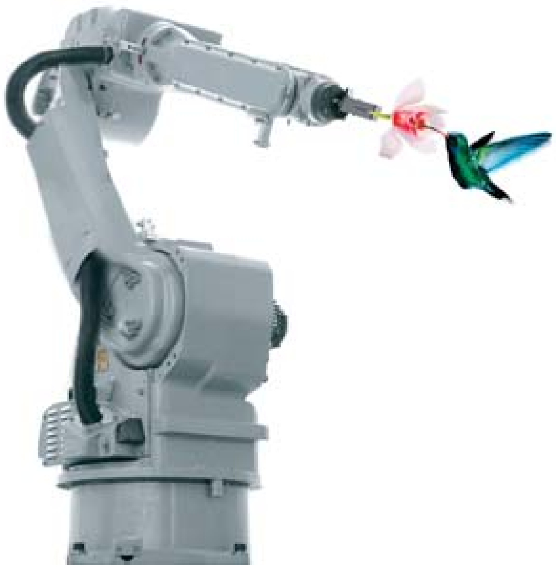
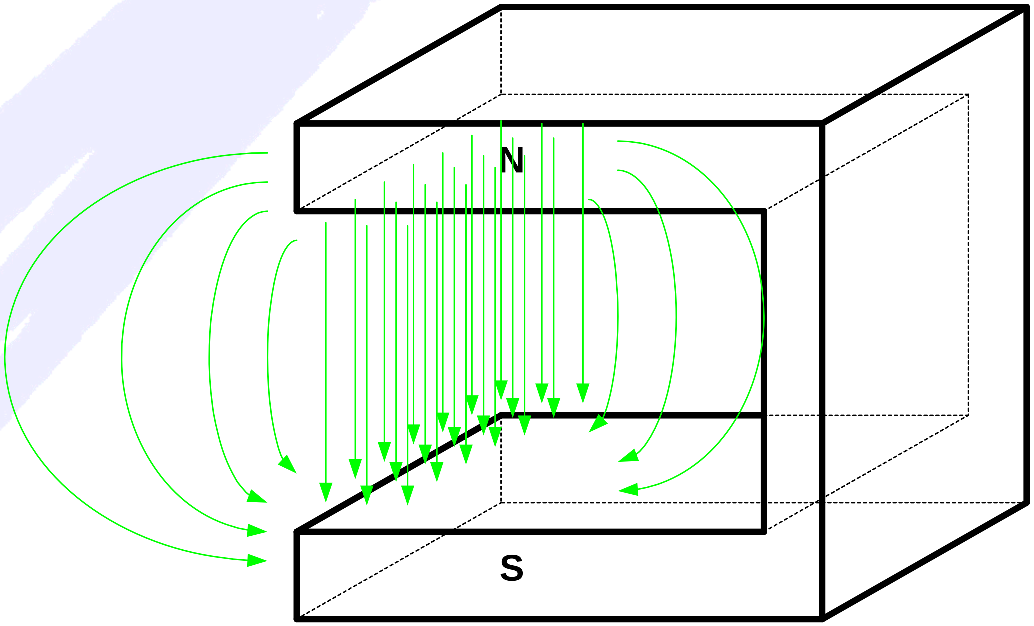
# Yaskawa Sales Training



**Hans-Peter Krug**
**Drive Basics**

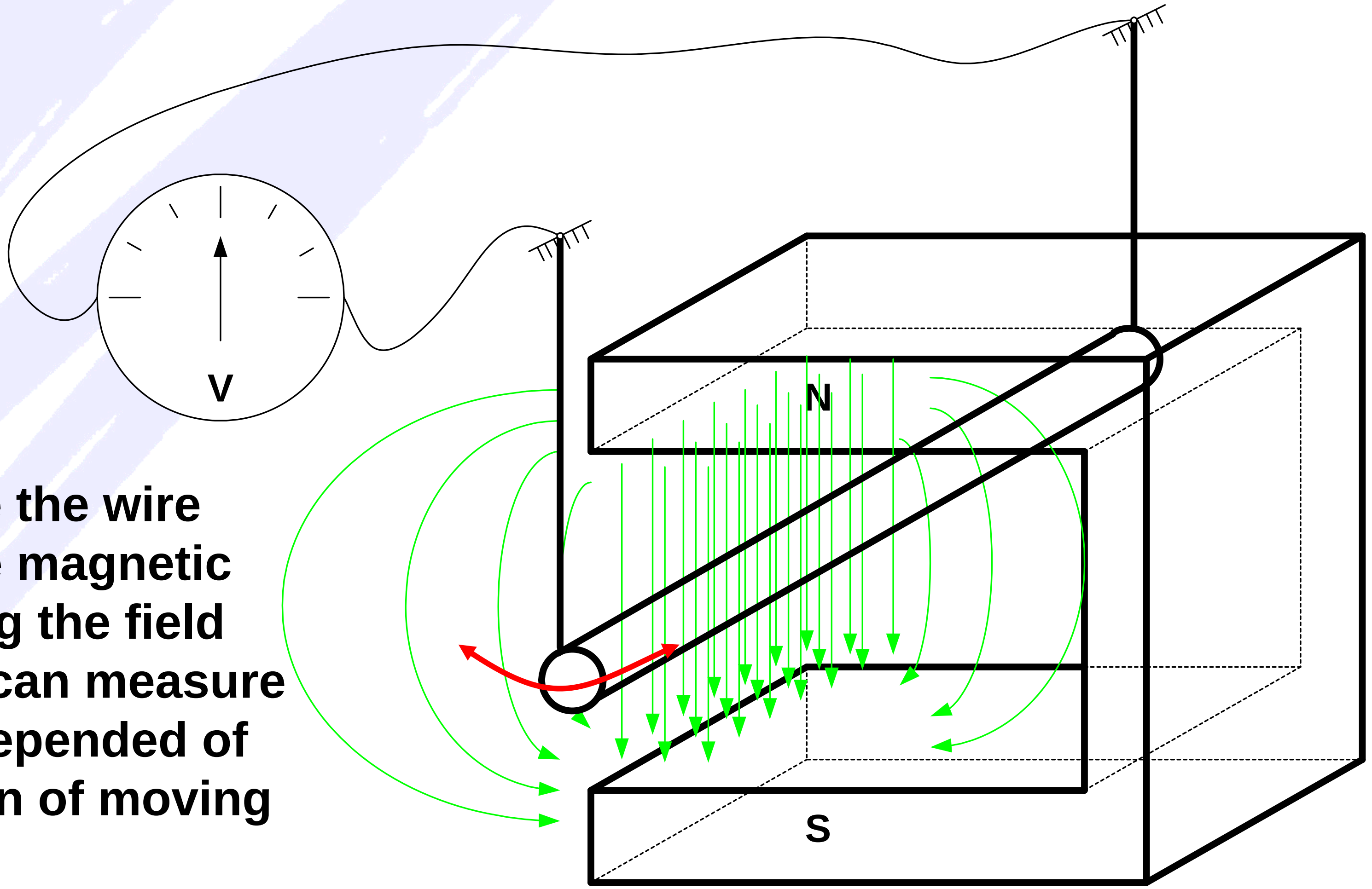
19 June 2009

# Magnetism



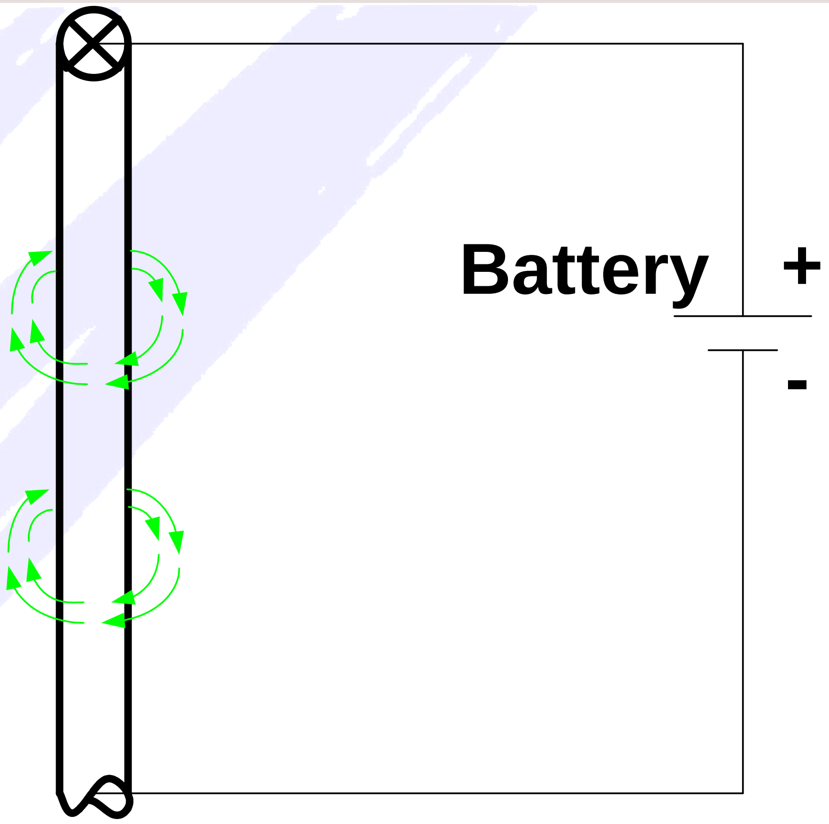

**Magnet with his field lines (green colour)**

# Wire in a Magnetic Field



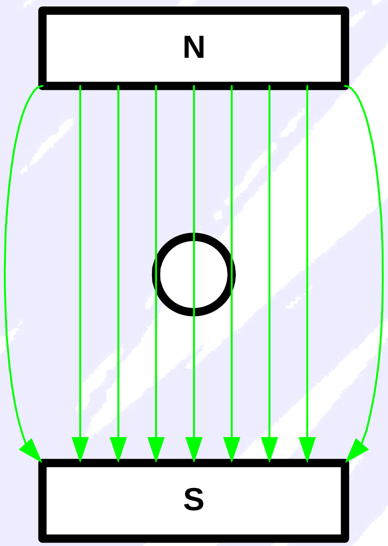

**If you move the wire through the magnetic field (cutting the field lines), you can measure a voltage depended of the direction of moving**

