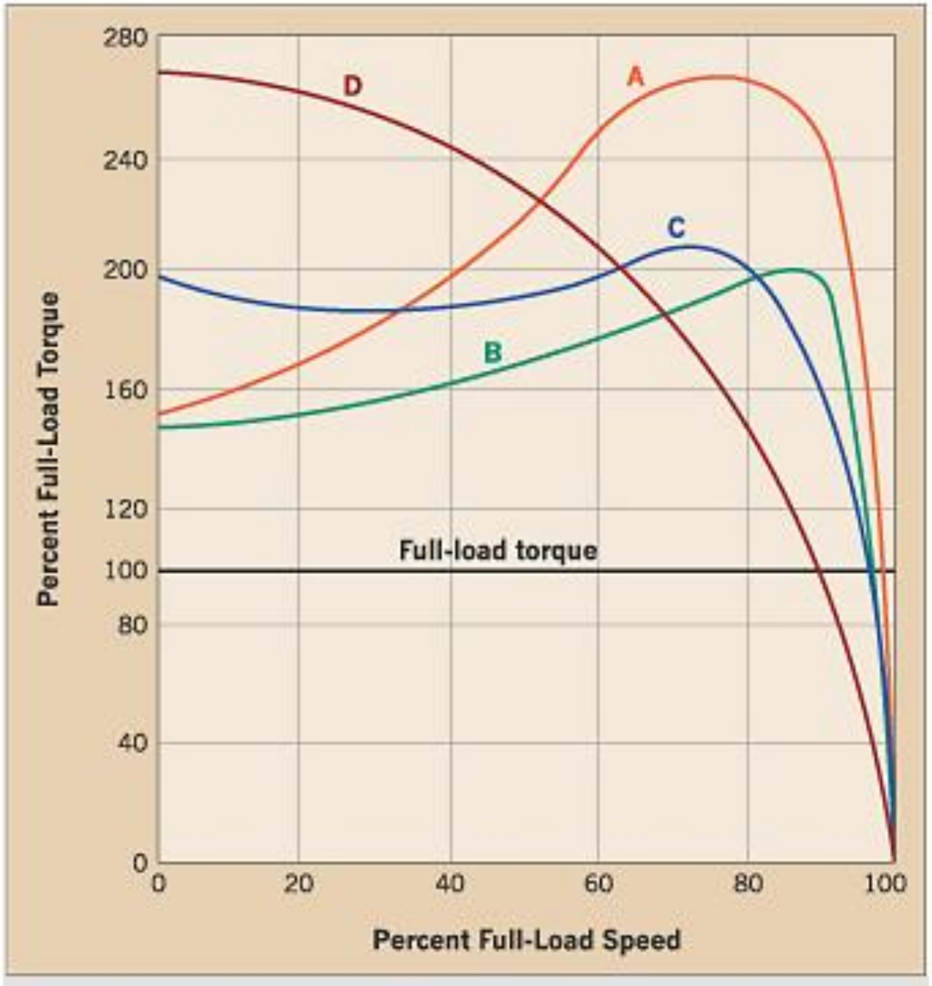
- Motor torque
  - The torque is zero at synchronous speed
  - The pullout torque can't be exceeded.
    (is 2 to 3 times the rated full-load torque)

Motor Poles	2	4	6	8	10	12	14
Synchronous speed	3600	1800	1200	900	720	600	514
Slip Speed (FLS)	3450	1750	1165	790	670	575	485



Motor
General information

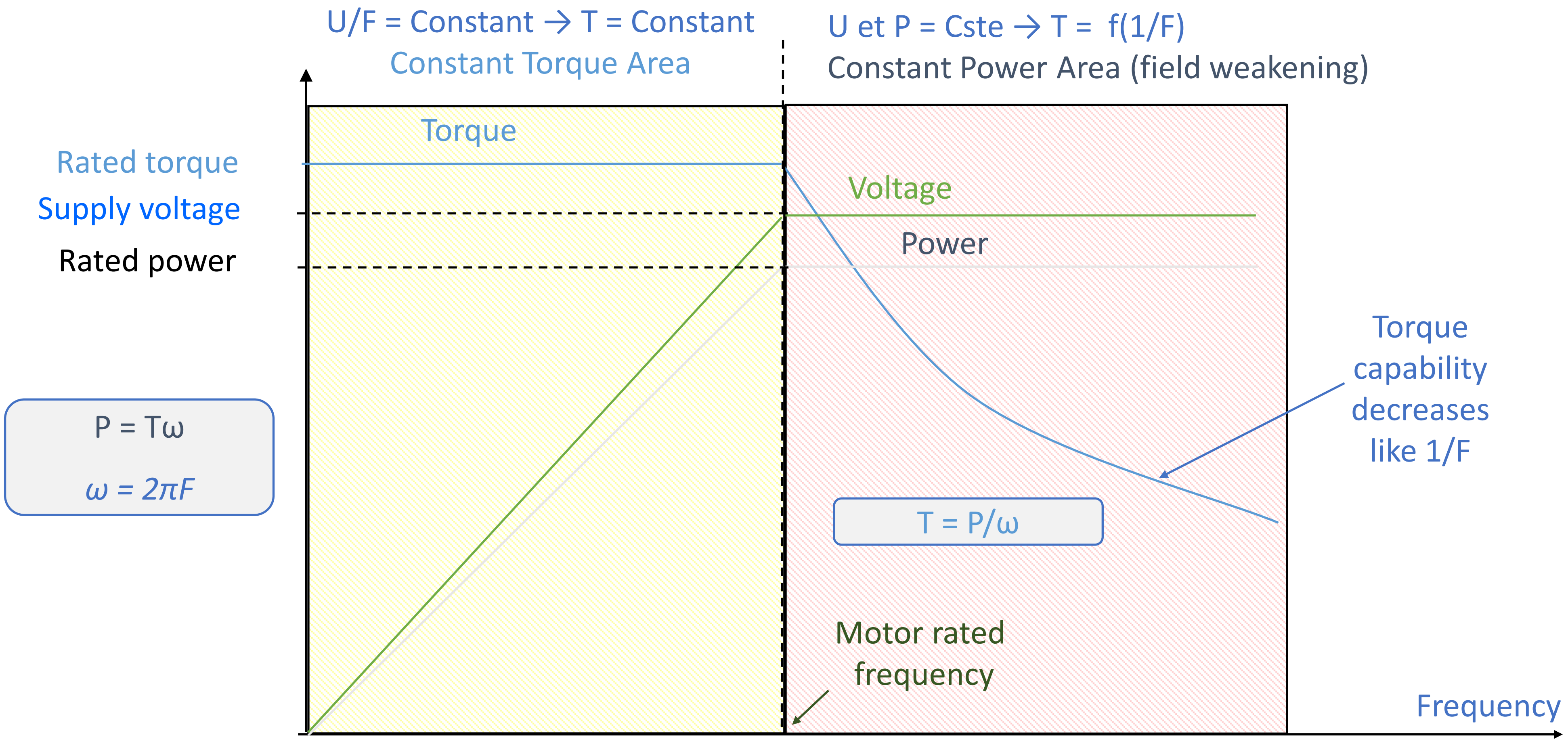
- Motor torque
  - NEMA Design Letter
  - Special torque characteristics could be needed
    for a certain application
  - Full load starting hoist require different characteristic than fan or pump
  - .
  - Most standard motors for general-purpose applications meet or exceed the values specified for Design B motors



Motor Control

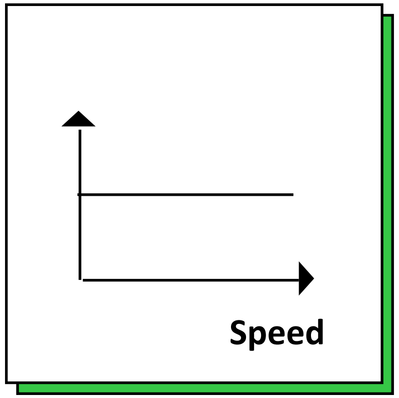
Load Analytics

- Voltage, Torque, Power characteristics with speed drives



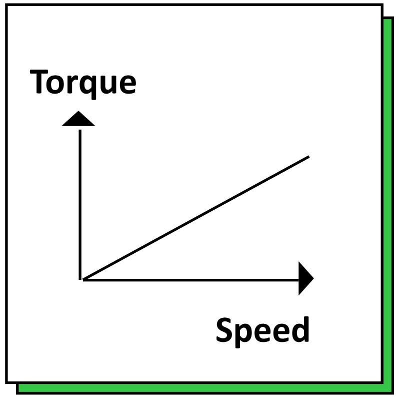
Motor Control

$$T_r = k$$



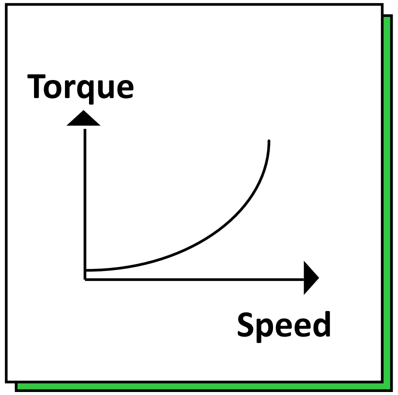
- Conveyors
- Hoisting

$$T_r = k\,.\,\omega$$



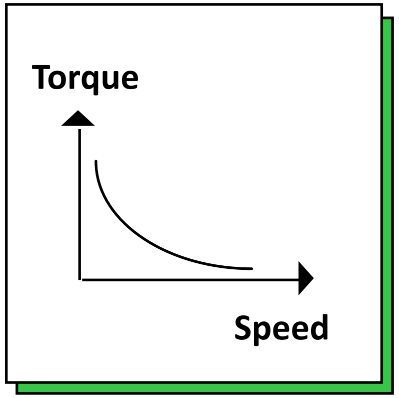
- Archimede screw

$$T_r = k\,.\,\omega^2$$



- Fans
- Centrifugal pumps

$$T_r = k\,.\,\frac{K}{\omega}$$

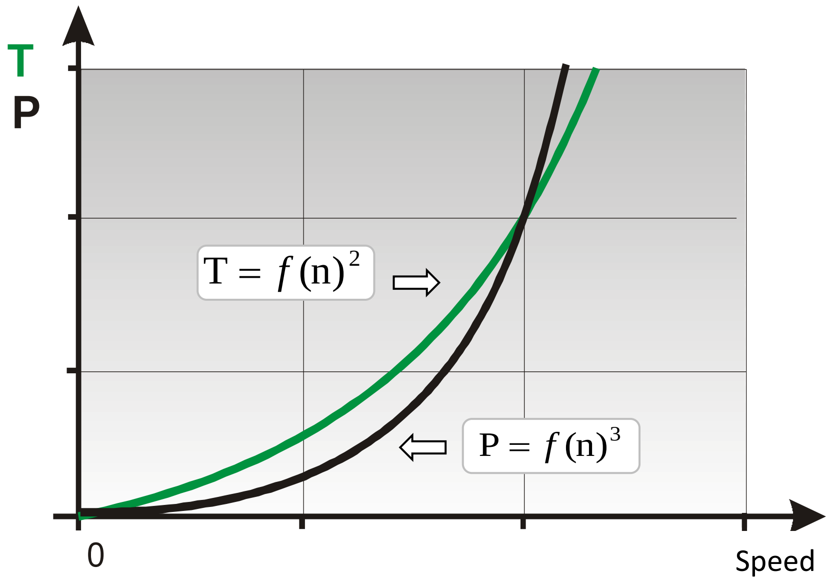


- Winders
- Machine tool

Load analytics

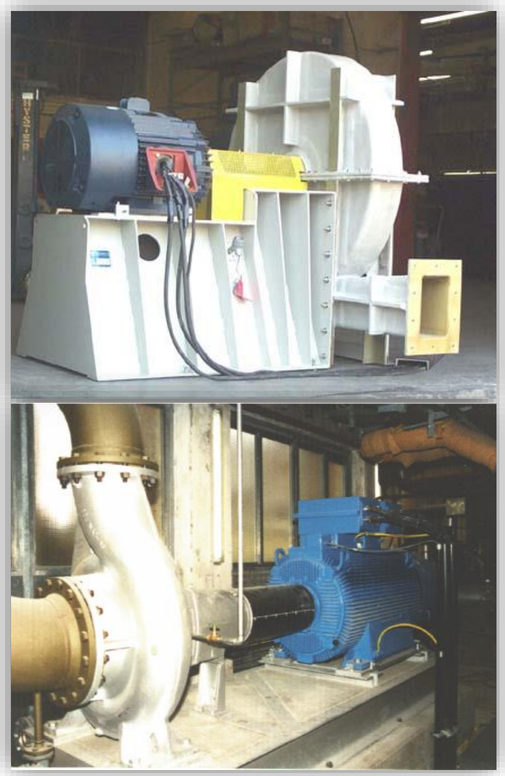
Analyzing the load characteristic

- Squared torque - Power rise cubed with speed



- $T = f(n^2)$
- $P = f(n^3)$

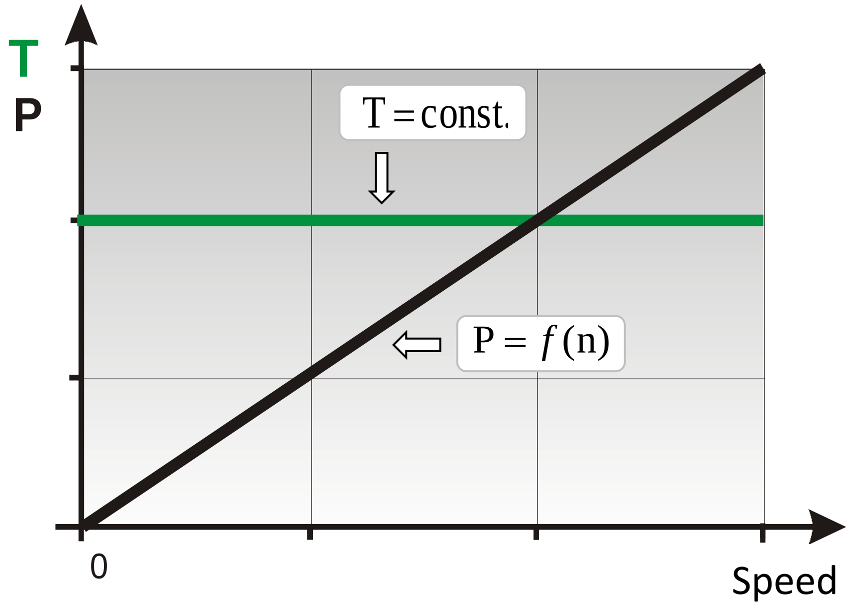
- Typical applications:
  Centrifugal pumps, Fans,
  Blowers Ventilators …



Load analytics

Analyzing the load characteristic

- Constant torque - Power rise linear with speed



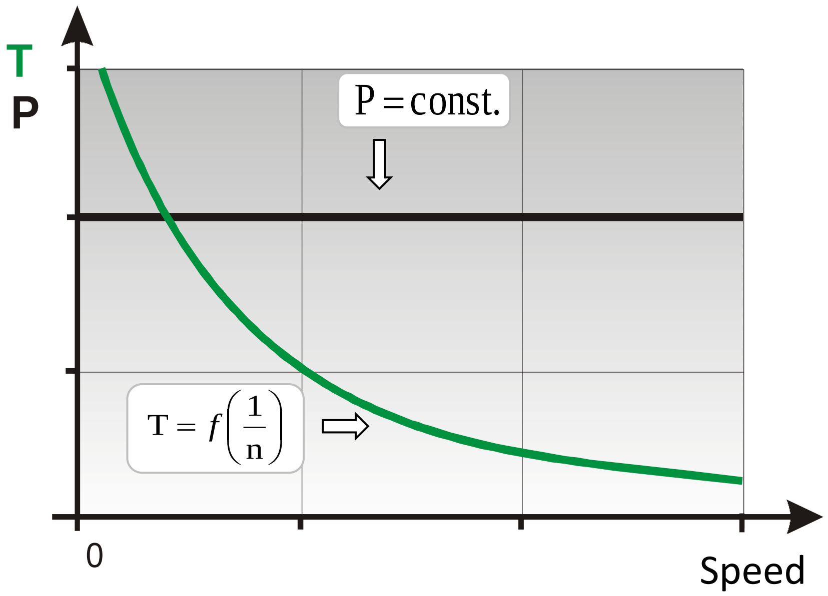
- T = constant
- P = f (n)

- Typical applications:
  Conveyor, Hoist, Compressor,
  screw pump, piston pump …

Load analytics

Analyzing the load characteristic

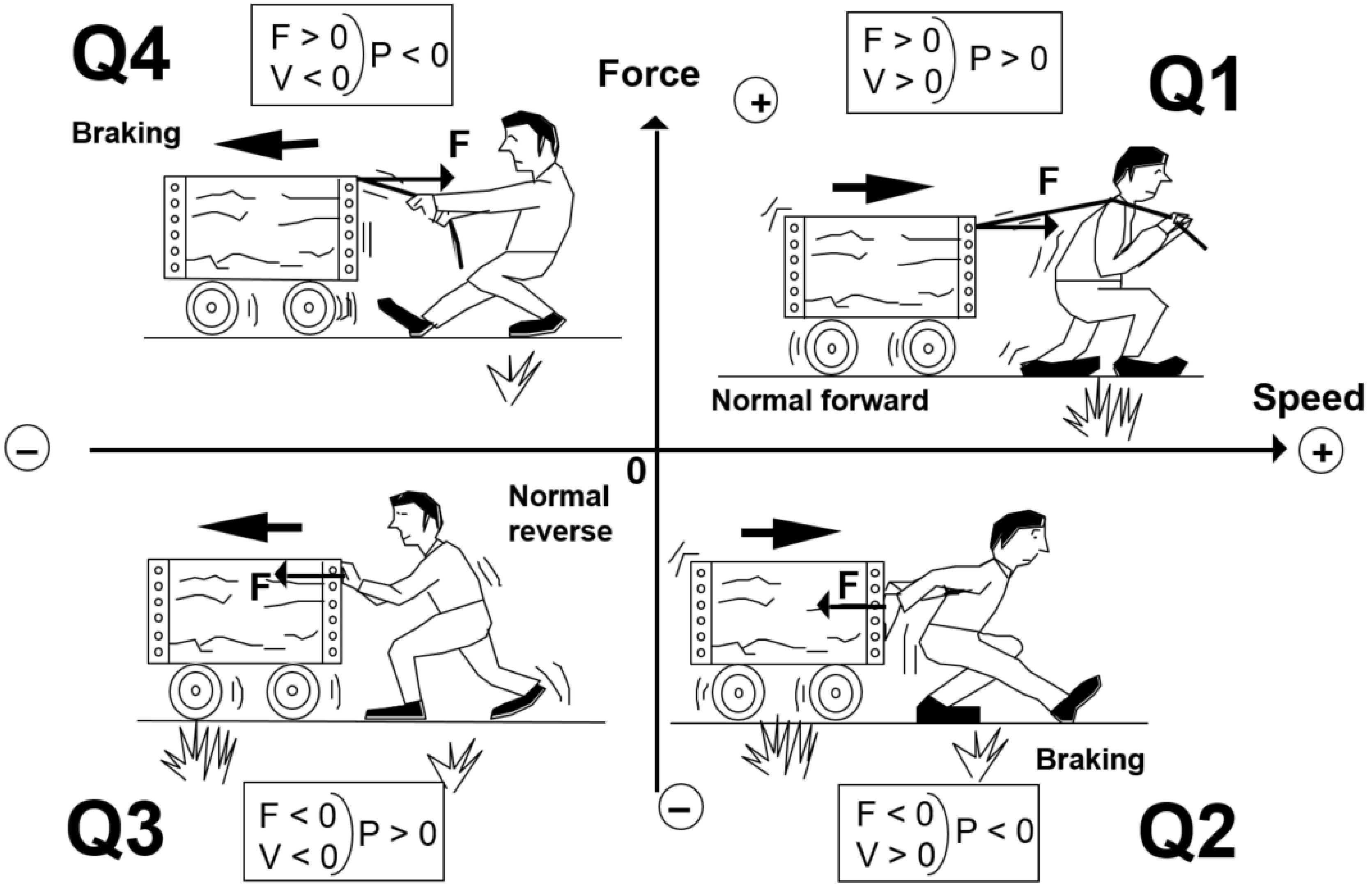
- Constant Power - Torque drops with speed



- T = f(1/n)
- P = constant

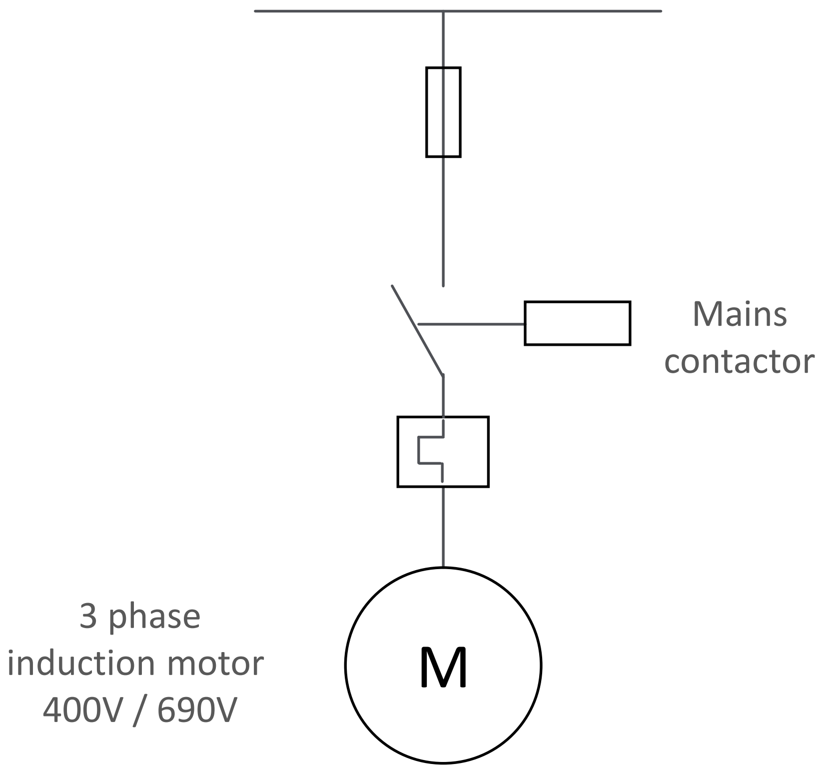
- Typical applications:
  Winder, Reel and Winches ...

Motor Control



Motor starting variants

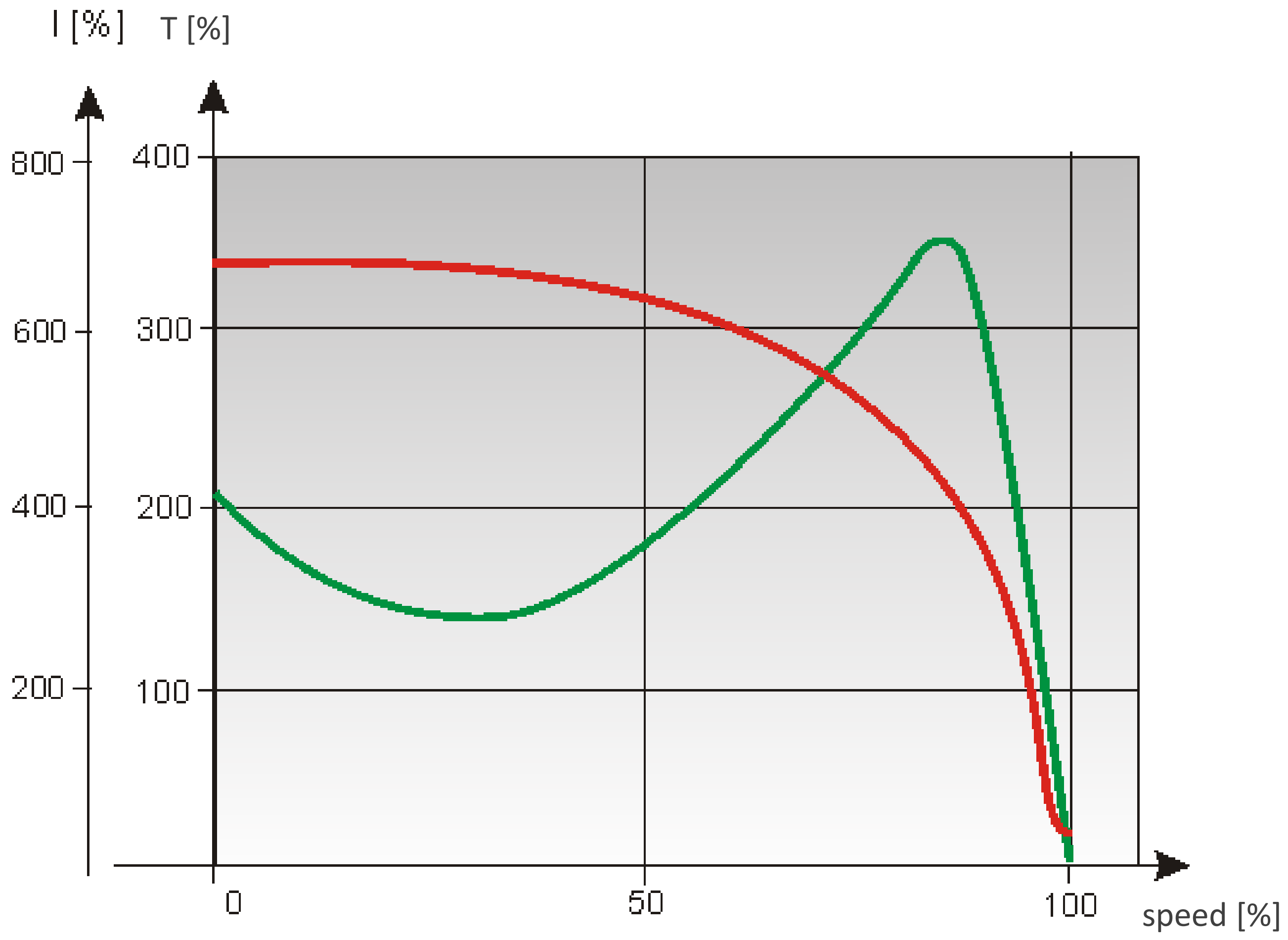
Starting DOL Direct On Line



- AC3 type for inductive motor loads
- Short circuit and overload protection obligatory

Motor starting variants

DOL – Direct On Line



- Starting torque ~ $2xT_n$
- Pull up torque ~ $1,5xT_n$
- Pull out torque (brake down) ~ $3xT_n$
- Nominal torque = T_n
- No load torque = $0xT_n$

- Inrush current ~ $7xI_n$
- Nominal current = I_n
- No load current ~ $0,3xI_n$

Motor starting variants

DOL – Direct On Line

☺

- Very simple
- Very compact
- Less investment

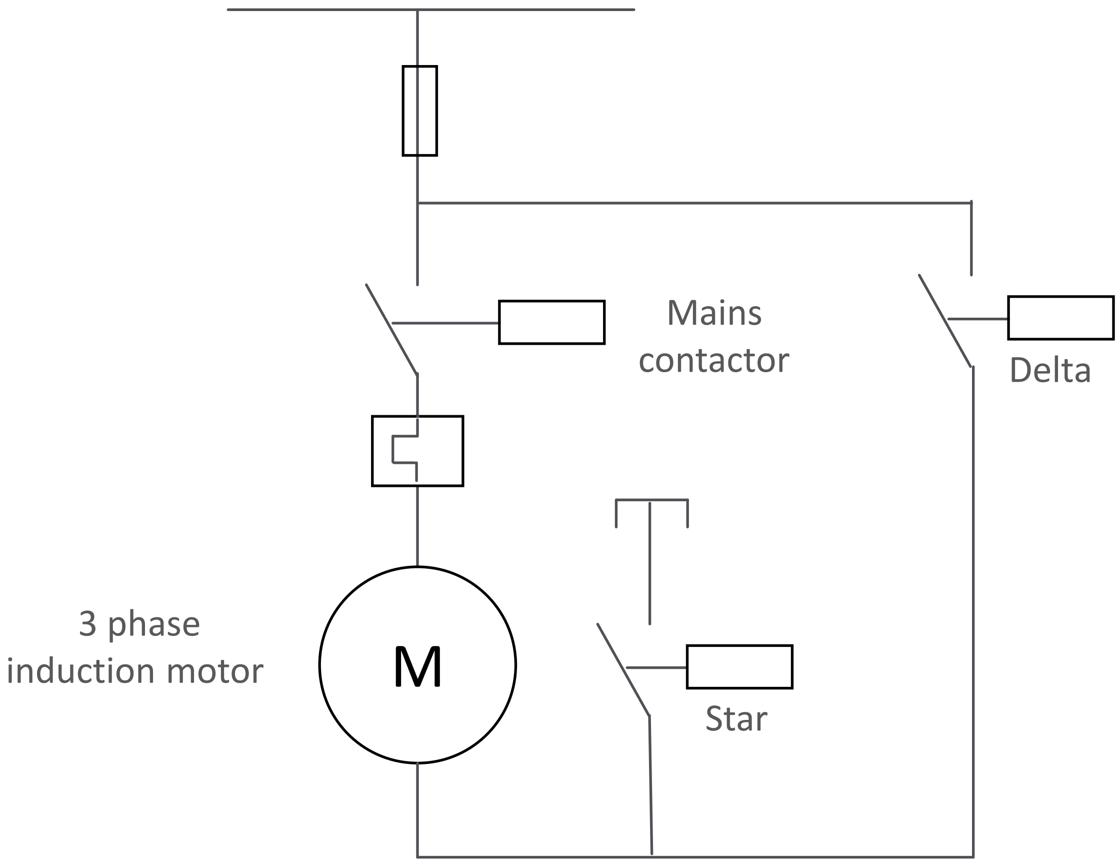
☹

- No energy savings - no speed control
- Power factor correction necessary
- High starting current leads to voltage drop and thermal stress on the motor windings
- High mechanical stress (torque stroke) during start and reversal