# Magnetic Field Around Wires

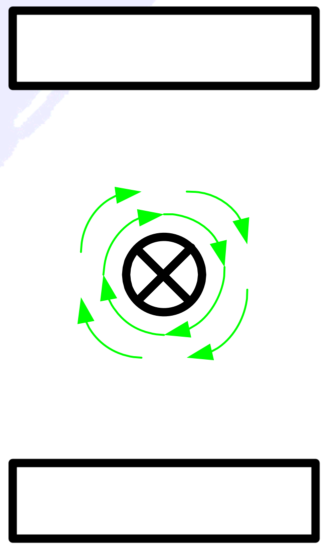



**All wires which have a current flow build a magnetic field around itself depending on the direction of the current.**

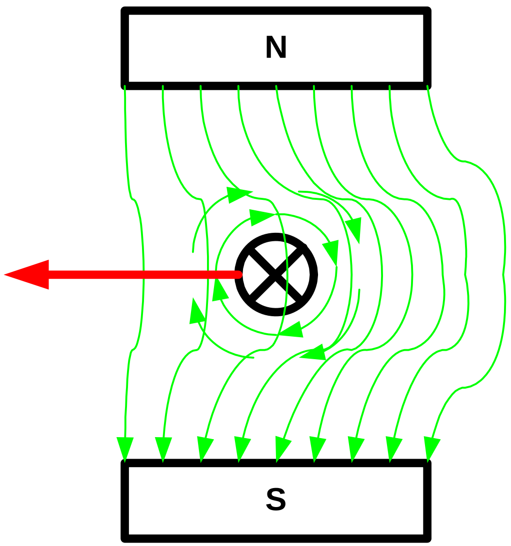
# Wire in a Magnetic Field with Current Flow




Wire in a magnetic field



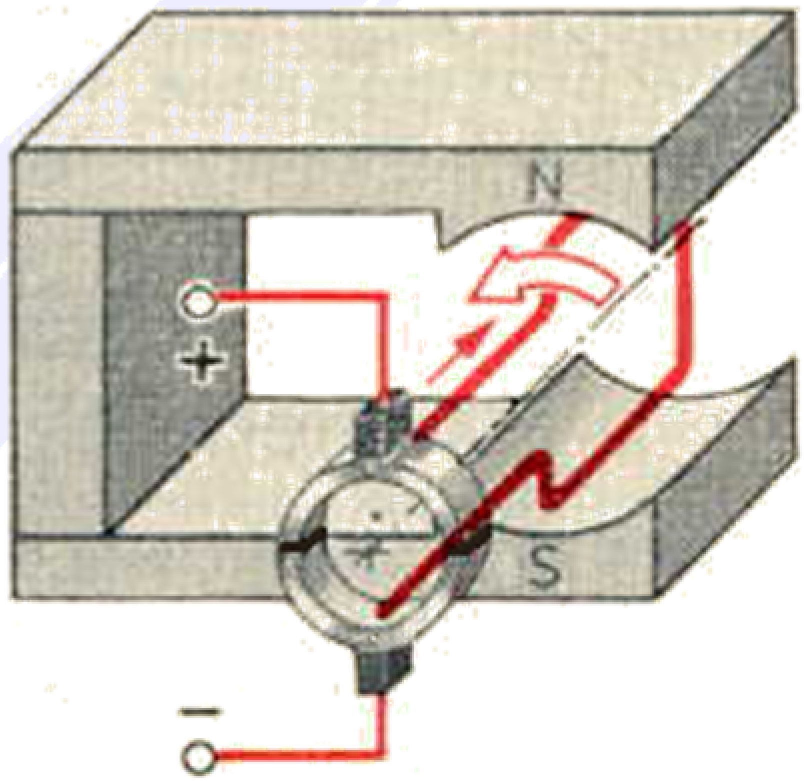
Wire with current flow




Wire with current flow in a magnetic field

**Wires with current flow have their own magnetic field lines. In a magnetic field the magnetic field lines will be added on one side and cancel each other out on the other side. Therefore we have a force in the direction of the red arrow.**

# DC Motor Principle




**Parts of the DC-Motor: Magnet with north and south pole, winding, commutator, brushes connect to DC**

# Voltage

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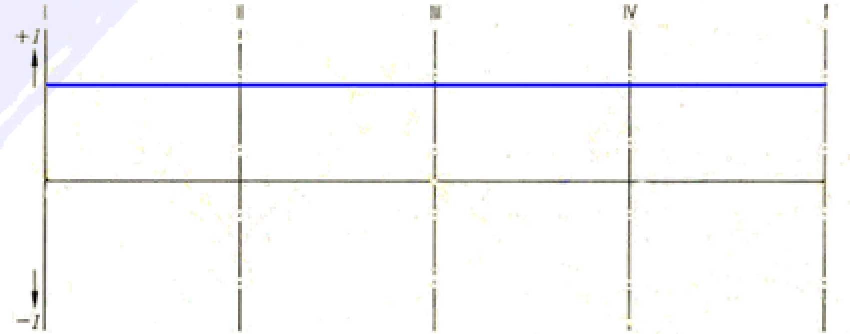
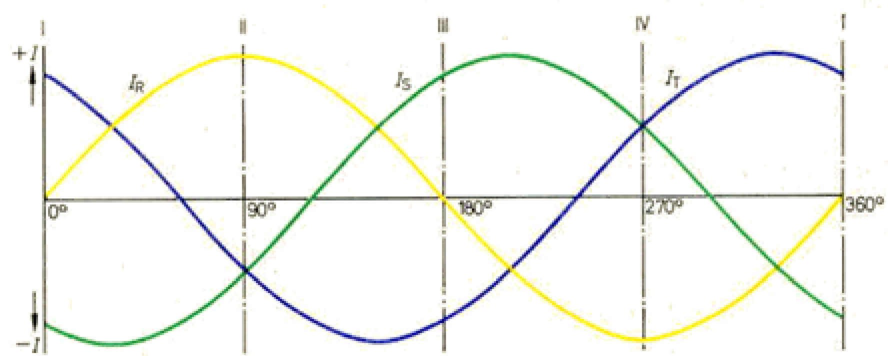
**DC Voltage is only in positive or negative area**