Motor starting variants

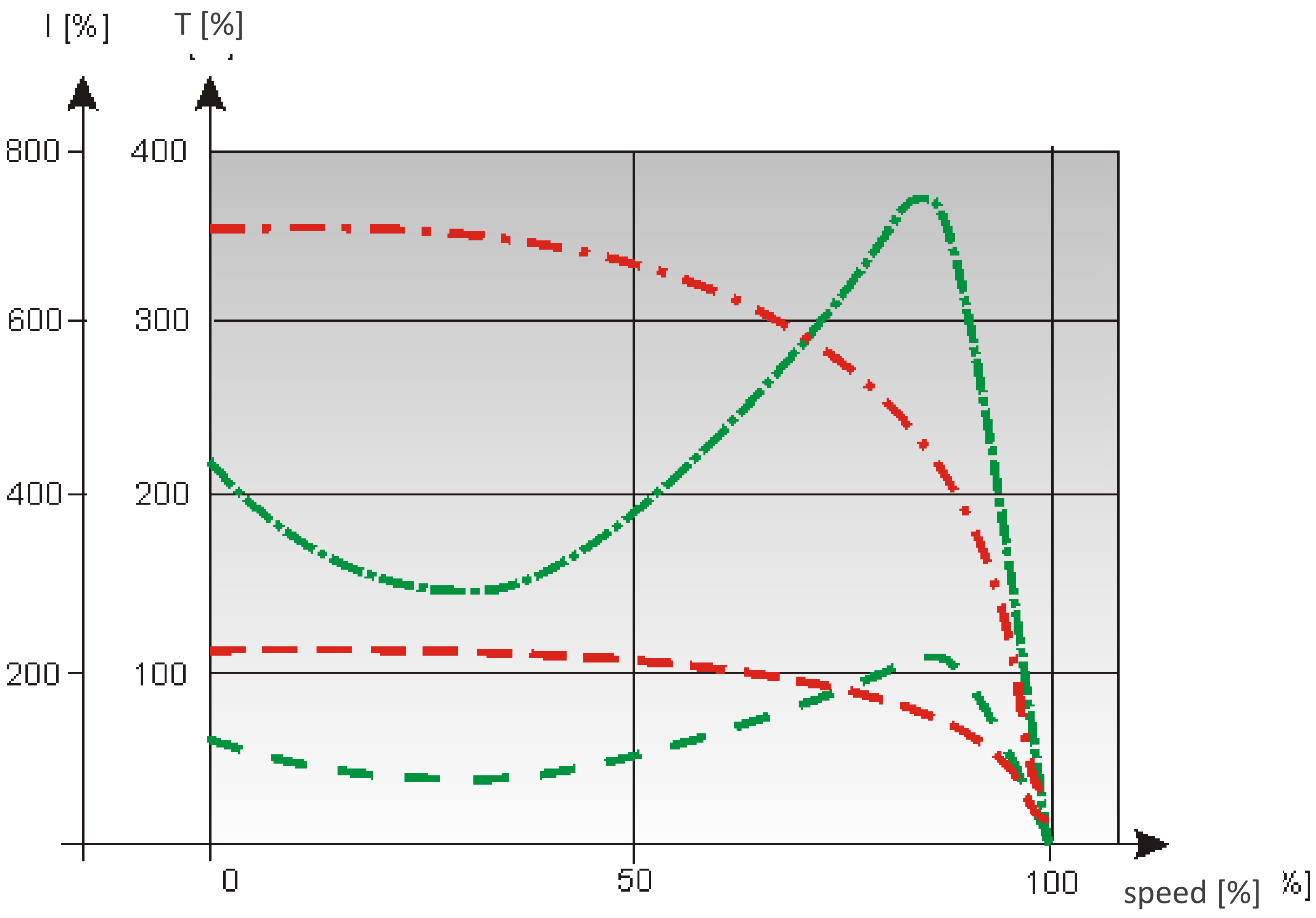
Star - Delta starting

- AC3 type for inductive motor loads
- Mains and Delta contactors Inom / √3
- Star contactor Inom / 3
- Short circuit and overload protection obligatory



Motor starting variants

Star - Delta starting

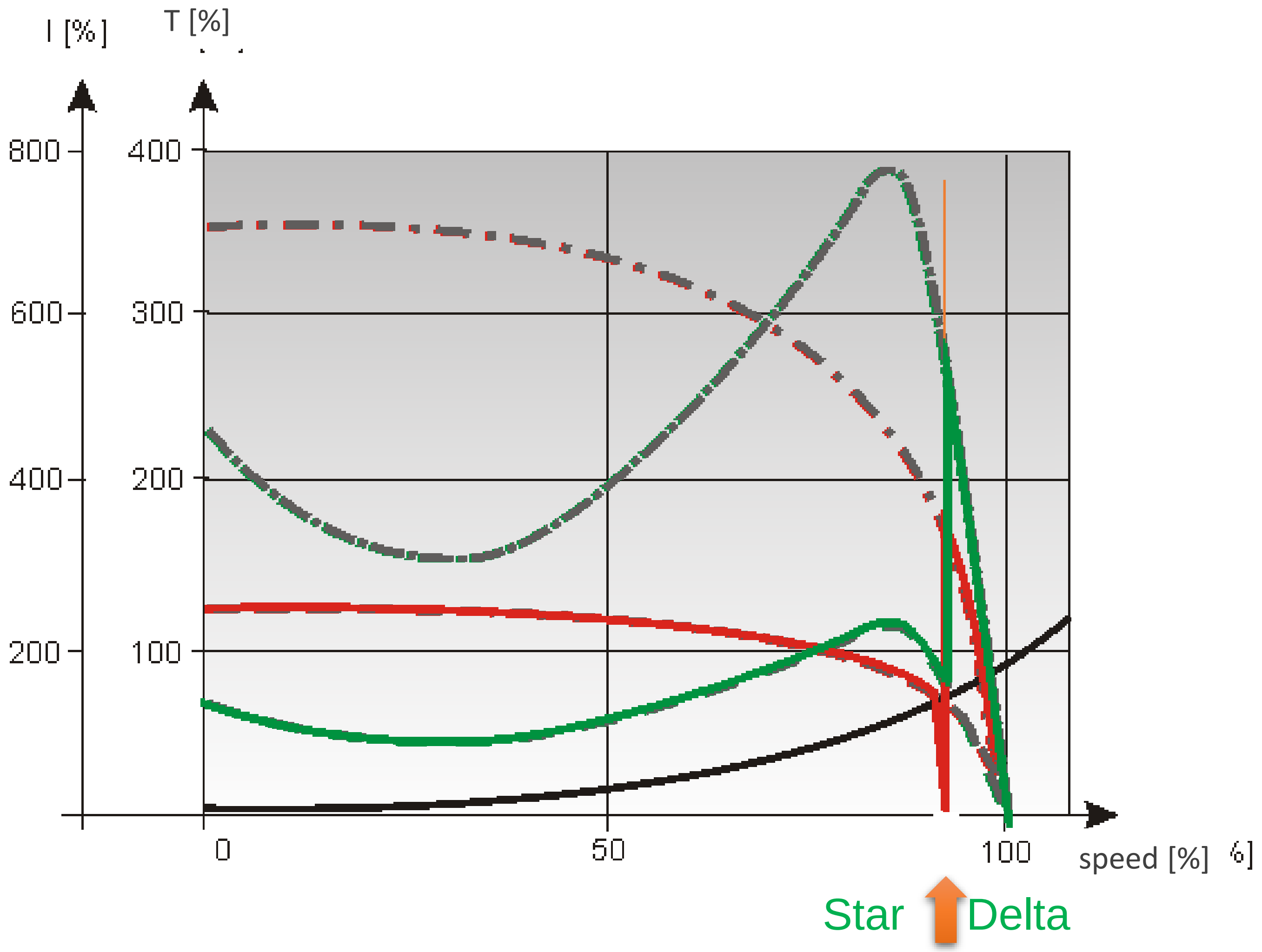


- $T = f(V^2)$
  V (Y) / V(D) = 230/400 =1/√3
  $(1/\sqrt{3})^2 = 1/3$ → **T = 1/3 T**
- I = f (V)
  1st $V = V_n/\sqrt{3}$, → I /√3
  2nd D → Y → I /√3

  I = I / (√3*√3) → **I= 1/3 I**

Motor starting variants

Star - Delta starting



- start in **Star** connection till reduced motor torque is as high as load torque
- afterwards motor get switched in **Delta** connection with full voltage, current and torque

Motor starting variants

Star - Delta starting

☺

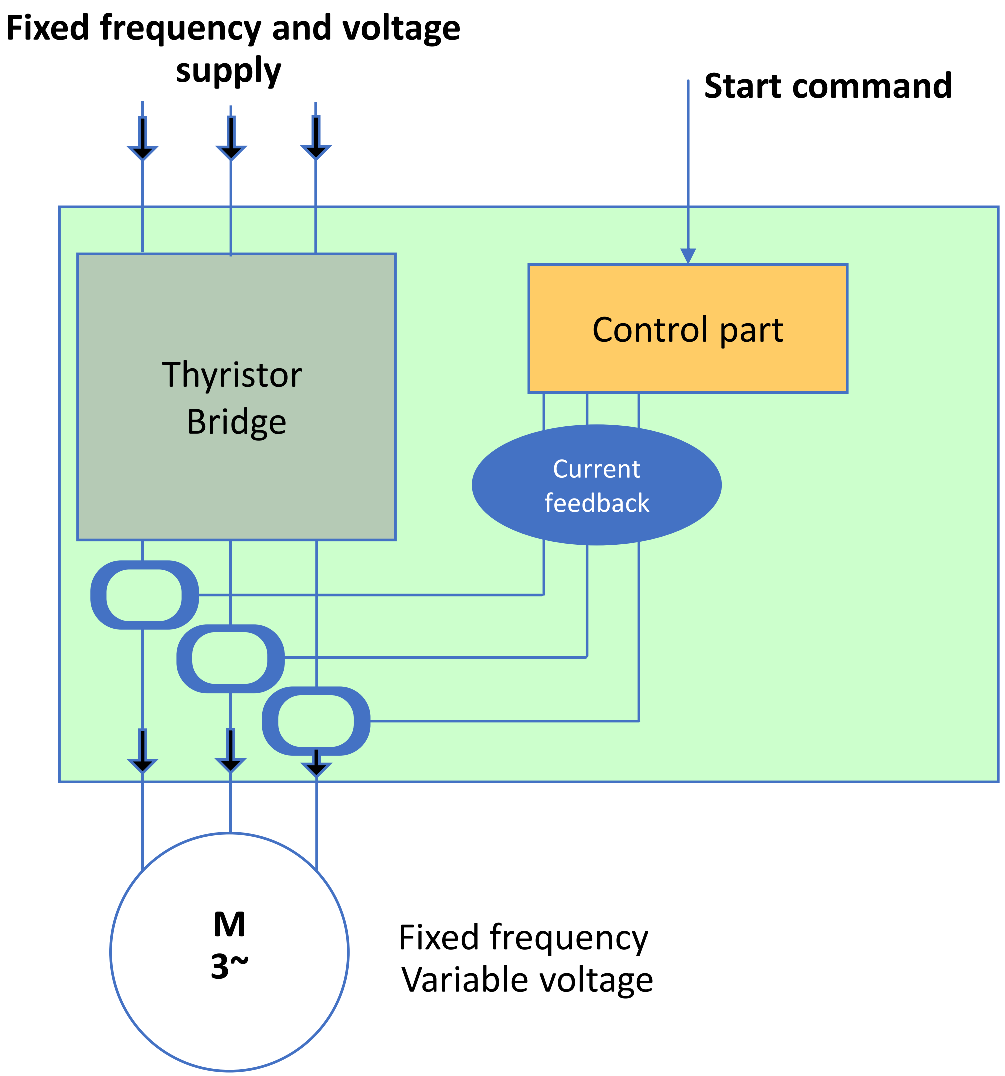
- Robust and simple
- Starting current is reduced to 33% compared to DOL
- Compact design
- Less investment

☹

- No energy savings - no speed control
- Power factor correction necessary
- Peak current and torque during switching from Star to Delta
- High mechanical stress during start and reversal

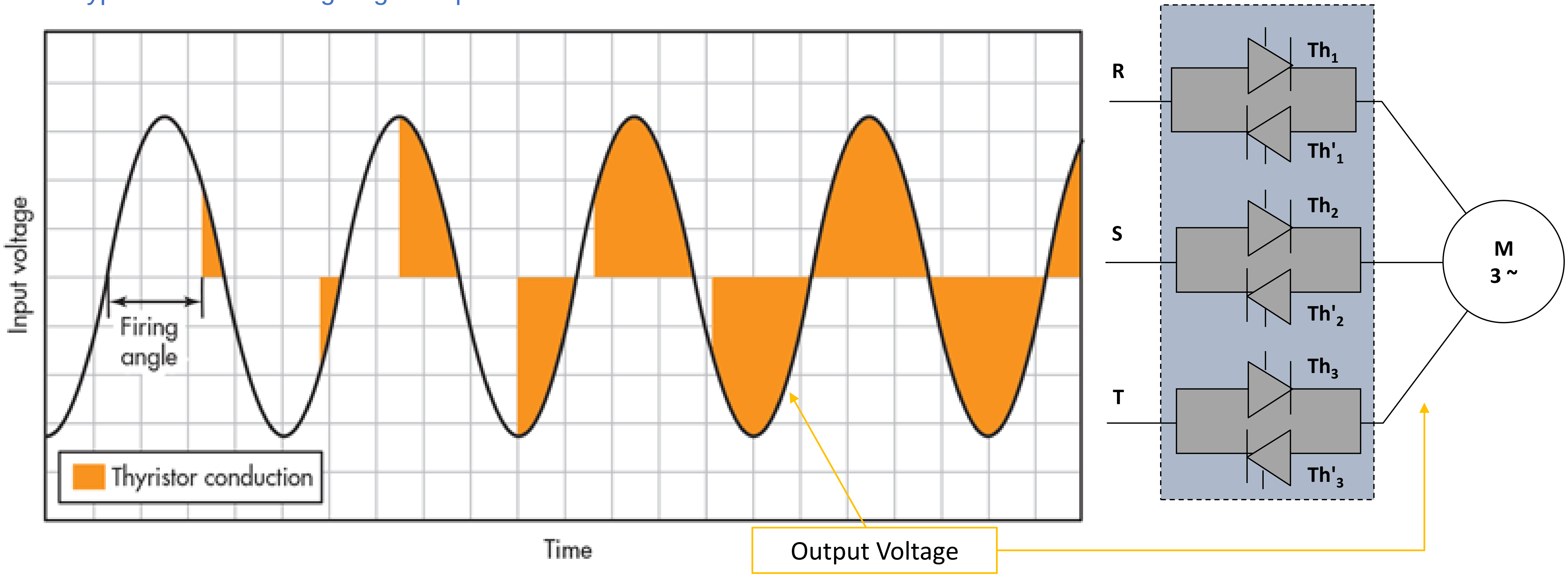
Basics on Soft Start

- Take the motor to its rated speed as smoothly as possible:
  - 0 => Nominal Speed
- Take the motor to stop as smoothly as possible:
  - Nominal Speed => 0
- Limit current inrushes
  - Optimise power distribution
- Limit torque jerking
  - Optimise machine structure