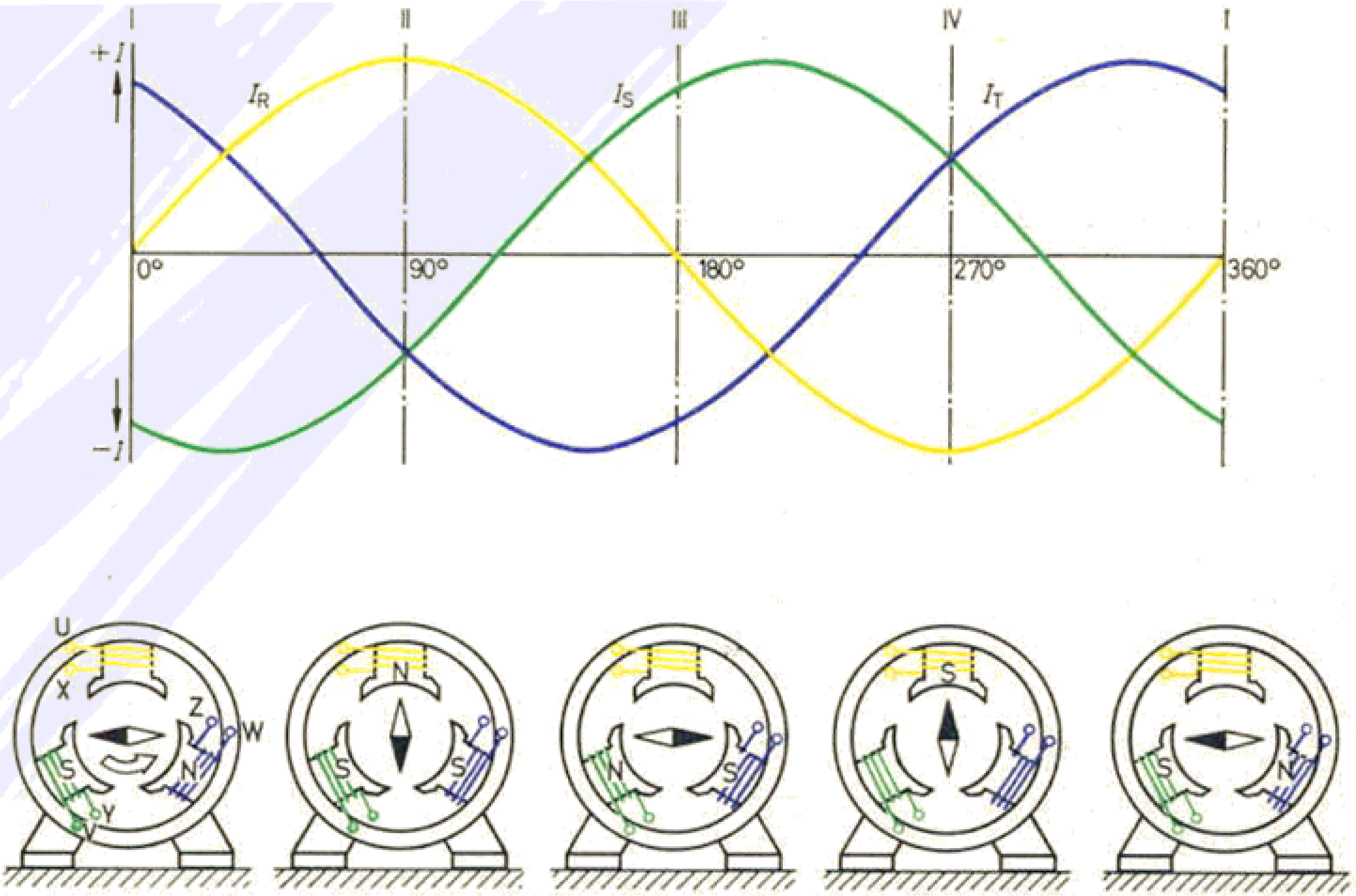


**Single phase AC voltage changes between positive and negative area**


**Three phase AC voltage consists of three single phase AC voltages but shifted about 120°**



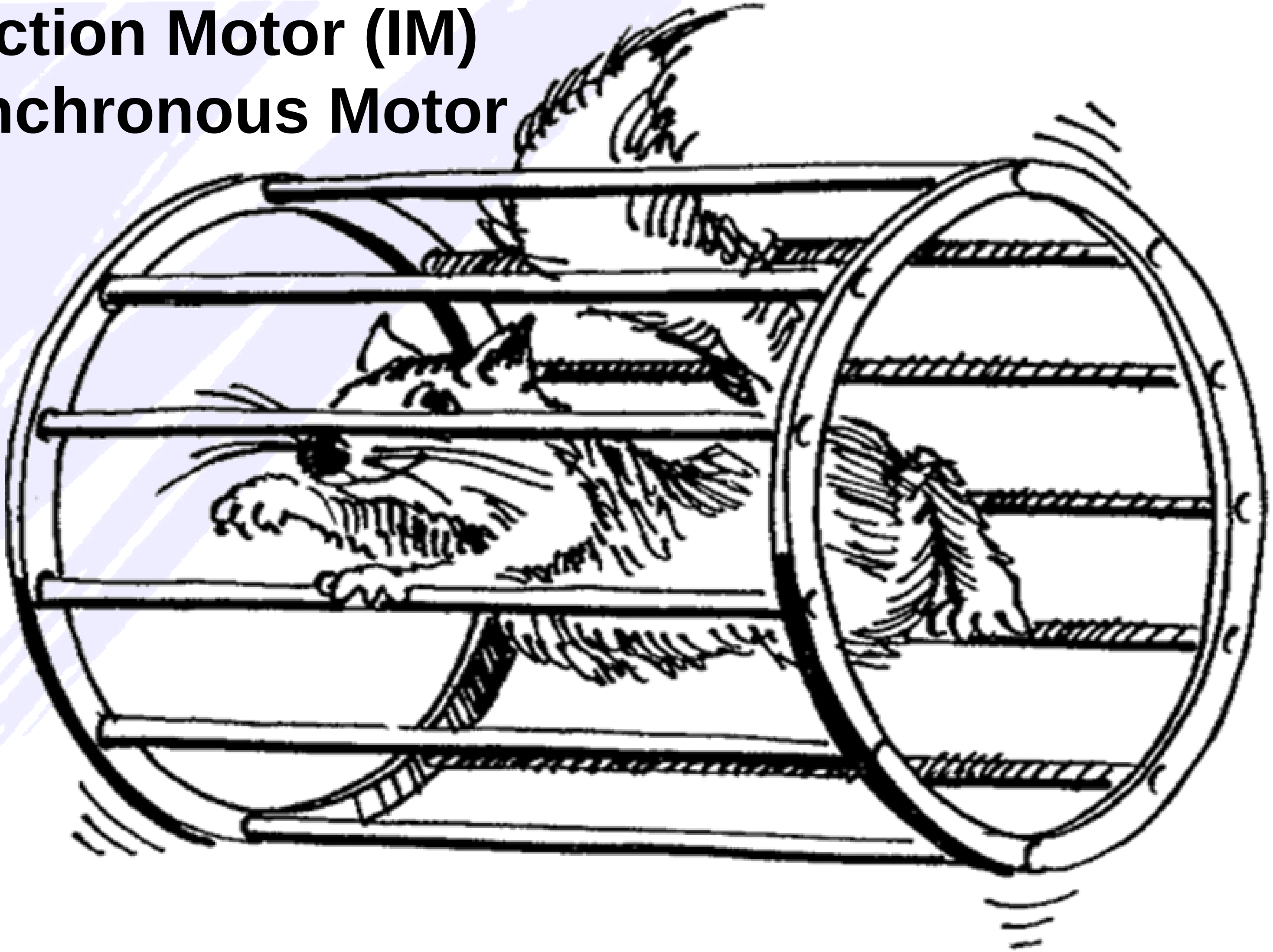
# Servo Motor Principle




**Depending on the rotation of the field the magnetic rotor will follow. (Permanent magnetic synchronous motor)**

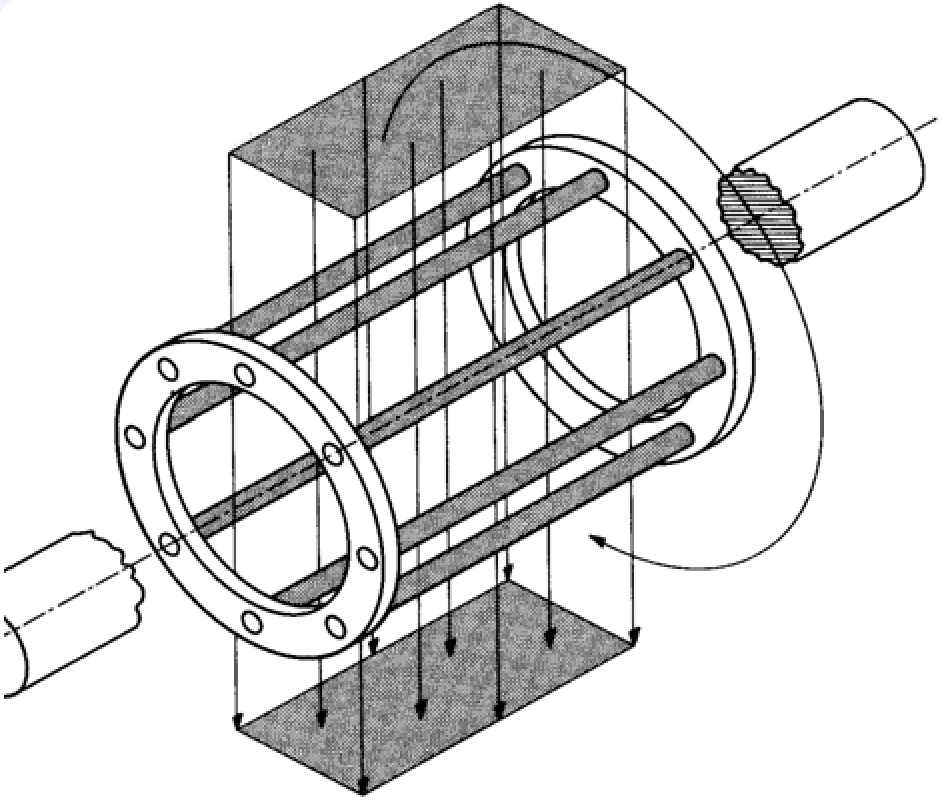
# Squirrel Cage Motor

## Induction Motor (IM)
## Asynchronous Motor

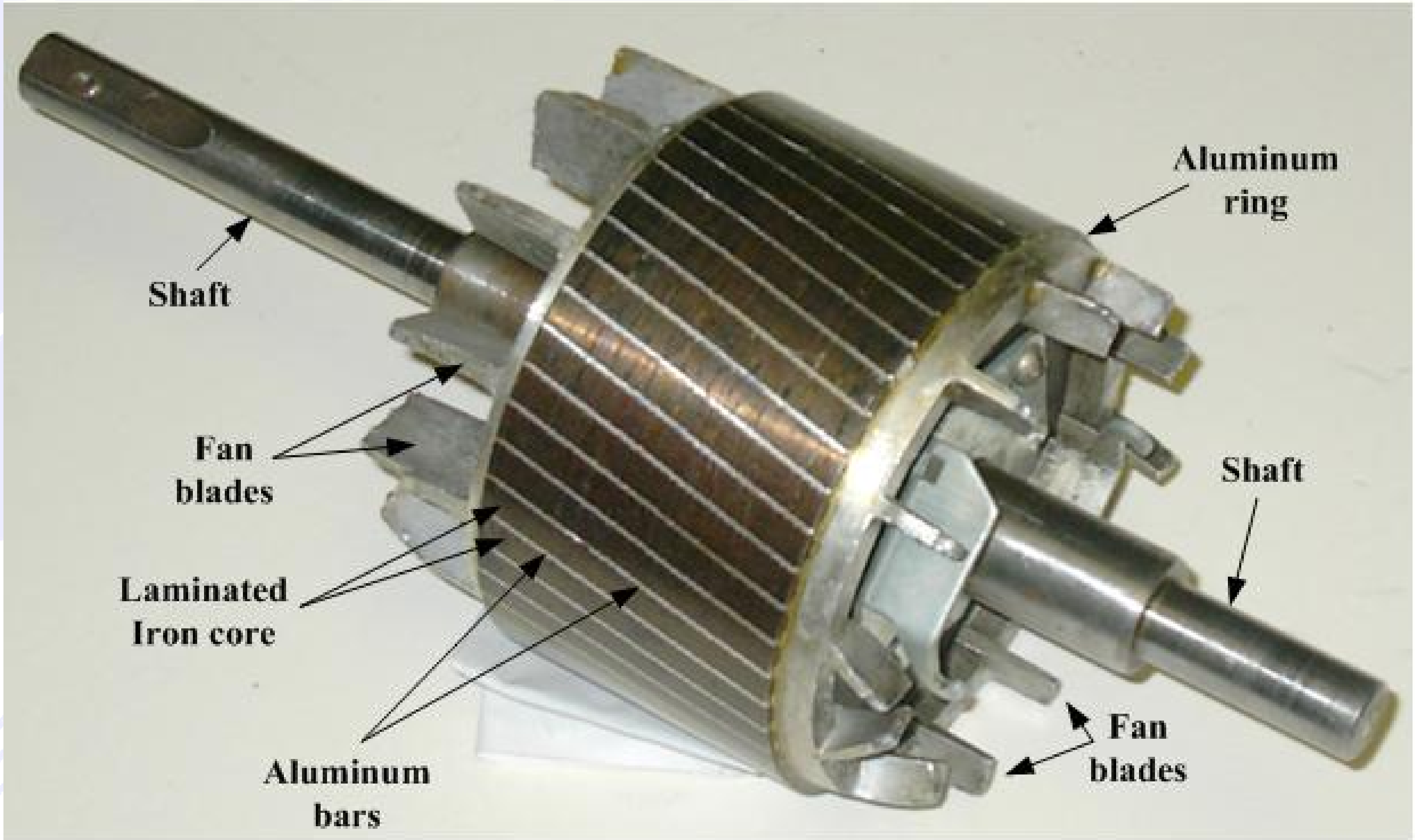


# Asynchronous Motor Principle

The rotating magnetic field induces a voltage in the rotor bars. This voltage creates a short circuit current as all bars are connected at each side with aluminium rings. Therefore every bar has a magnetic field which creates a force and helps rotating the rotor. The rotor always rotates a little bit slower than the rotation field. Because: With same speed no magnetic field change happens and therfore no voltage  would be induced in the bars.



# Rotor of Squirrel Cage Motor (IM)



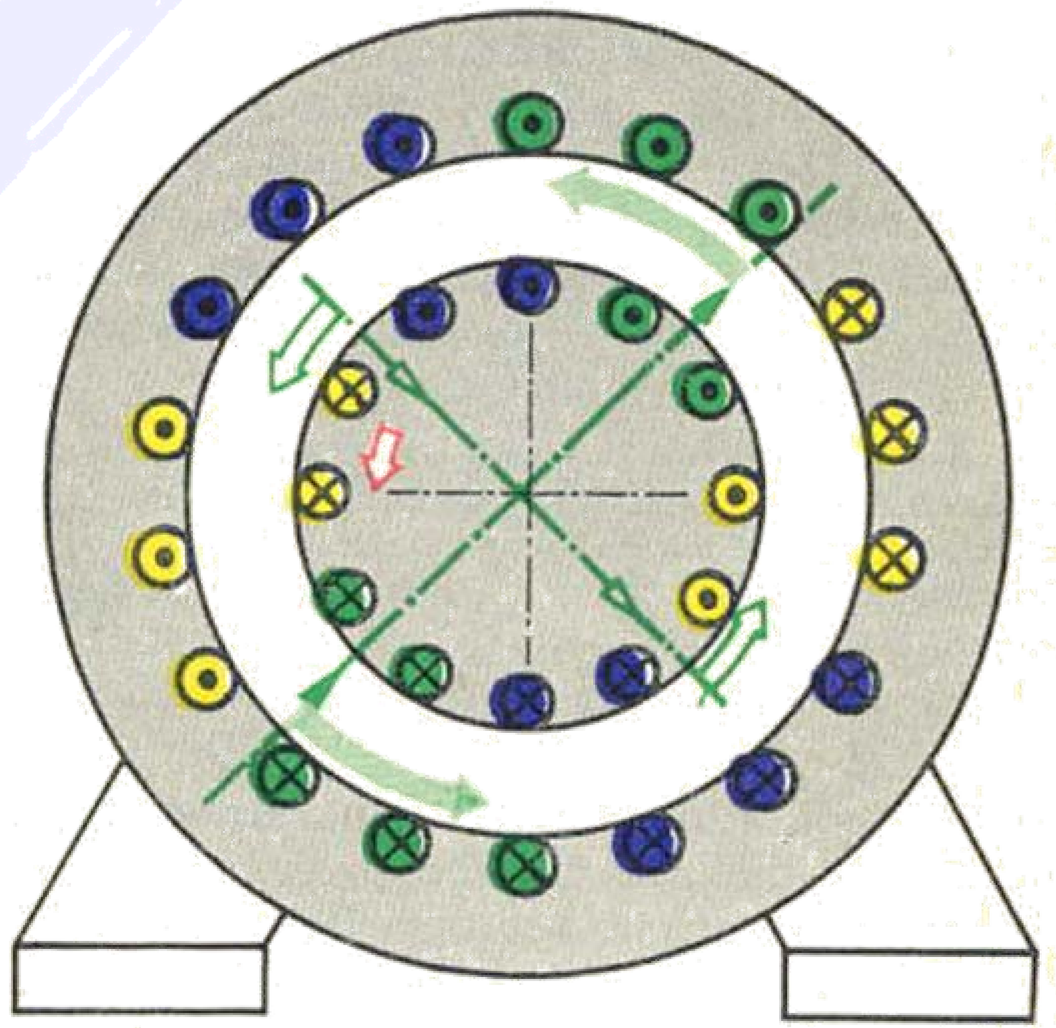
# Asynchronous Motor

Magnetic axis of stator

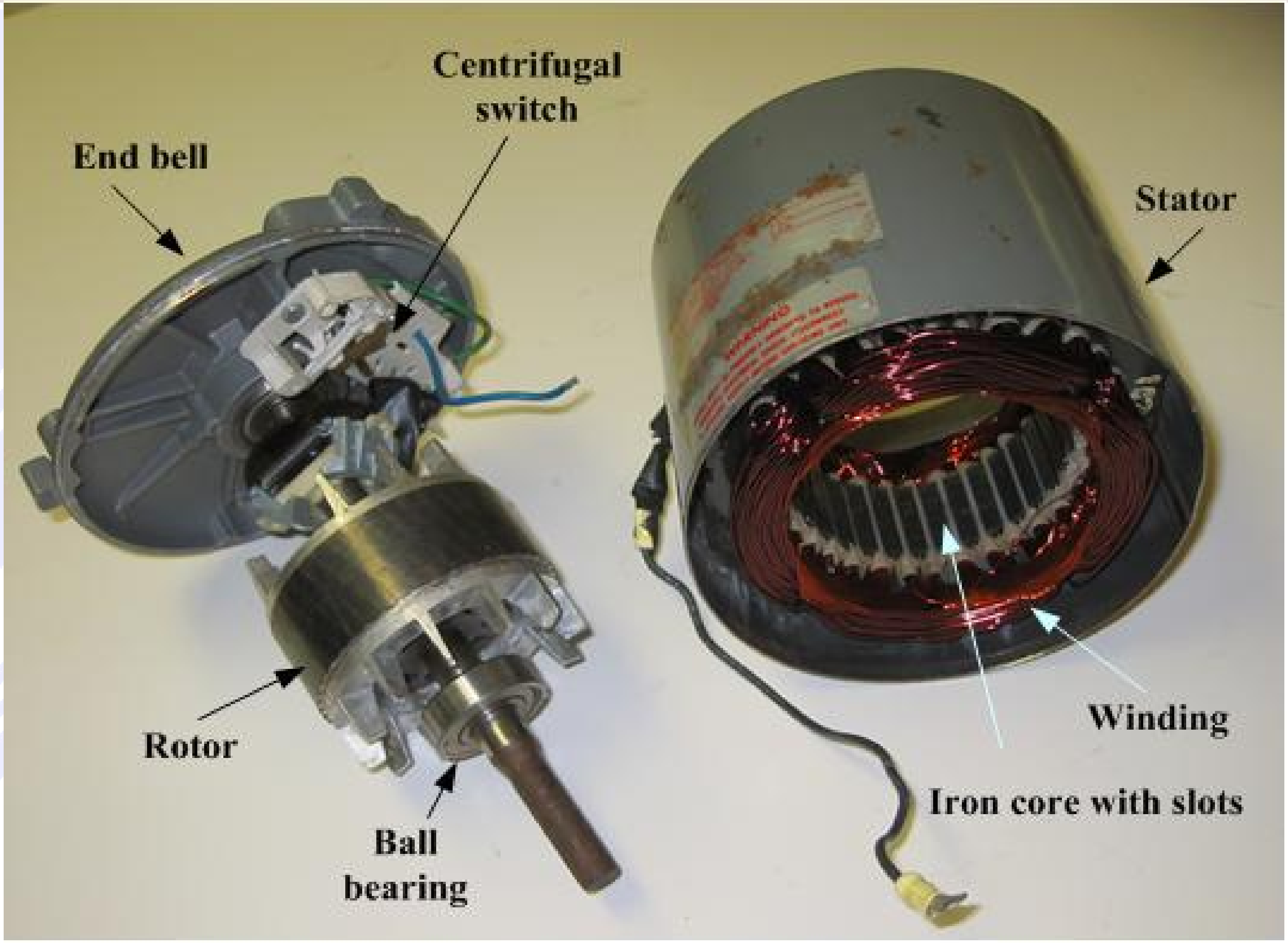
Magnetic axis of rotor

Direction of stator field

Direction of rotor field



# Asynchronous Motor (Induction Motor IM)



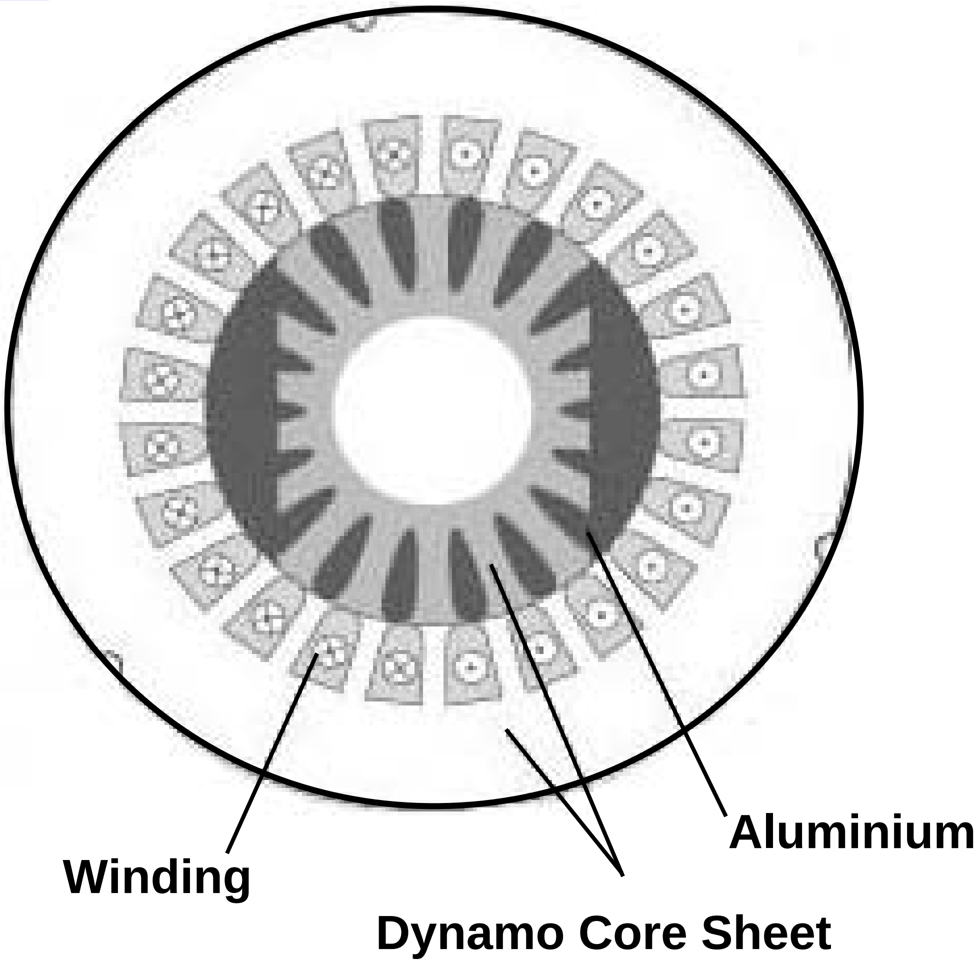

**Induction motor components.**

# Advantages of Asynchronous Motor

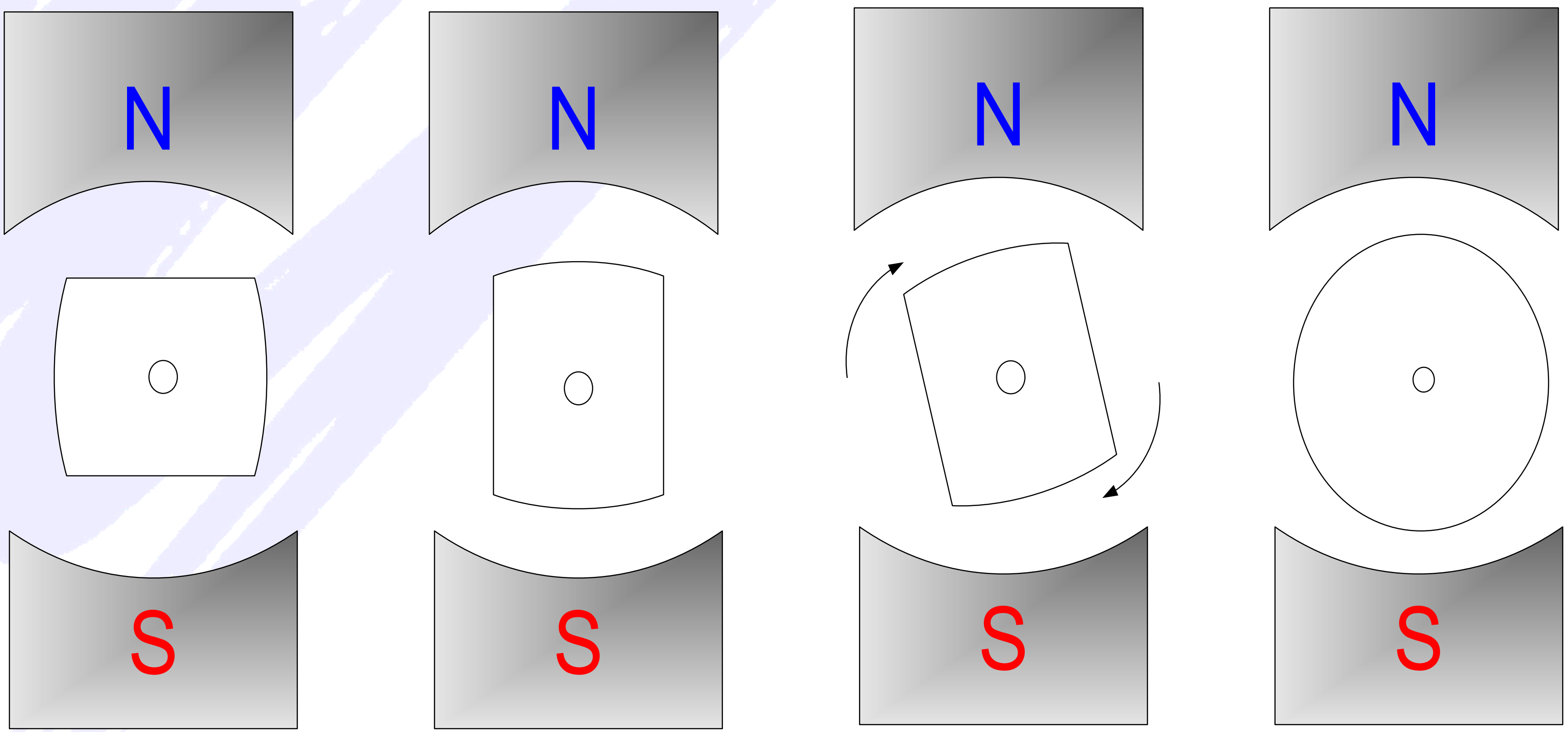
- **Standard**
  - **High Production Quantity**
  - **Reasonable  Price**
  - **Stock**
  - **Different Manufactures**
- **No Maintenance**
- **High Protection Class**
- **Simple Explosion Proof**

# Synchronous Reluctance Motor

Three-phase input creates a sinusoidal rotating field in the air gap. This causes a reluctance torque to be created on