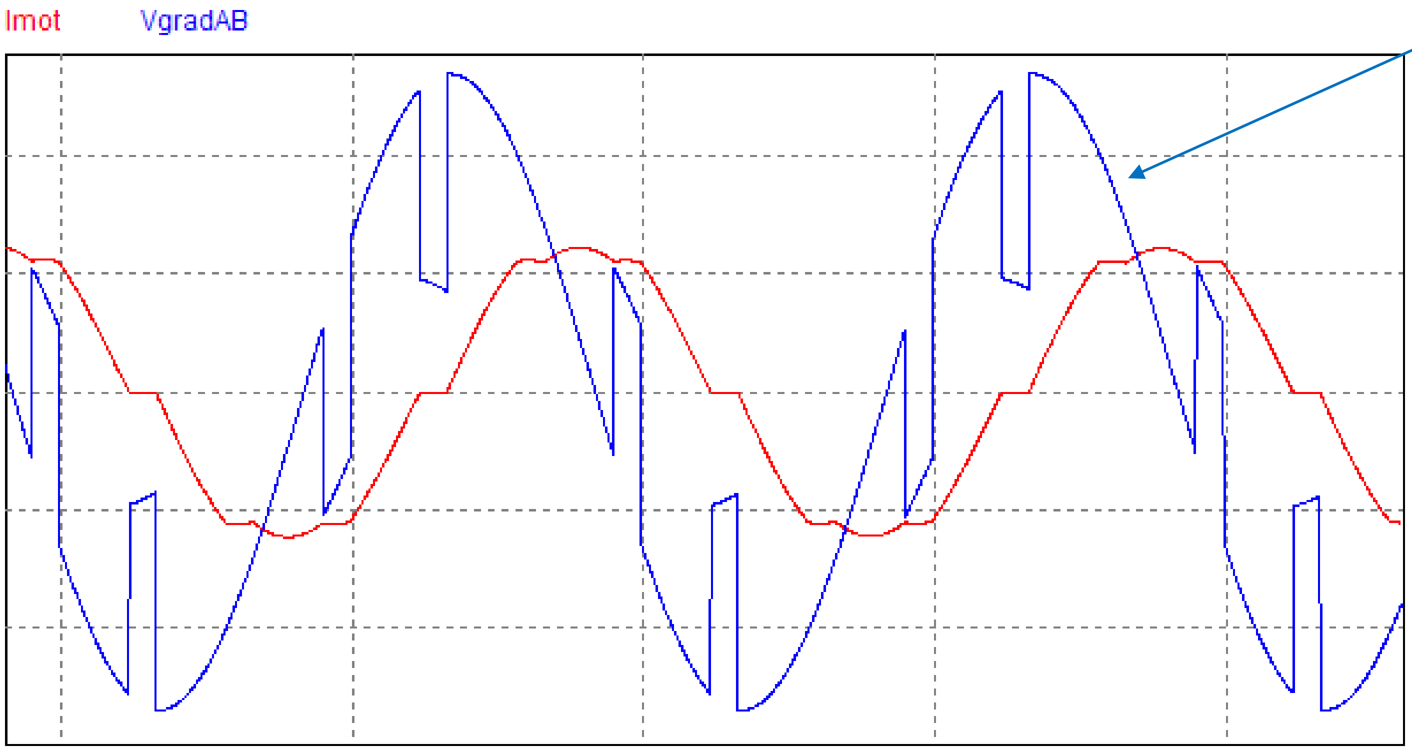
Basics on Soft Start

- Typical soft start firing angle sequence

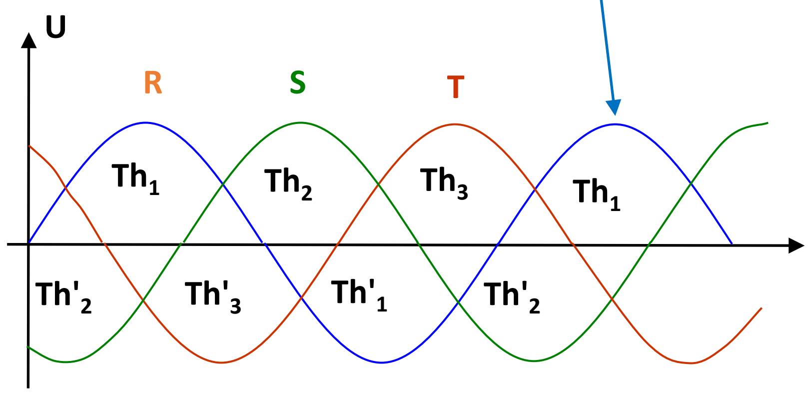


Basics on Soft Start

- 6-thyristor three-phase installation on resistive and inductive load



Current and voltage waveform example during a soft start

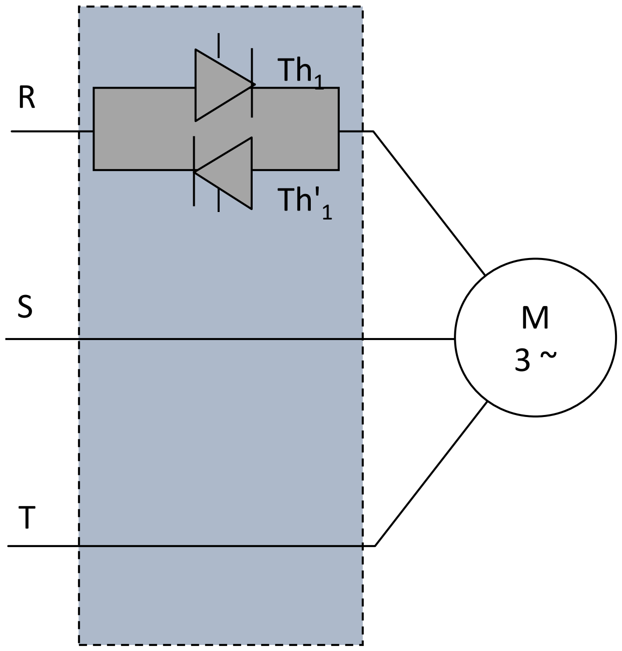


Basics on Soft Start

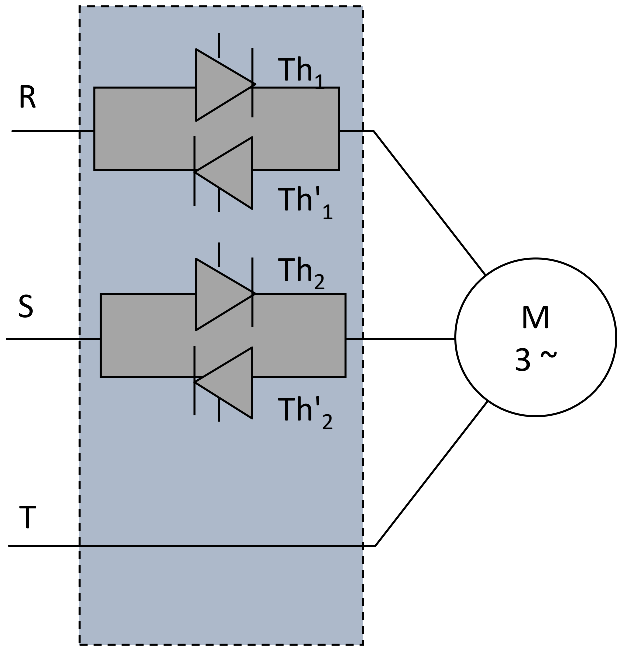
No possible to run in reverse mode.

Most use additional contactor.

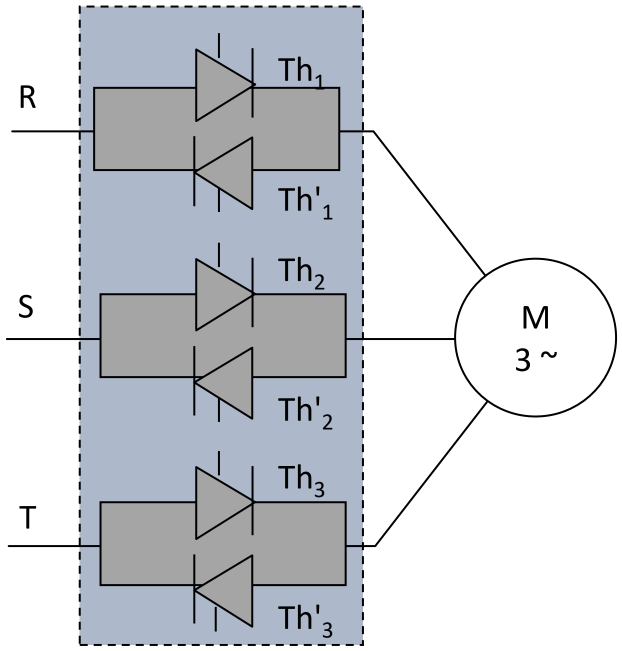
- Looking inside of Soft Start with 1, 2 or 3 phases control