the rotor because the magnetic field induced in the rotor causes it to align with the stator field in a minimum reluctance position.



# Reluctance Torque




(1) motionless (2) motionless (3) rotate (4) motionless

# Advantages of Synchronous Reluctance Motor

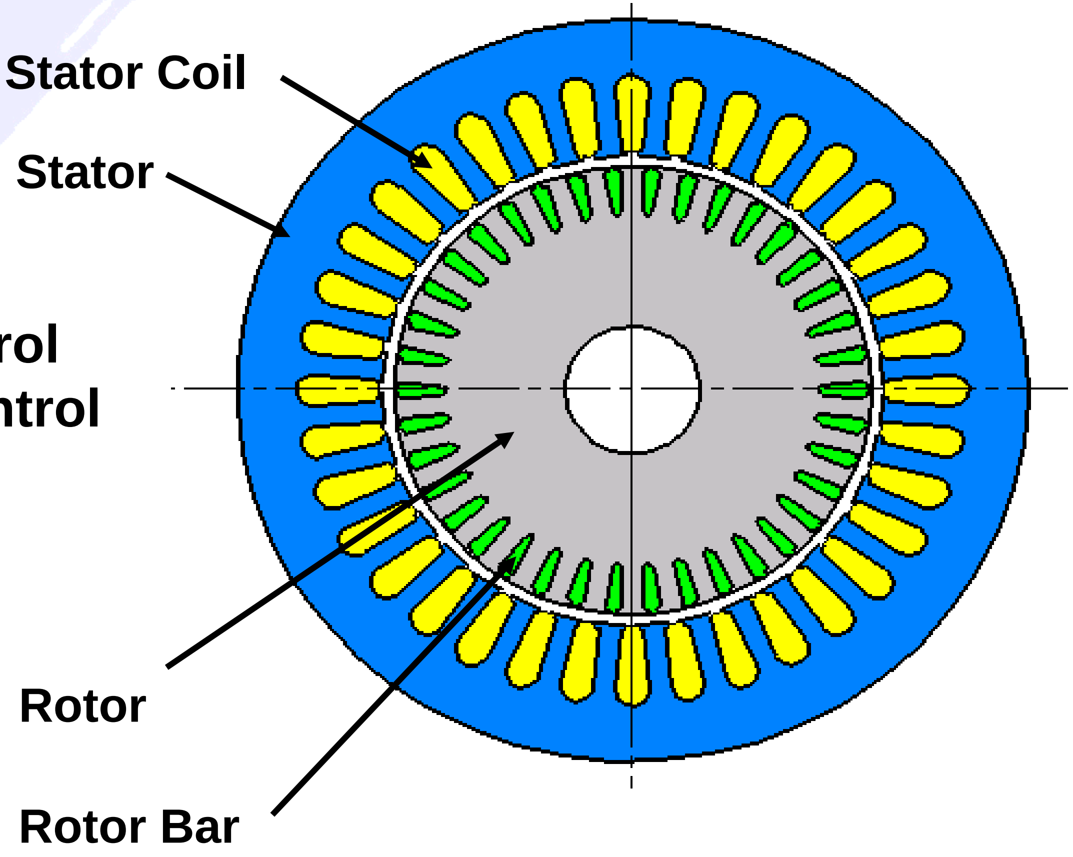
- Reluctance torque
- Performance can approach that of induction motor
- Slightly heavier
- Mass production cost is still uncertain

# Asynchronous Motor Induction Motor (IM)

## Induction Motor

- V/F control
- Open Loop Vector Control
- Closed Loop Vector Control

Very robust

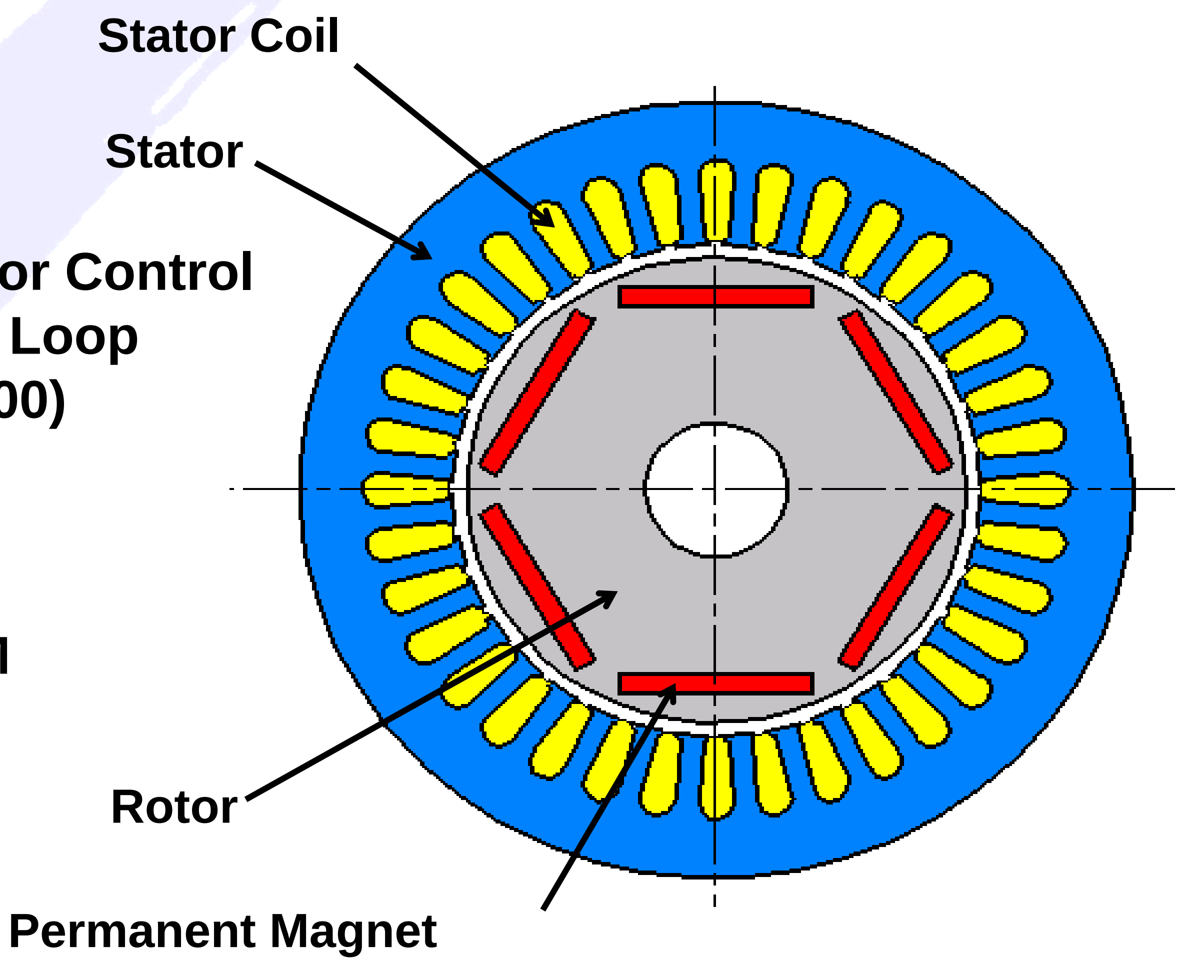


# Interior Permanent Magnet Motor (IPM)

## IPM motor

- PM Open Loop Vector Control
- Advanced PM Open Loop Vector Control (A1000)
- Closed Loop Vector Control (A1000)

More robust than SPM
Good for high speed



# Surface Mounted Permanent Magnet Motor (SPM)

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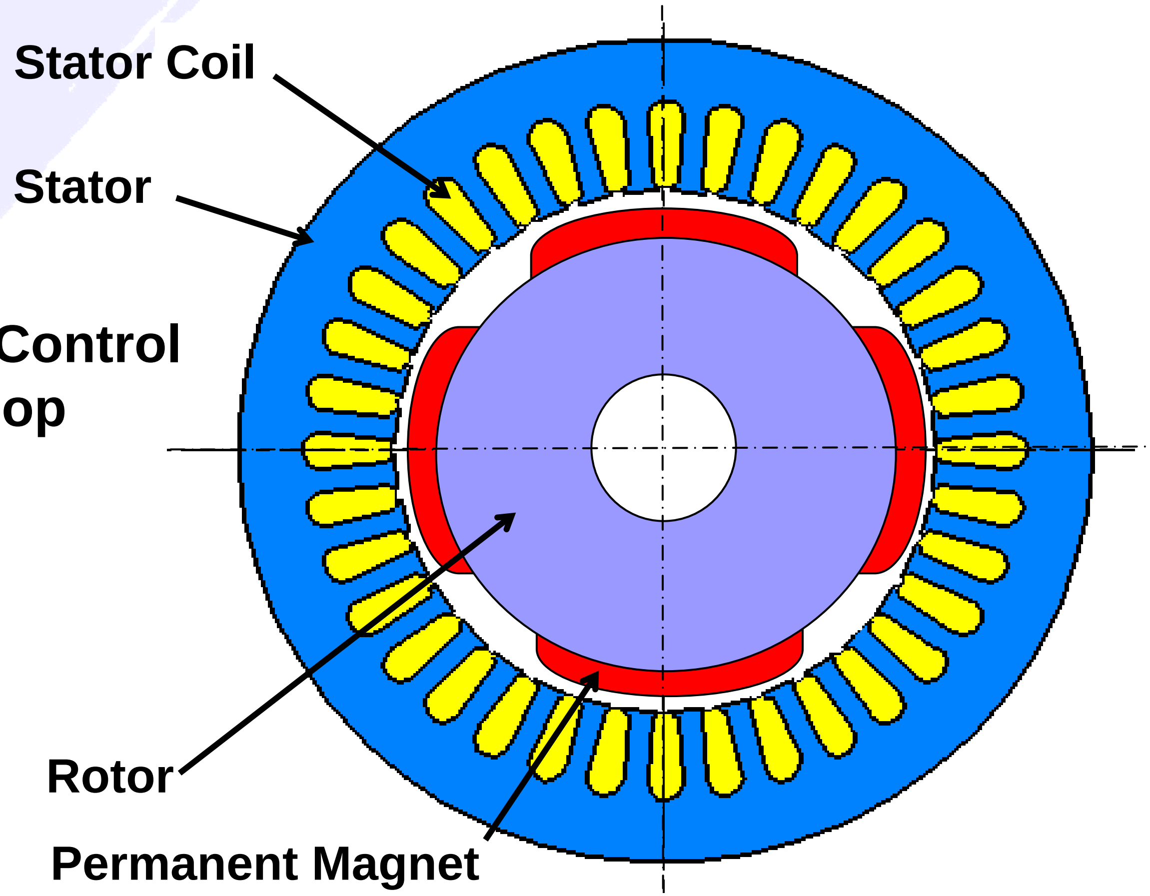
## SPM motor

- PM Open Loop Vector Control
- Advanced PM Open Loop Vector Control (A1000)
- Closed Loop Vector Control (A1000)

Popular
No reluctance torque

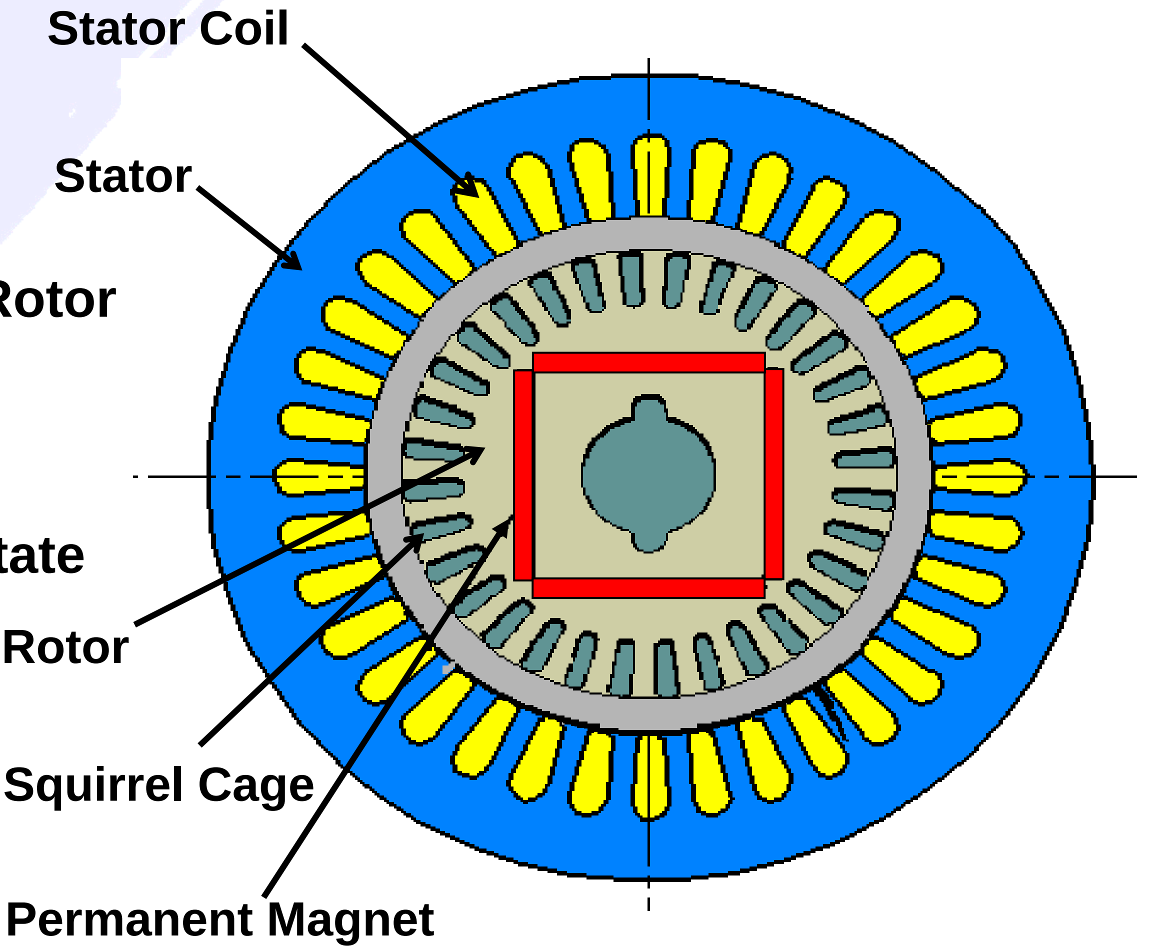


# Direct Start IPM Motor

## Direct Start IPM Motor

**Squirrel Cage Rotor + PM Rotor**

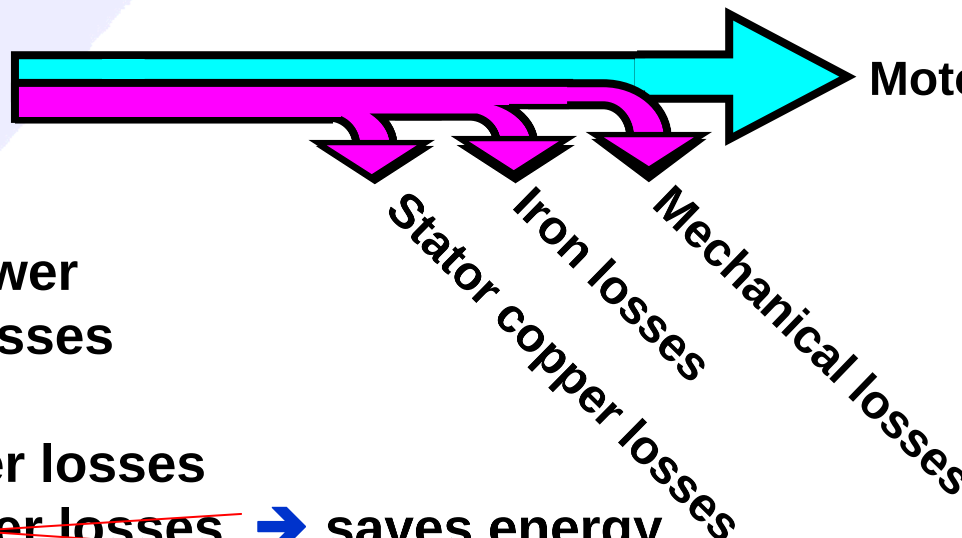
**Good Starting torque**
**High Efficiency at steady state**



# PM Motor Advantages

- Higher power density and efficiency
- Elimination of copper loss
- Lower rotor inertia

Motor input power




Motor output power

Motor Input power
- Mechanical losses
- Iron losses
- Stator coppper losses
- ~~no rotor copper losses~~ → saves energy