ATS01N1



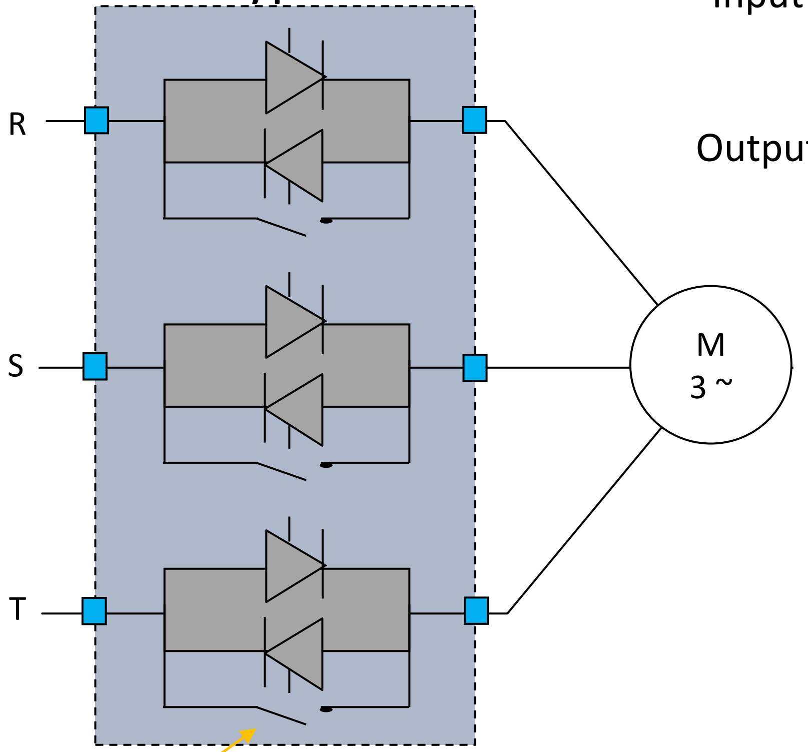
ATS01N2



ATS 22 / ATS48

Basics on Soft Start

Internal Shunting Bypass

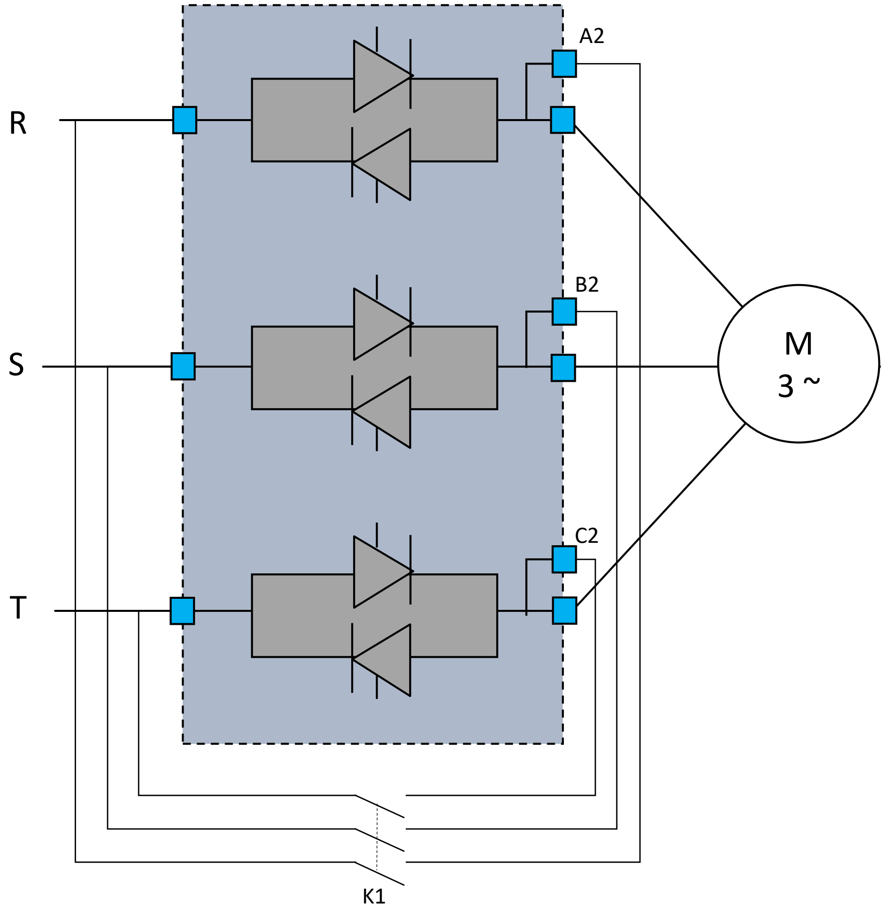


Input Voltage

=

Output Voltage

Full Voltage Bypass



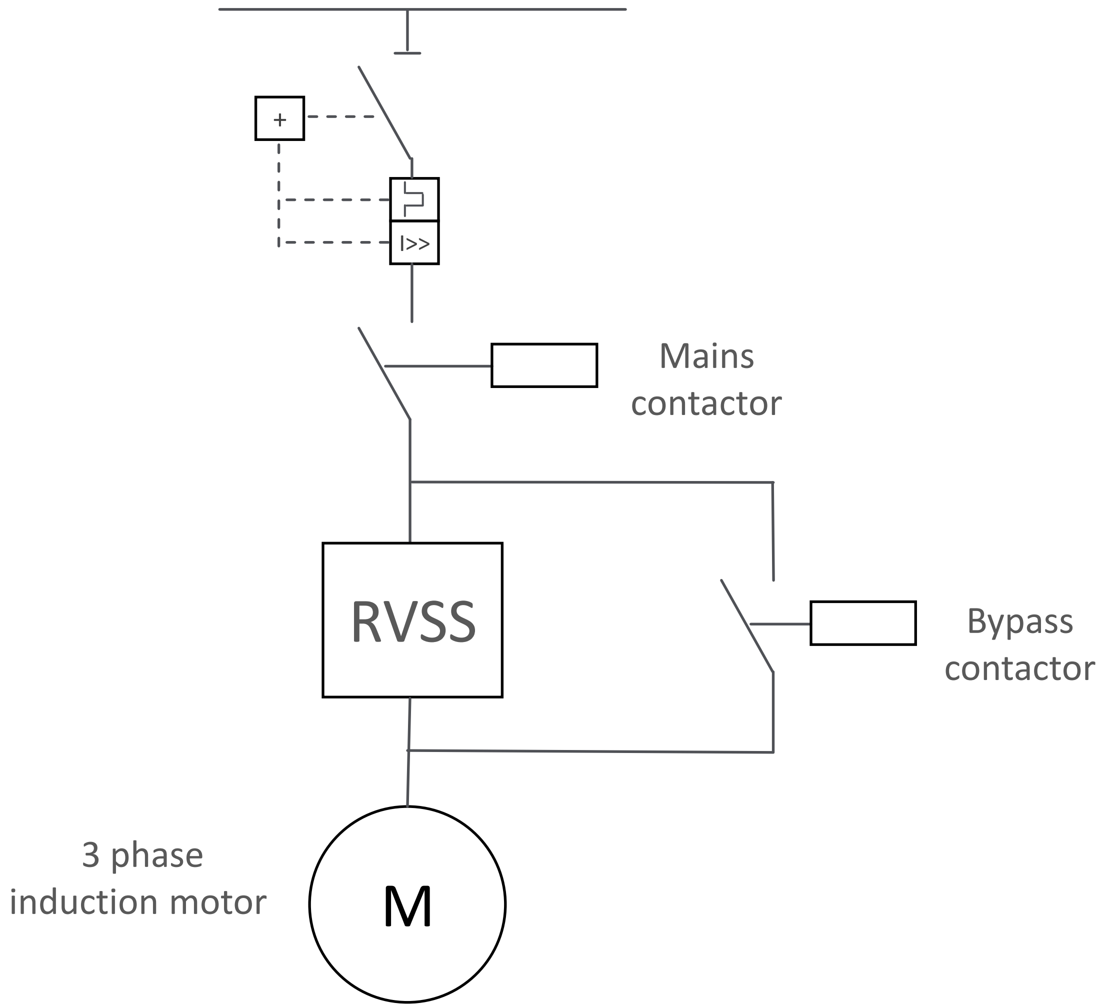
Embedded bypass

External bypass

Motor starting variants

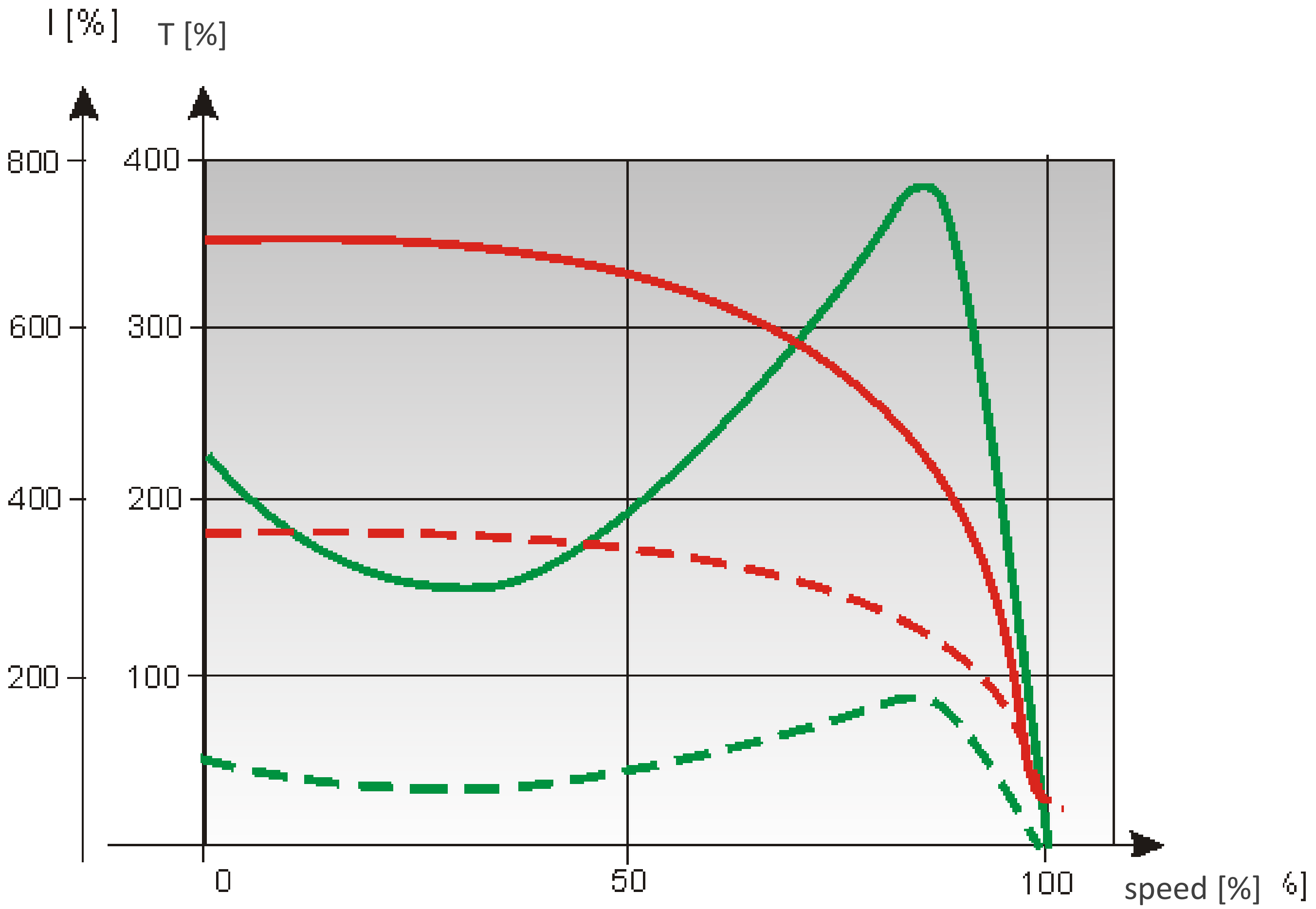
RVSS – Soft Start

- Reduction of the starting torque to protect mechanical parts
- 1, 2 and 3 phase system
- Multiple application functions
- Reduce Starting current until 3x I_n
- Variable voltage ramp (no speed ramp)



Motor starting variants

RVSS Soft Start



- T = ƒ (V²)

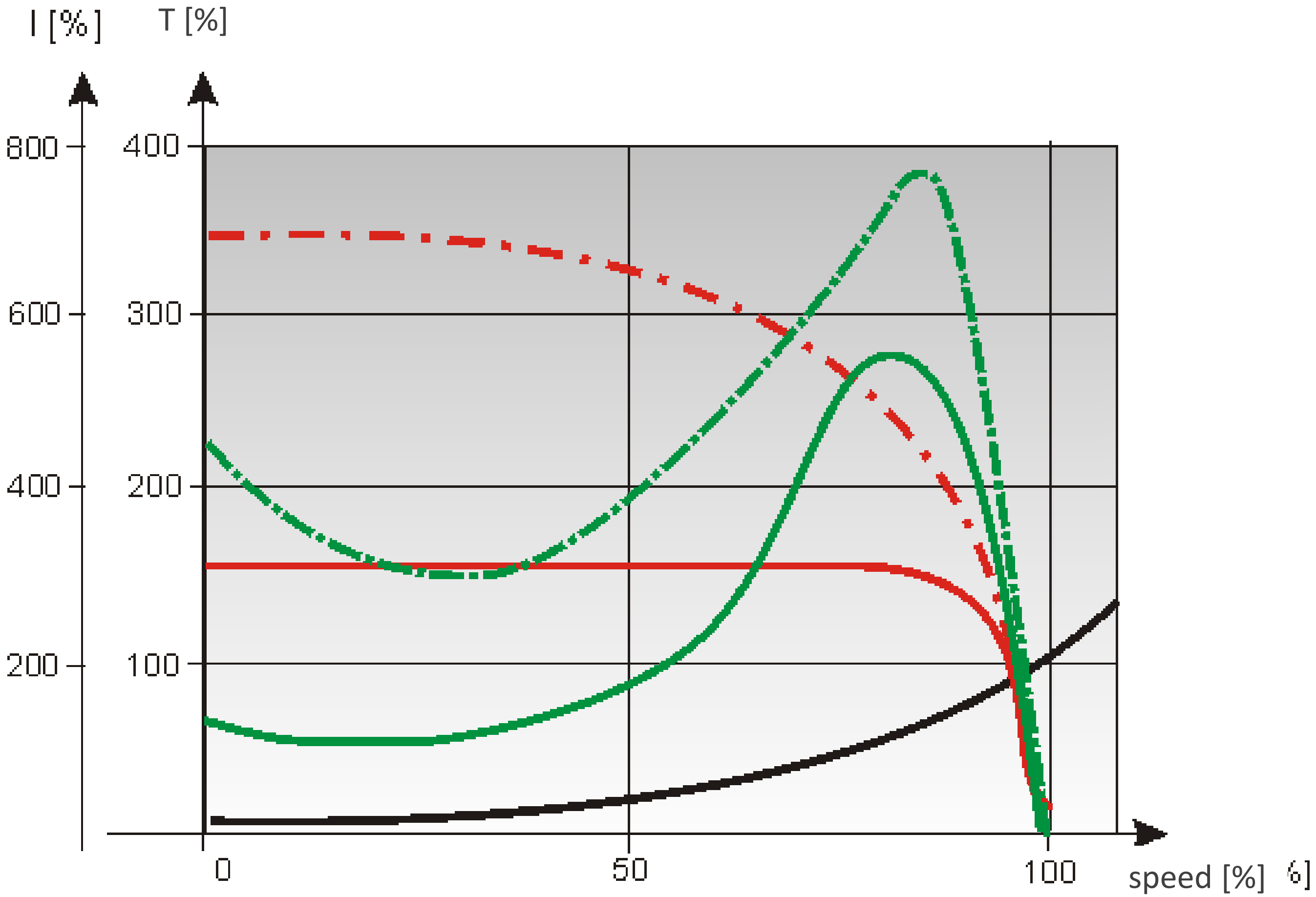
  ½ V → ¼ T_n

- I = ƒ (V)

  ½ V → ½ I_n

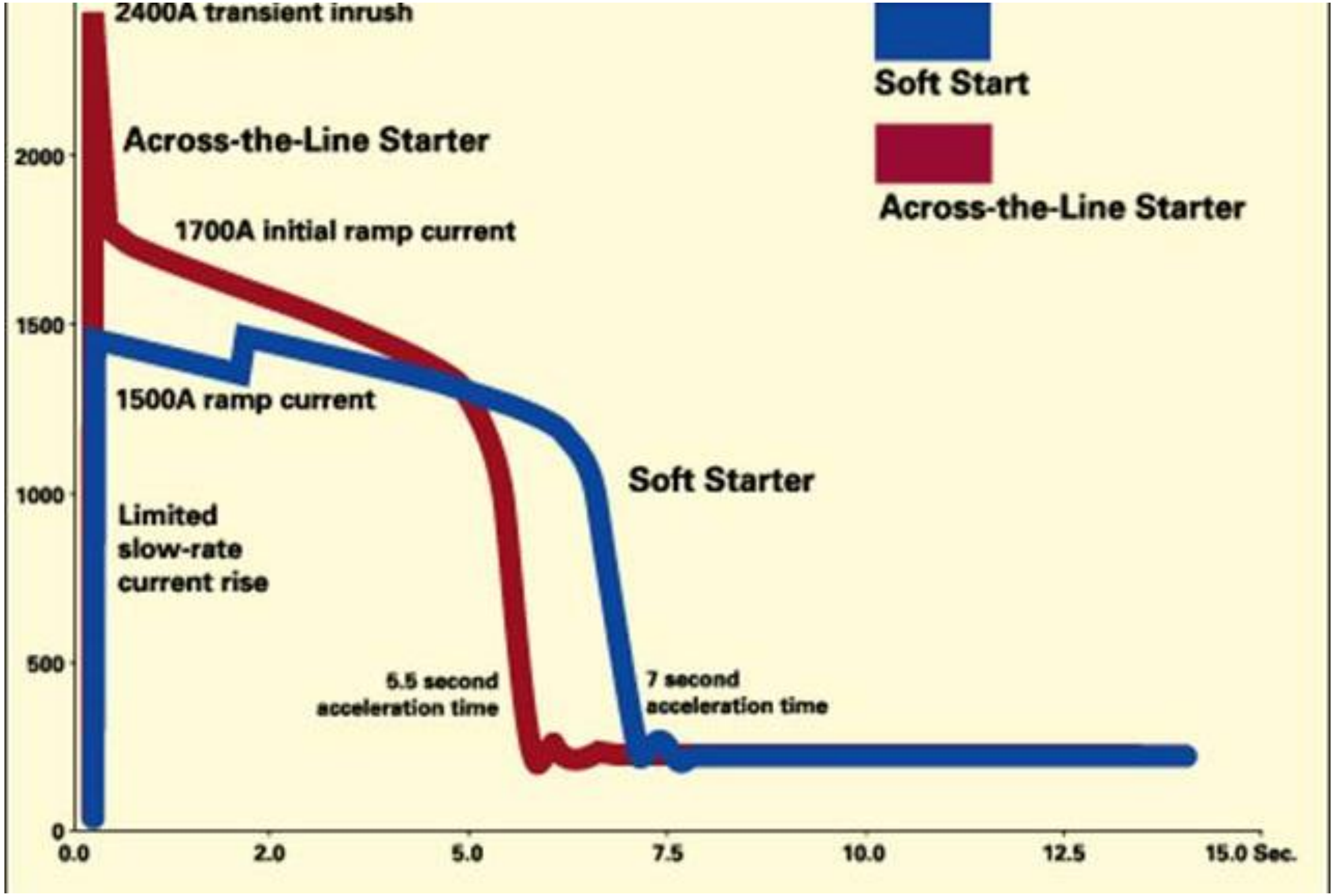
Motor starting variants

ATS – Soft Start



- Motor Torque

- Motor Current
  (with active current limitation)



Inrush Current Comparison (300HP)

Motor starting variants

RVSS Soft Start

☺

- Smooth torque reduces mechanical stress
- Smooth starting current due to adjustable
- voltage ramp with current limiting function
- Speed reversion via contactors

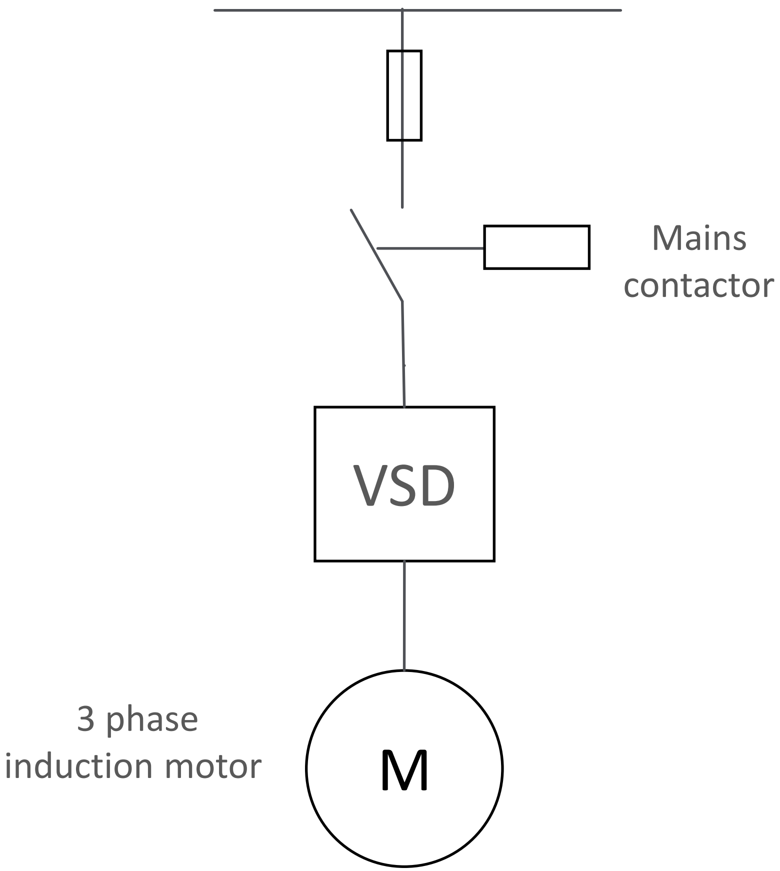
☹

- No energy savings – no speed control
- Power factor correction necessary
- No linear speed ramps

Motor starting variants

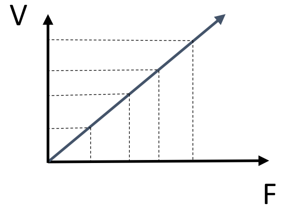
Variable Speed Drive

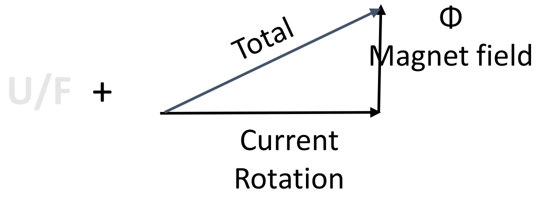
- Variable motor speed
- Change voltage and the frequency
- Integrated motor protection
- A lot of application functions
-