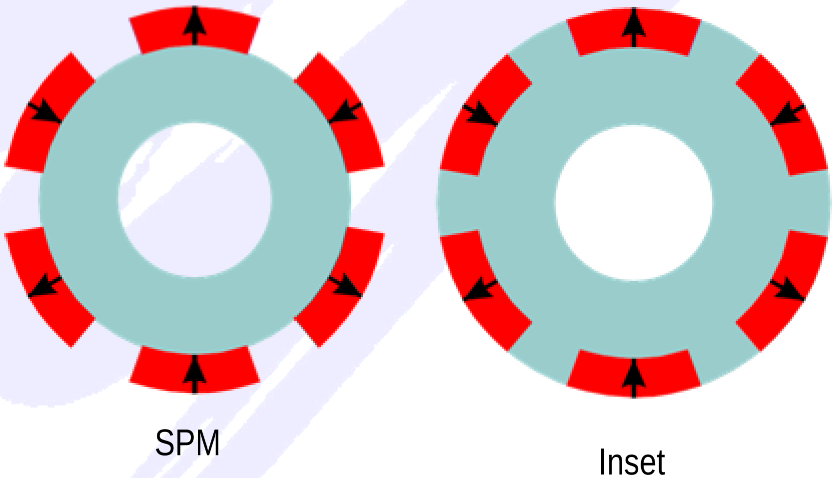
= Motor output power

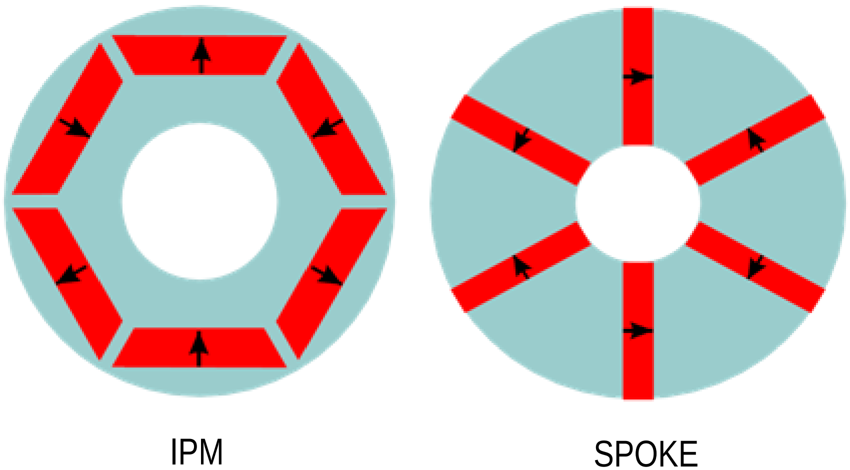
# PM Motor Disadvantages

- Magnetic characteristics change with time
- Temperature sensitive (Loss of magnetization)
- Some permanent magnets are brittle ceramics
- Cost of permanent magnets

# PM Motor Rotor Structures

Two popular PM motor structures:

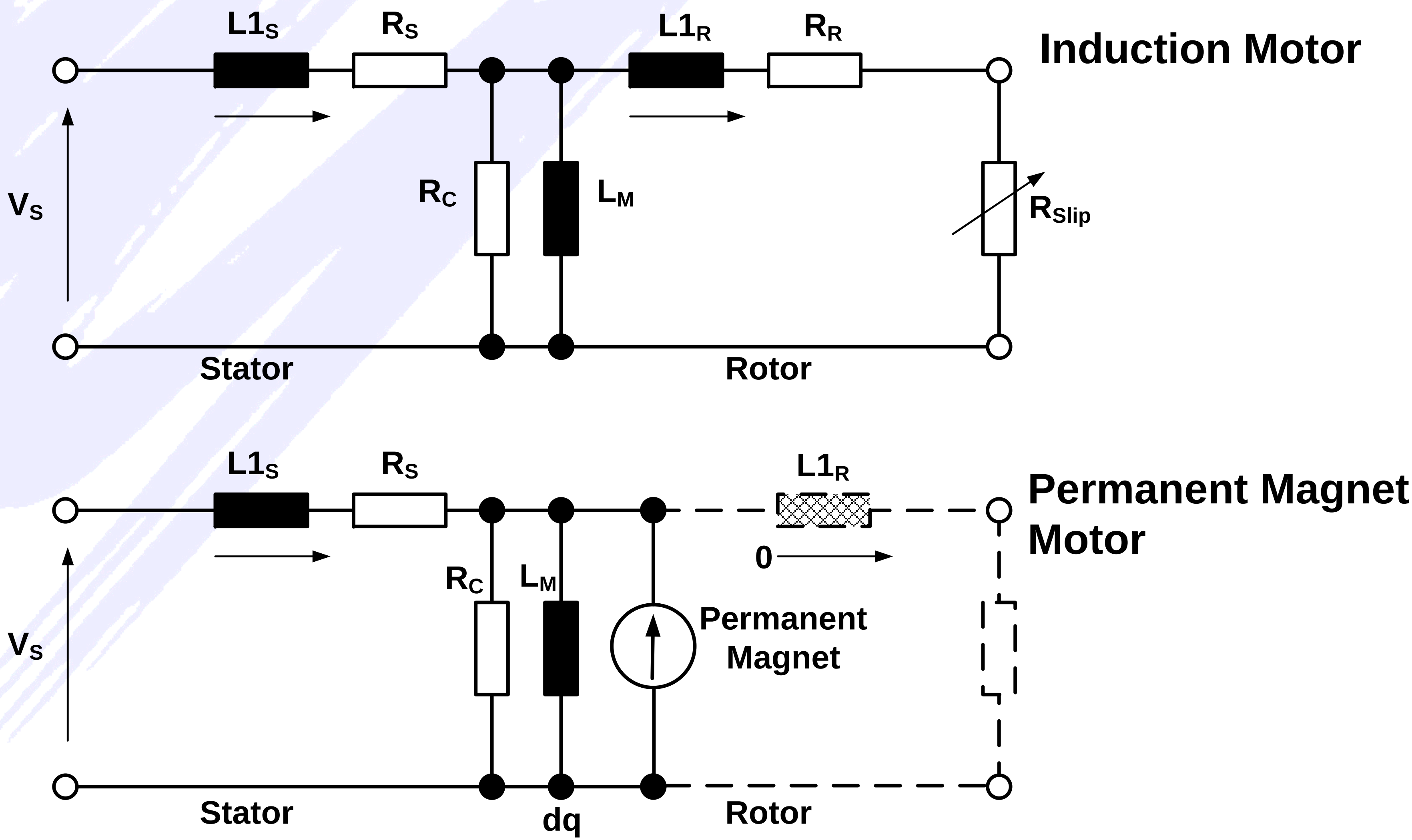



**1) Surface PM machines**
**- sinusoidal and trapezoidal**

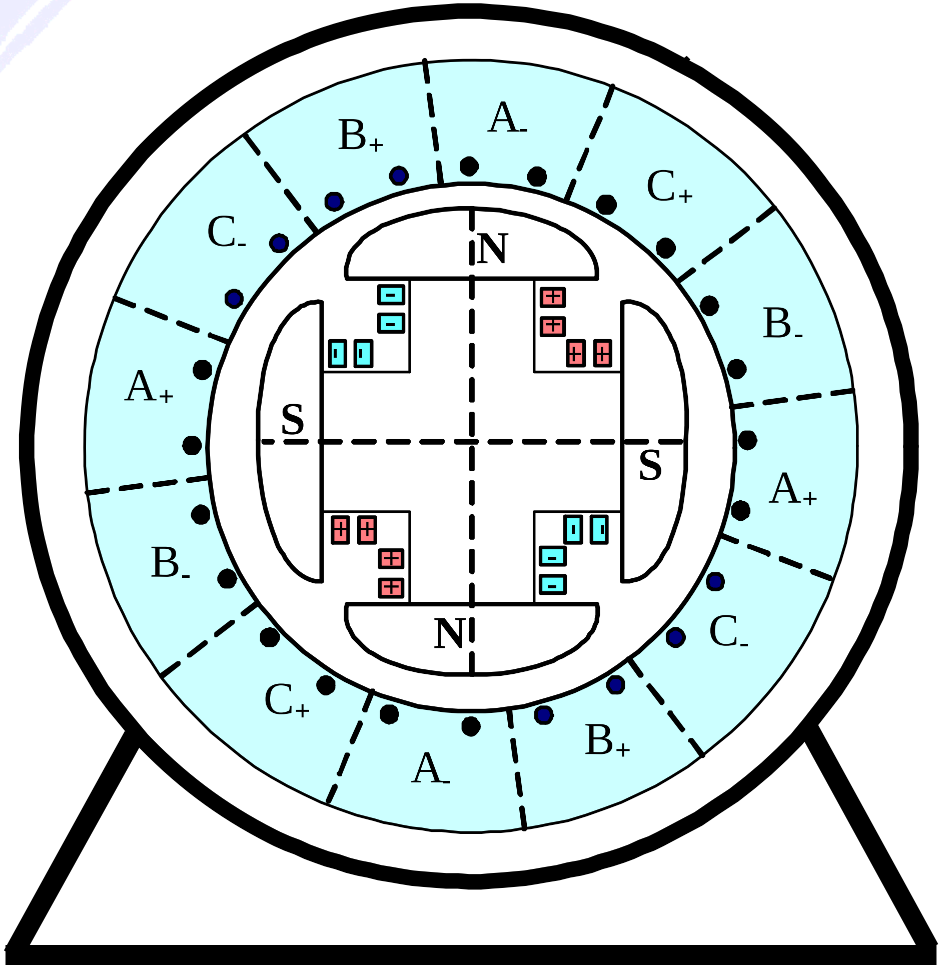
**2) Interior PM machines**
**- regular and transverse**