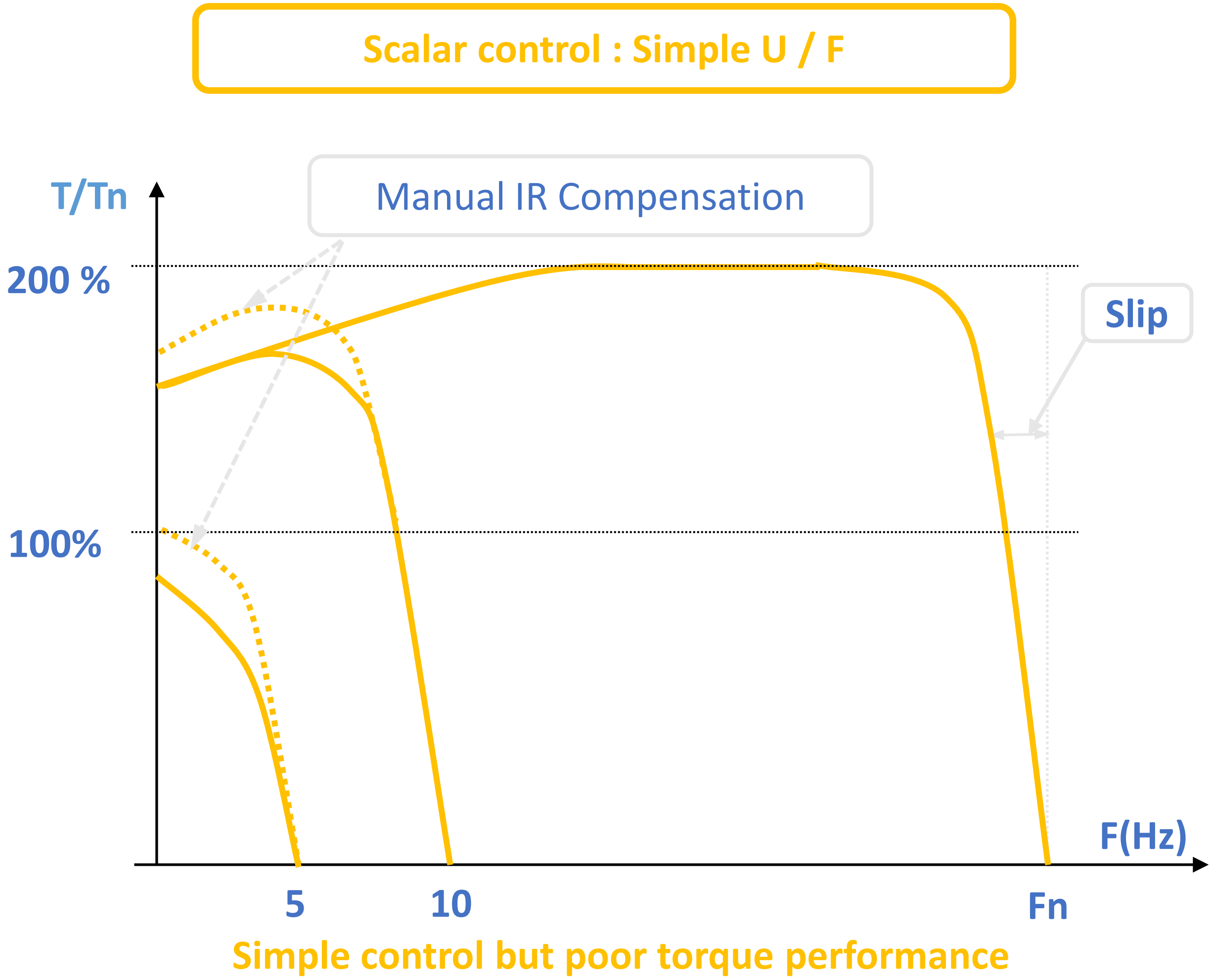
Motor Control

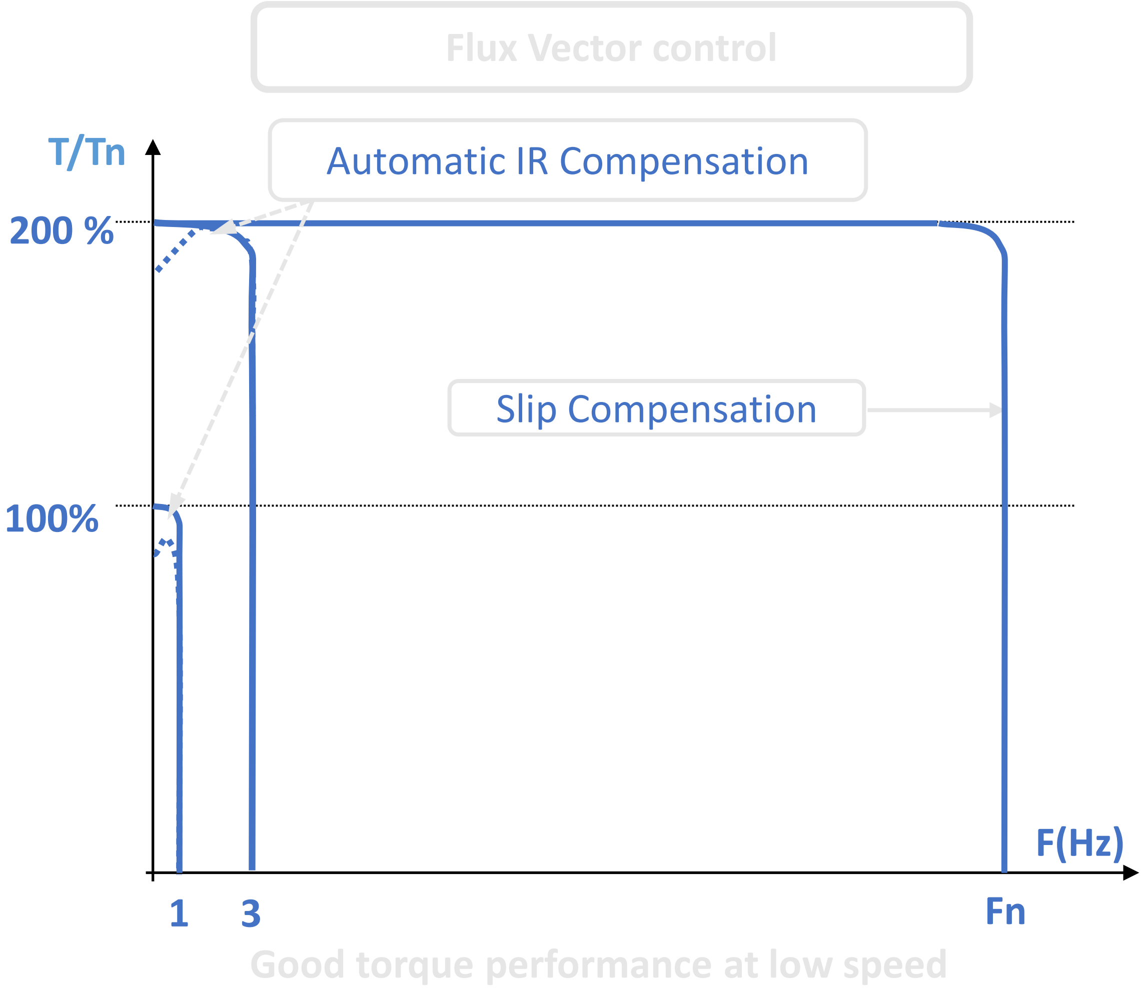
- **Altivar motor control laws for Asynchronous motors :**
  - Different types of laws can be used depending on the applications and the load type
- Two main families for Asynchronous motor control laws :
  - **Volt Hertz (or U/F) – scalar laws**
    - Simple algorithm **without speed loop regulation and slip compensation**
    - Different types depending on applications and load types
  - **Flux Vector control laws**
    - **Full flux vector control algorithm with speed loop regulation**
    - For heavy duty and dynamic applications
    - **Open or closed loop** motor control are available





Motor Control





Motor starting variants

ATV – Variable Speed Drive

☺

- Speed can be adapted to actual needs
- Reduced speed leads to lower energy consumption
- Smooth torque reduces mechanical stress
- No high starting current at all
- cos phi1 >0,98 -> no PF correction necessary

☹

- Higher initial costs
- Drive size larger than other solutions
- Non sinusoidal mains current could make harmonic mitigation necessary

Motor starting variants

Comparison

	DOL	Y / D	RVSS	VSD
Inrush current on motor	7 x I_{nom}	2,3 x I_{nom}	2,8 - 4 x I_{nom}	0,4 x I_{nom}
Inrush current on mains	7 x I_{nom}	2,3 x I_{nom}	2,8 - 4 x I_{nom}	0,05 x I_{nom}
Voltage drop during start	☹☹	😐	😐	☺☺
Harmonic distortion	0	0	0	~40% THDi standard ~15% with passive filter ~2% with AFE
Cos phi (full load)	~ 0,85	~ 0,85	~ 0,85	~ 0,99
Reactive current	30% at nominal load 500% at start	30% at nominal load 150% at start	30% at nominal load 200% at start	1% at nominal load 1% at start
PF correction	necessary	necessary	necessary	Not necessary

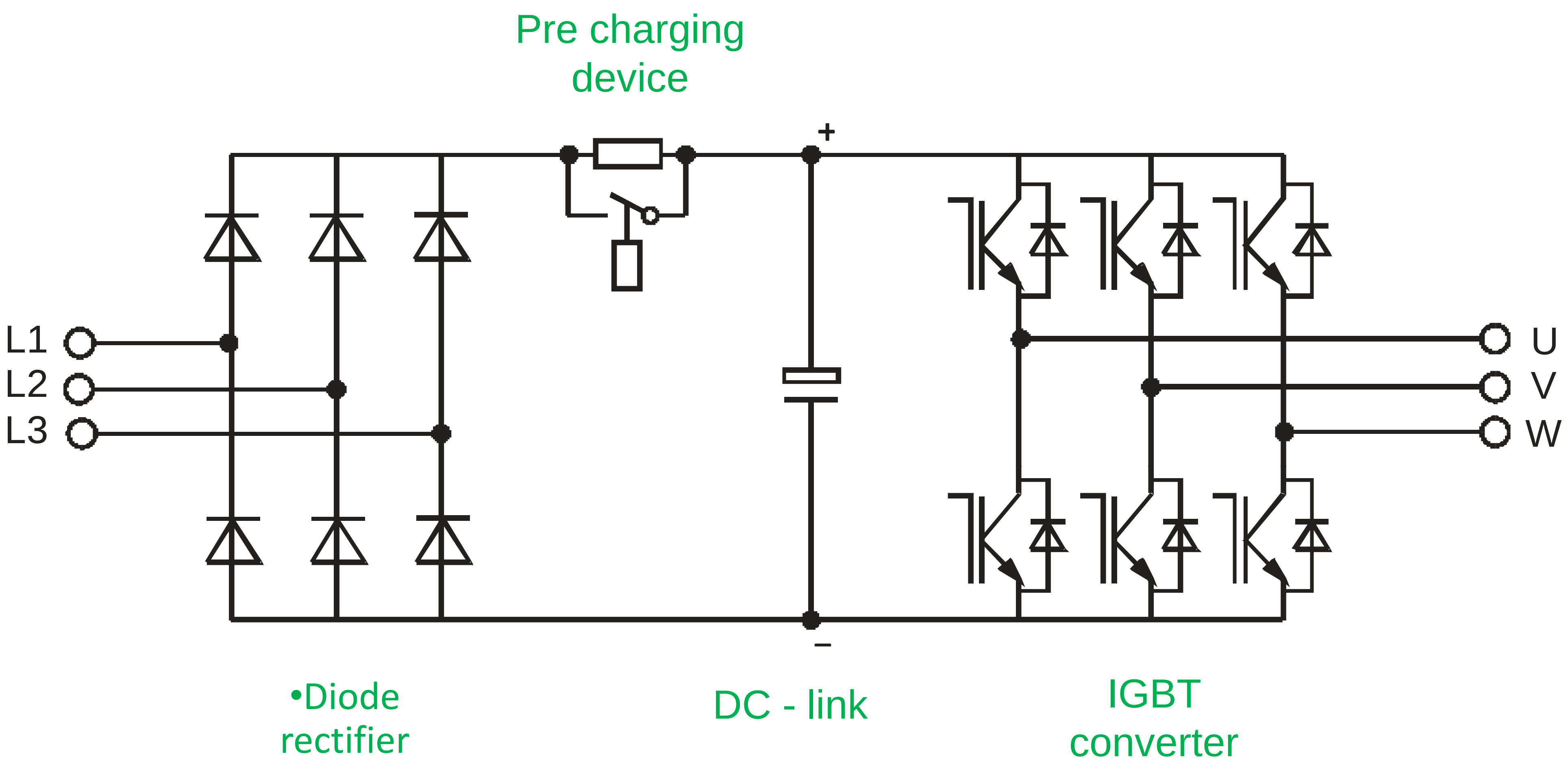
Motor starting variants

Comparison

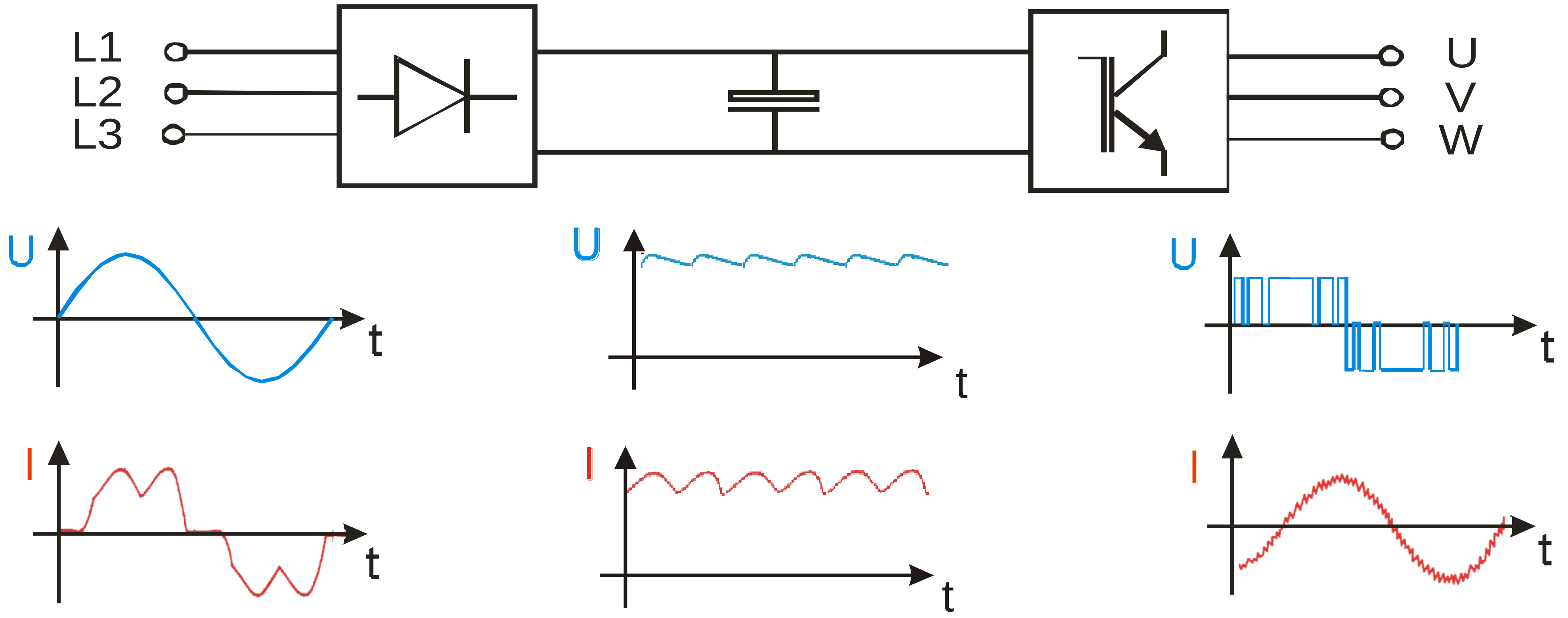
	DOL	Y / D	RVSS	VFD
Speed control	fix speed	fix speed	fix speed	variable speed
Starting torque	~ 2 x T_{nom}	Start in Y ~ 0,66 x T_{nom}	linear voltage ramp Start voltage ~40% ~ 0,32 x T_{nom}	According application needs ~ 0,2 - 1,5 x T_{nom}
Max. torque	brake down torque 3 x T_{nom}	torque peak Y->D 2,5 x T_{nom}	smooth torque curve 2 x T_{nom}	smooth torque curve 1,5 x T_{nom}
Mechanical stress	☹ ☹	☹	☺	☺ ☺
Start time	non linear, appr. 2 s	non linear, appr. 6 s	non linear, appr. 15 s	linear adjustable
ramp time setting	no	no	Voltage ramp	Speed ramp
Footprint	☺ ☺	☺	😐	☹
CAPEX	☺ ☺	☺	😐	😐
Energy consumption (OPEX)	☹	☹	☹	☺ ☺

VFD basic knowledge

Voltage Source Inverter - VSI



VFD basic knowledge

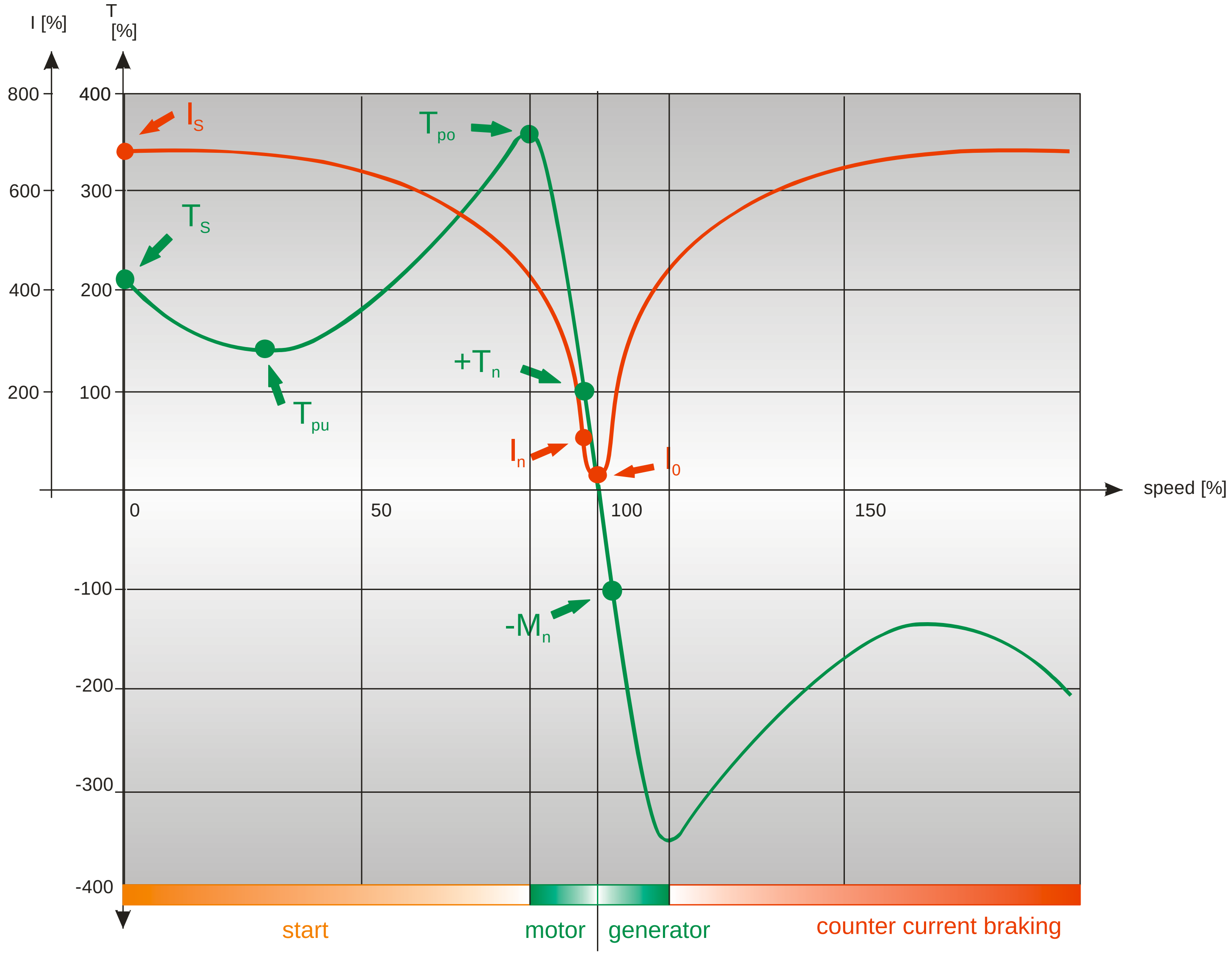


•As non linear load, VSD´s input current is not sinusoidal
THDi ~ 40%

Output voltage is Pulse Width Modulate which lead to sinusoidal currents with slightly current ripples

Behavior ASM on VSD

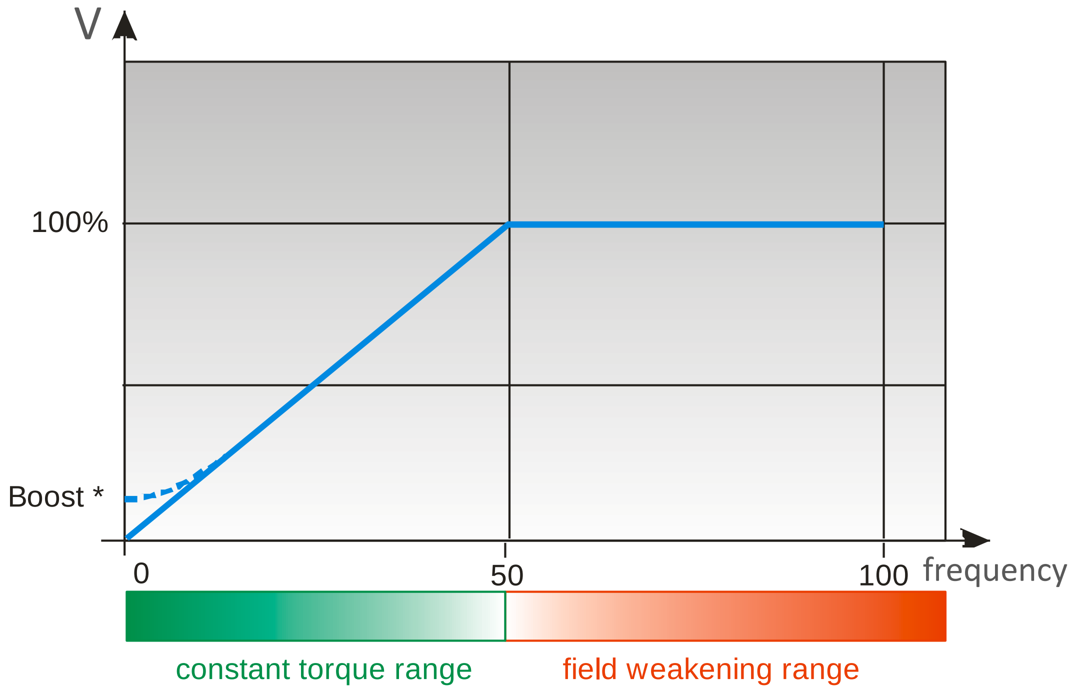
Torque / Speed characteristic in all quadrants

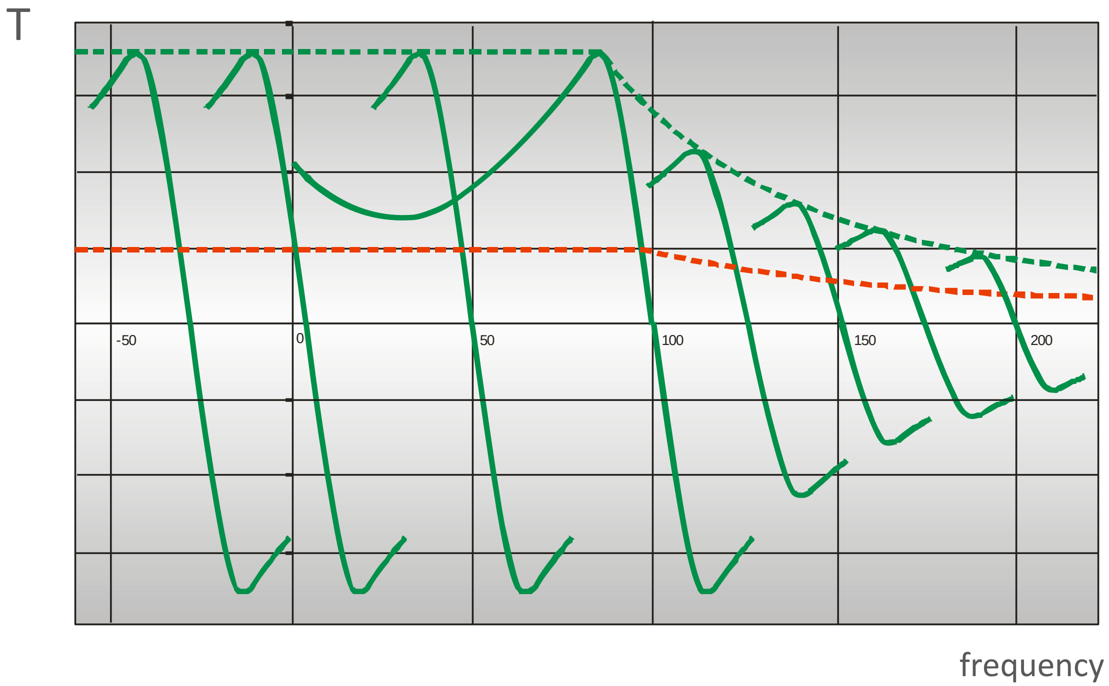


- T_S - Starting Torque
- T_{PU} - Pull Up Torque
- T_{PO} - Pull Out Torque
- T_N - Nominal Torque

- I_S - Inrush Current
- I_N - Nominal Current
- I_0 - No Load Current

Behavior ASM on VSD





Basic V/f curve of a VSD

speed accuracy and dynamic behavior of the motor depends on VSD control algorithm (FVC, SVCU …)

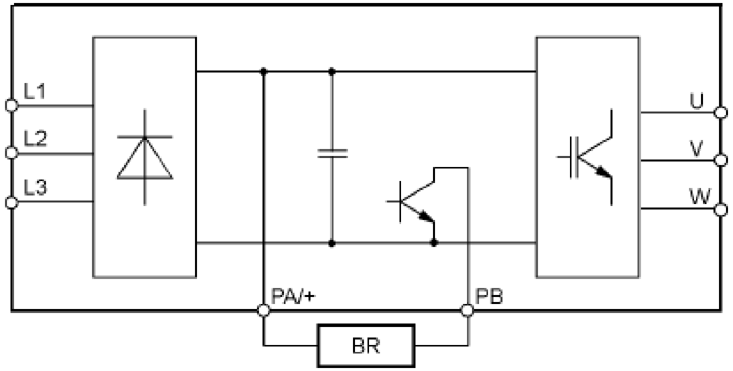
Torque / Speed behavior of motor in VSD operation

in field weakening (constant power range) the behavior of torque and slip changes !

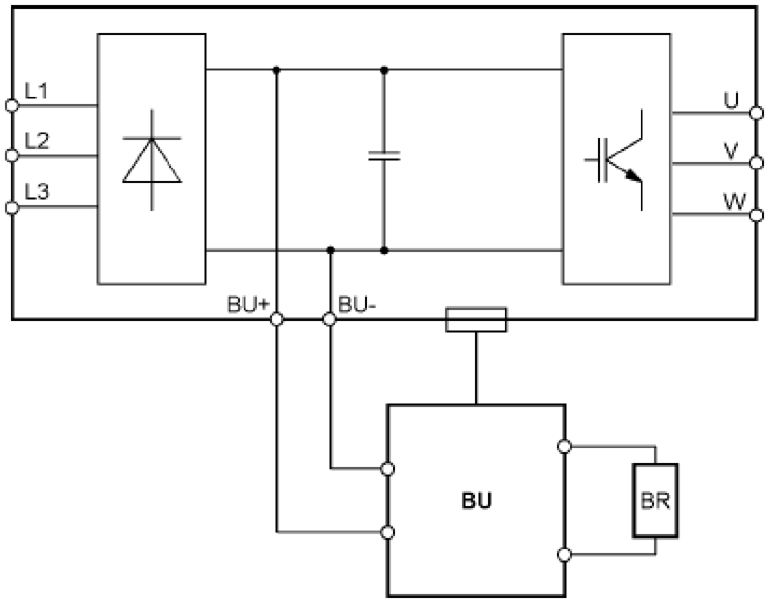
Behavior ACM on VSD

braking units

•The diode rectifier bridge works like a valve and do not allow a reverse flowing current,
therefore the braking energy must be fed to an additional braking devices in case of dynamic braking (hoist, downhill conveyor, test stand …)



Build in braking unit with
external braking resistor
e.g. ATV340

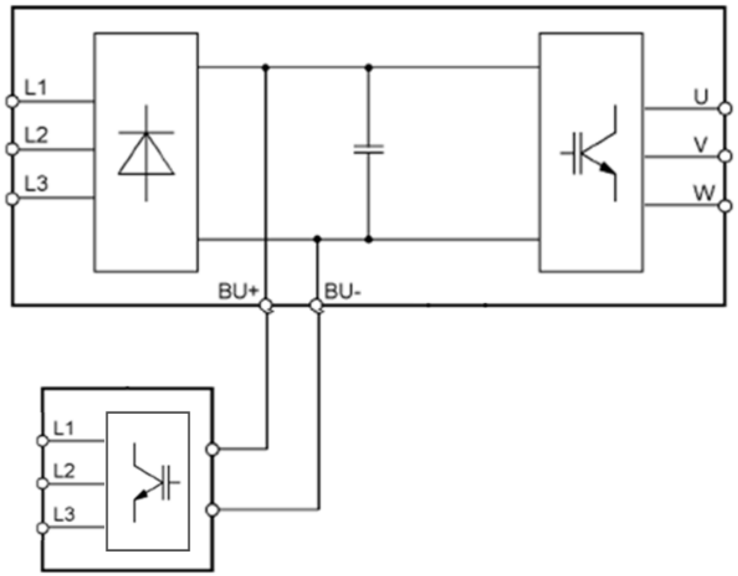


External braking unit with braking resistor
e.g. ATV930 >160kW

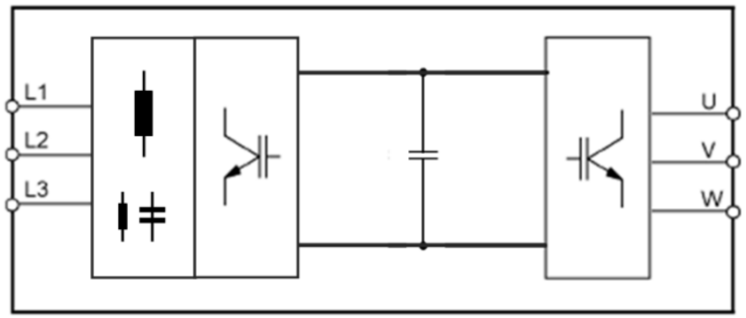
Behavior ACM on VSD

regenerative braking

•Braking resistors are turning electric energy to heat losses, a high efficient braking system can feed the braking energy back to mains - recuperative systems.

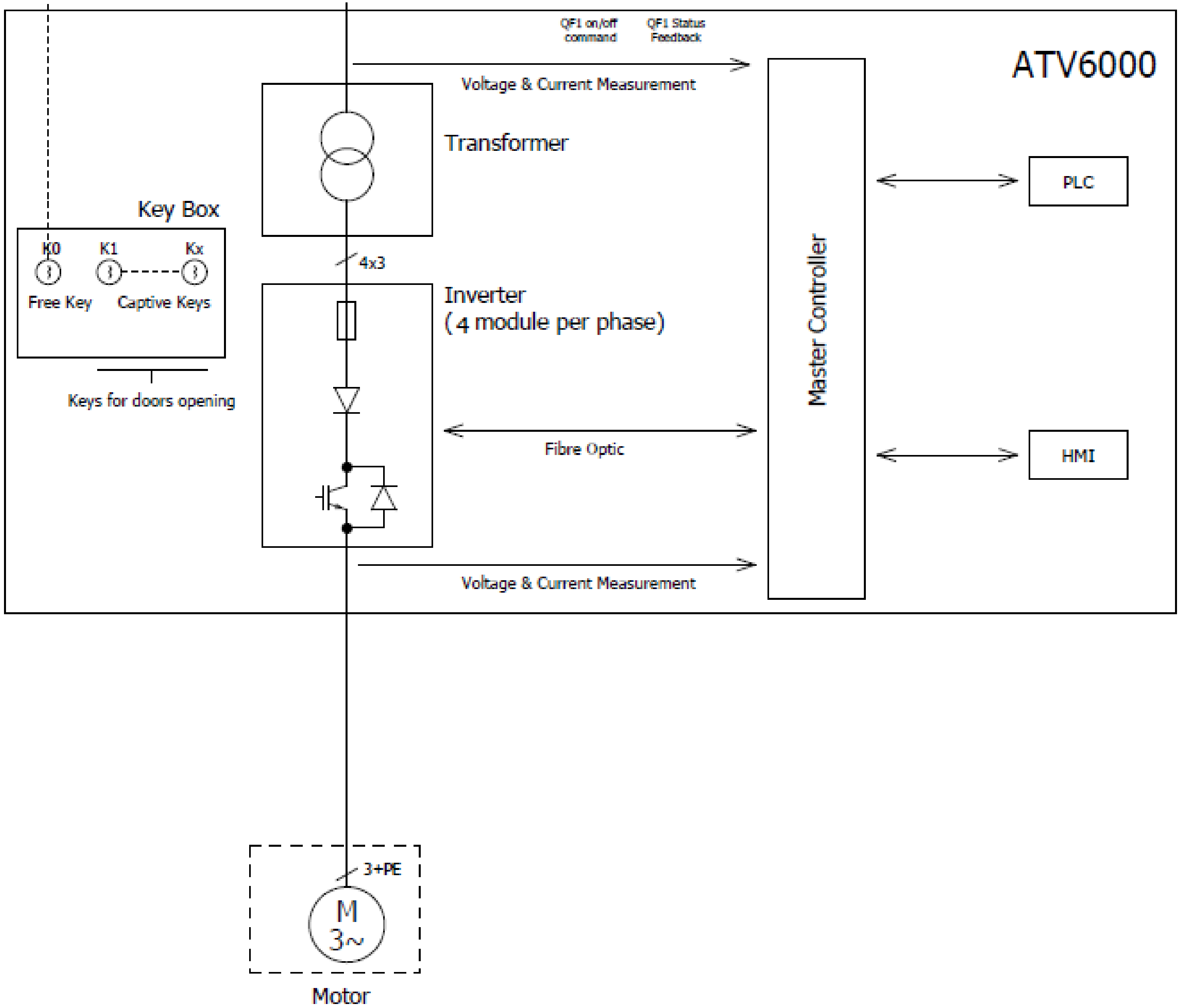


external recuperative braking unit
e.g. ATVR



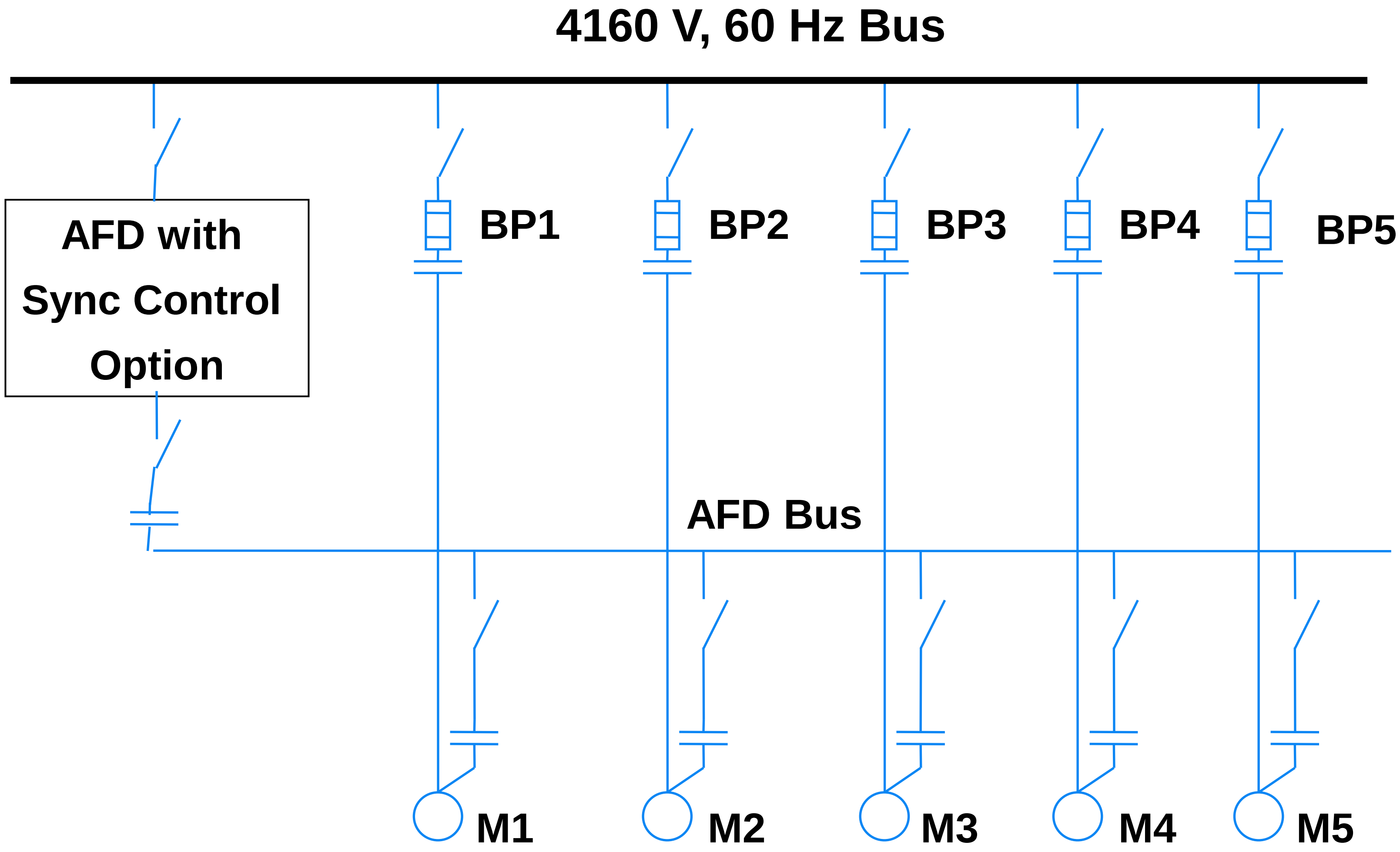
Active Frond End solution, which acts additional as Low harmonic drive as well

MV VFD

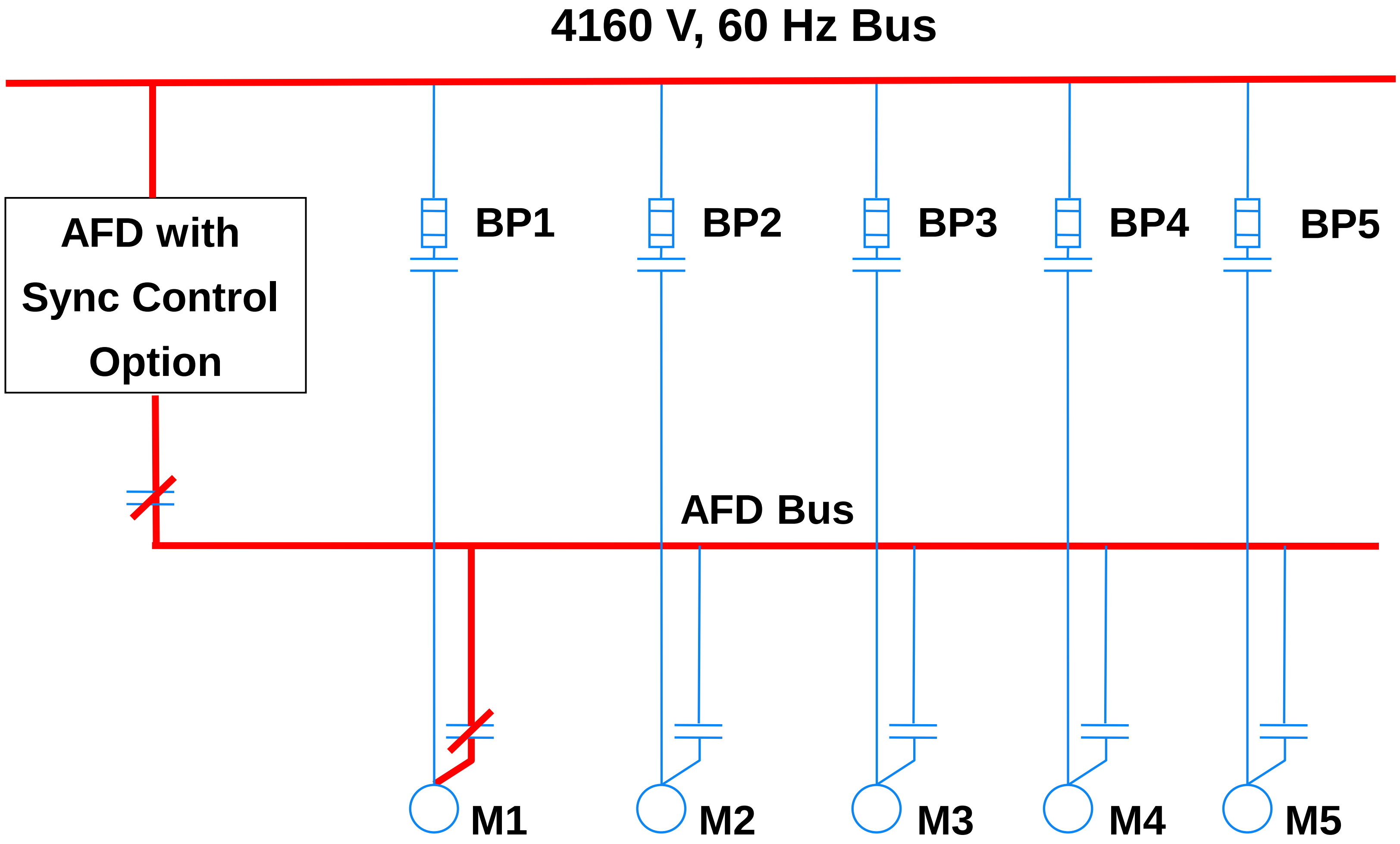


ATV6000
QF1 on/off command
QF1 Status Feedback
Voltage & Current Measurement
Transformer
Key Box
K0
K1
Kx
Free Key
Captive Keys
Keys for doors opening
4x3
Inverter
(4 module per phase)
Fibre Optic
Voltage & Current Measurement
Master Controller
PLC
HMI
3+PE
M
3~
Motor

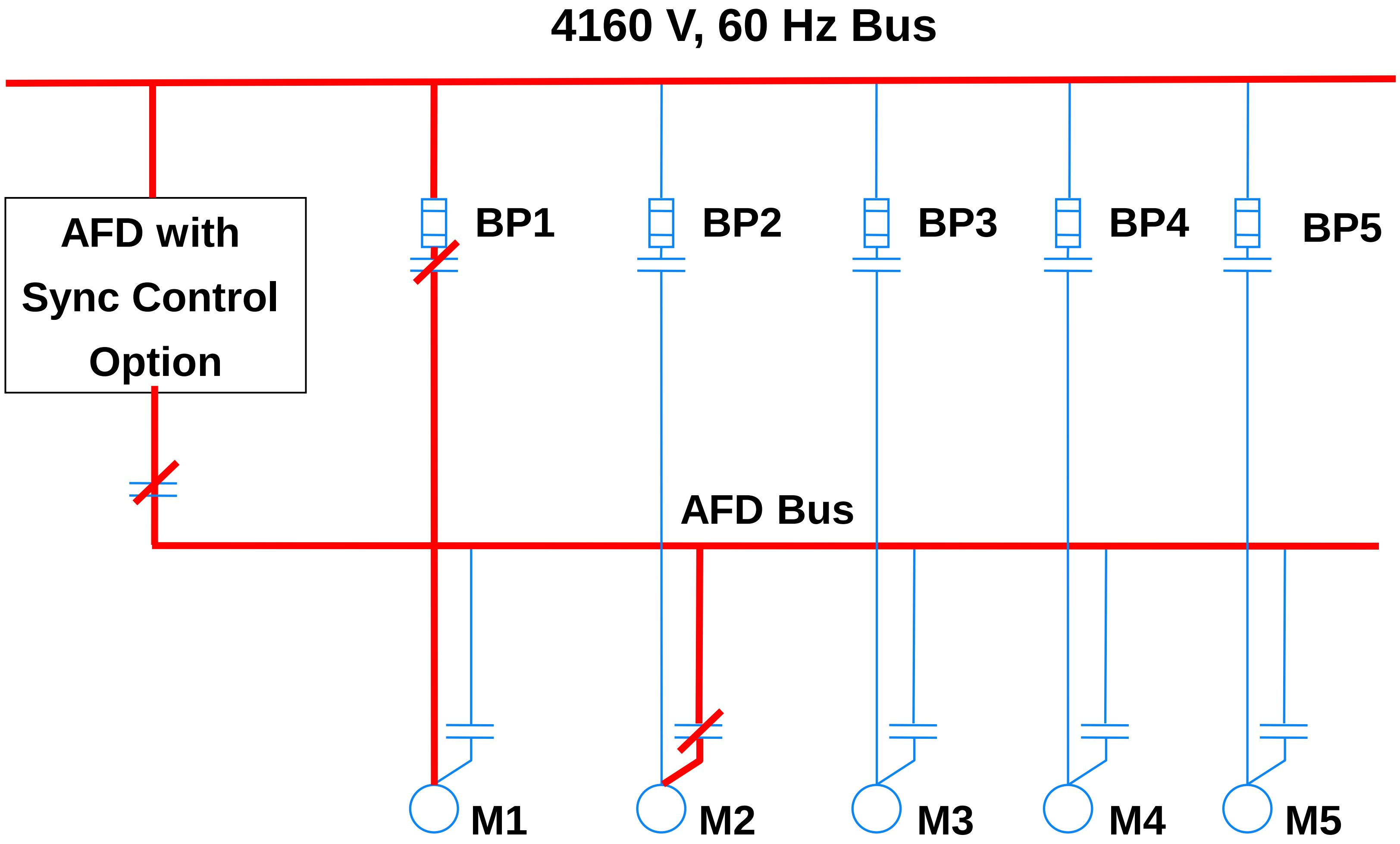
Synchronous Transfer



Synchronous Transfer



Synchronous Transfer




THANK YOU
Life Is On
Schneider Electric