# Equivalent Circuit Model

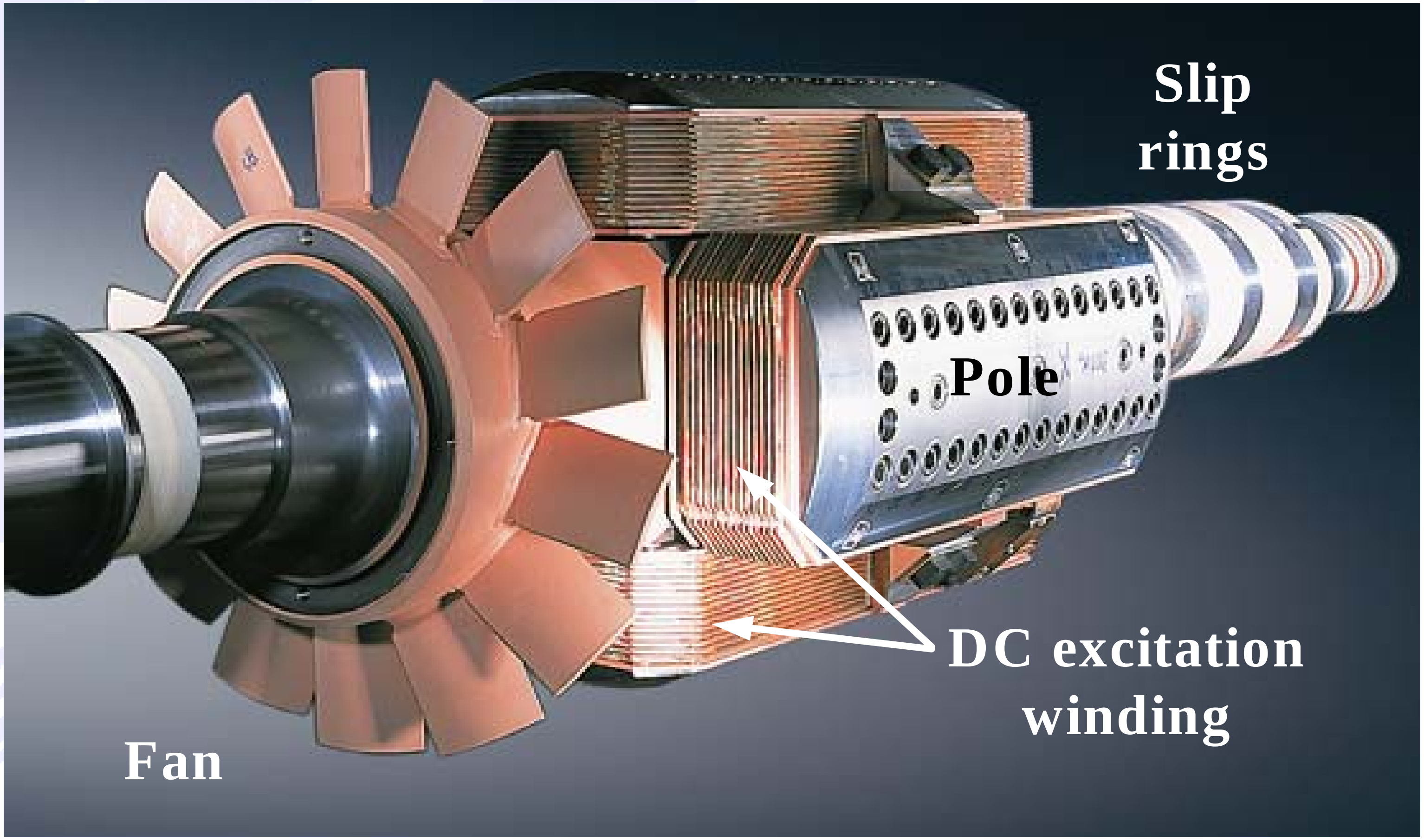


# Synchronous Machines

- **Bulky**
- **External DC power supply via slip rings**
- **Mainly used for generator applications and very big motors**



# Synchronous Machines




Rotor of a four-pole salient pole generator.

# Result

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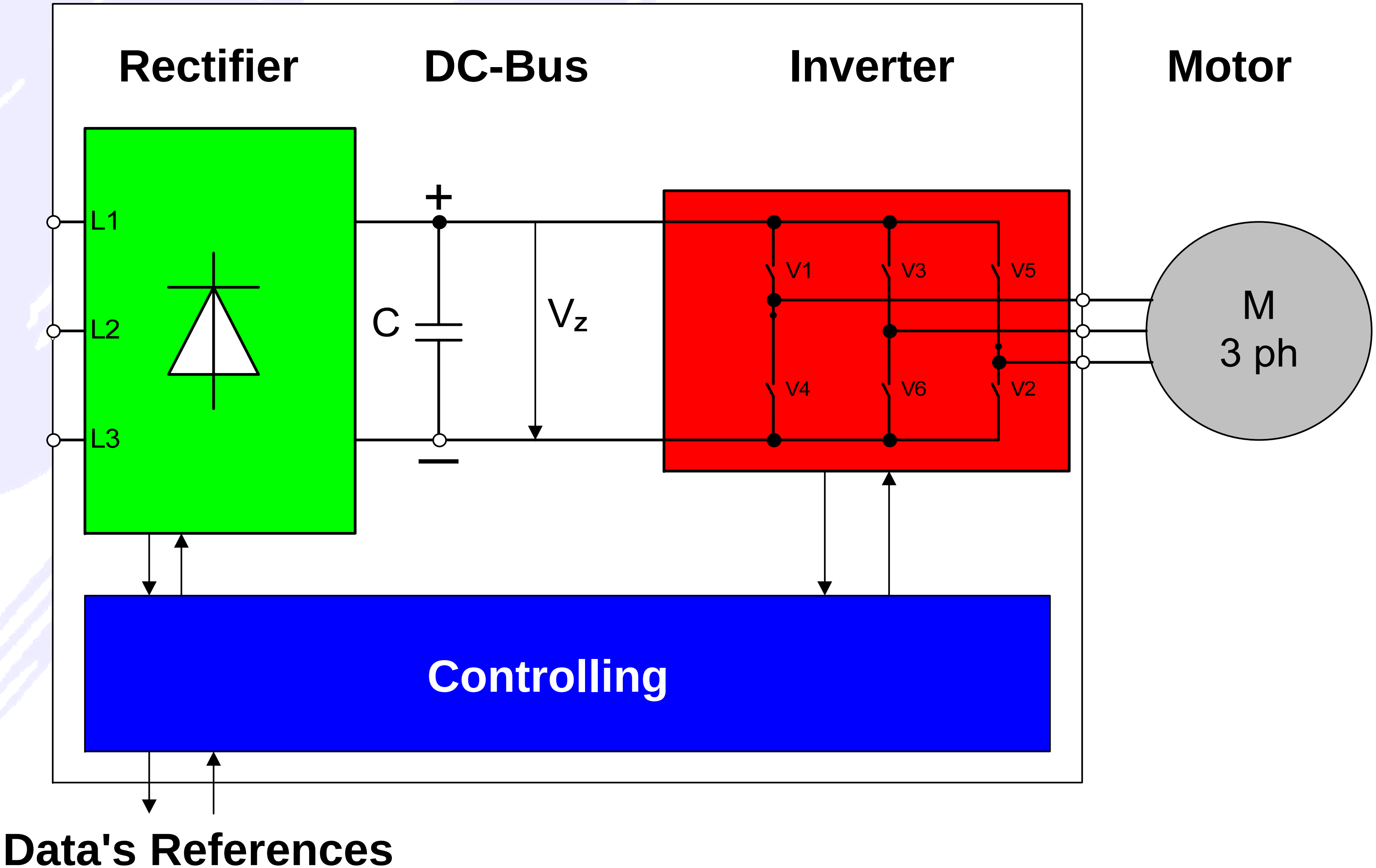
With the help of the magnetism, and from the magnetism around the wires with current flow it is possible to get a running motor.

In general there are 3 different motor types:

- DC Motors,
- Synchronous Motors, and
- Asynchronous Motors.

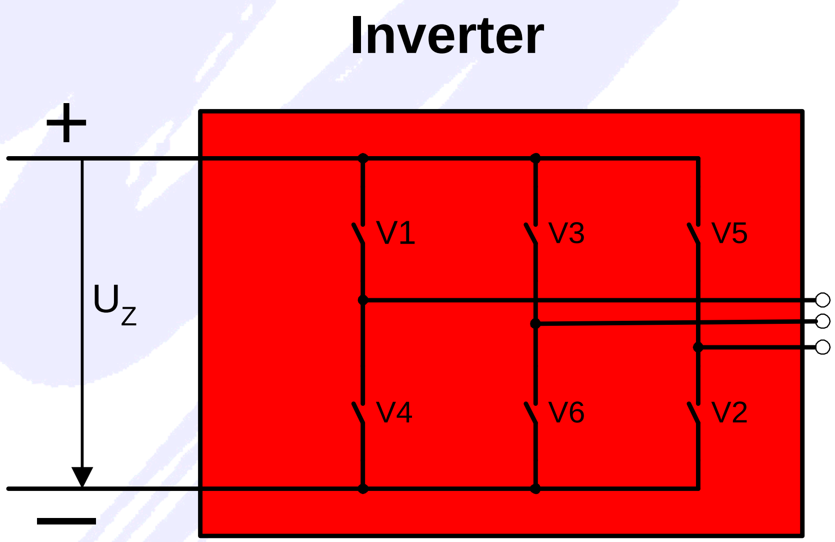
The 3 phases motor, with all the advantages has the disadvantage fixed speed depended of the frequency of the power supply.
Therefore it is necessary to have inverters to control the speed of servo motors and asynchronous motors.

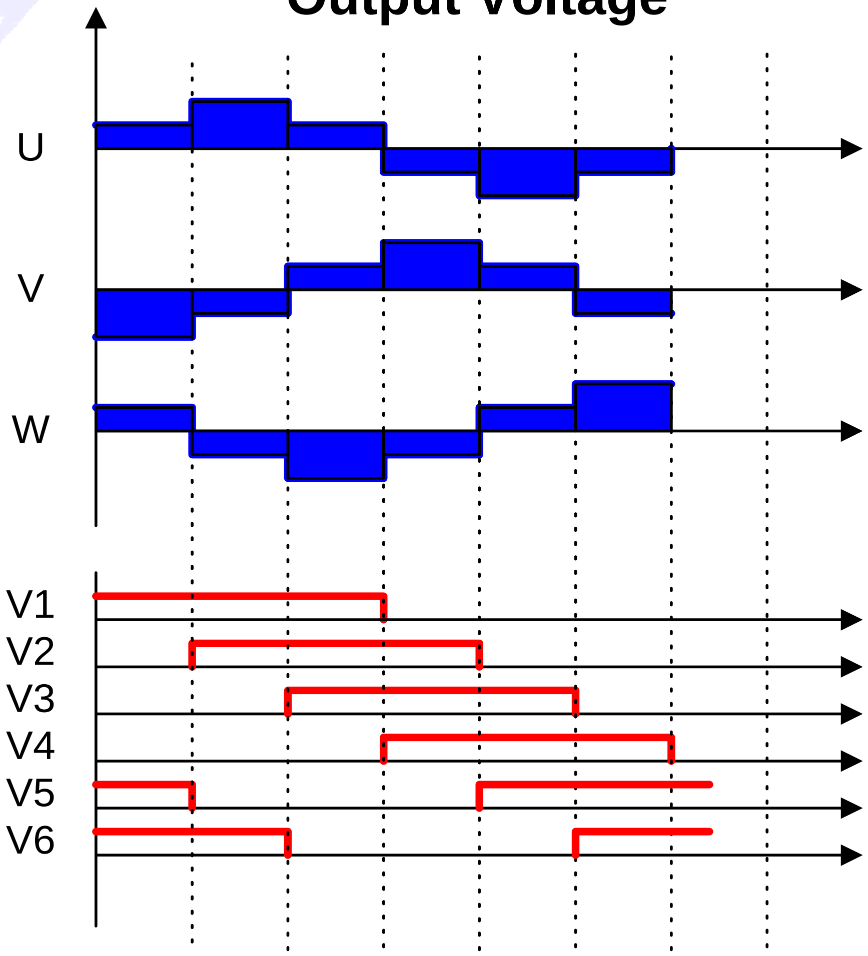
# Inverters



Rectifier
DC-Bus
Inverter
Motor
L1
L2
L3
+
C
Vz
V1
V3
V5
V4
V6
V2
M
3 ph
Controlling
Data's References

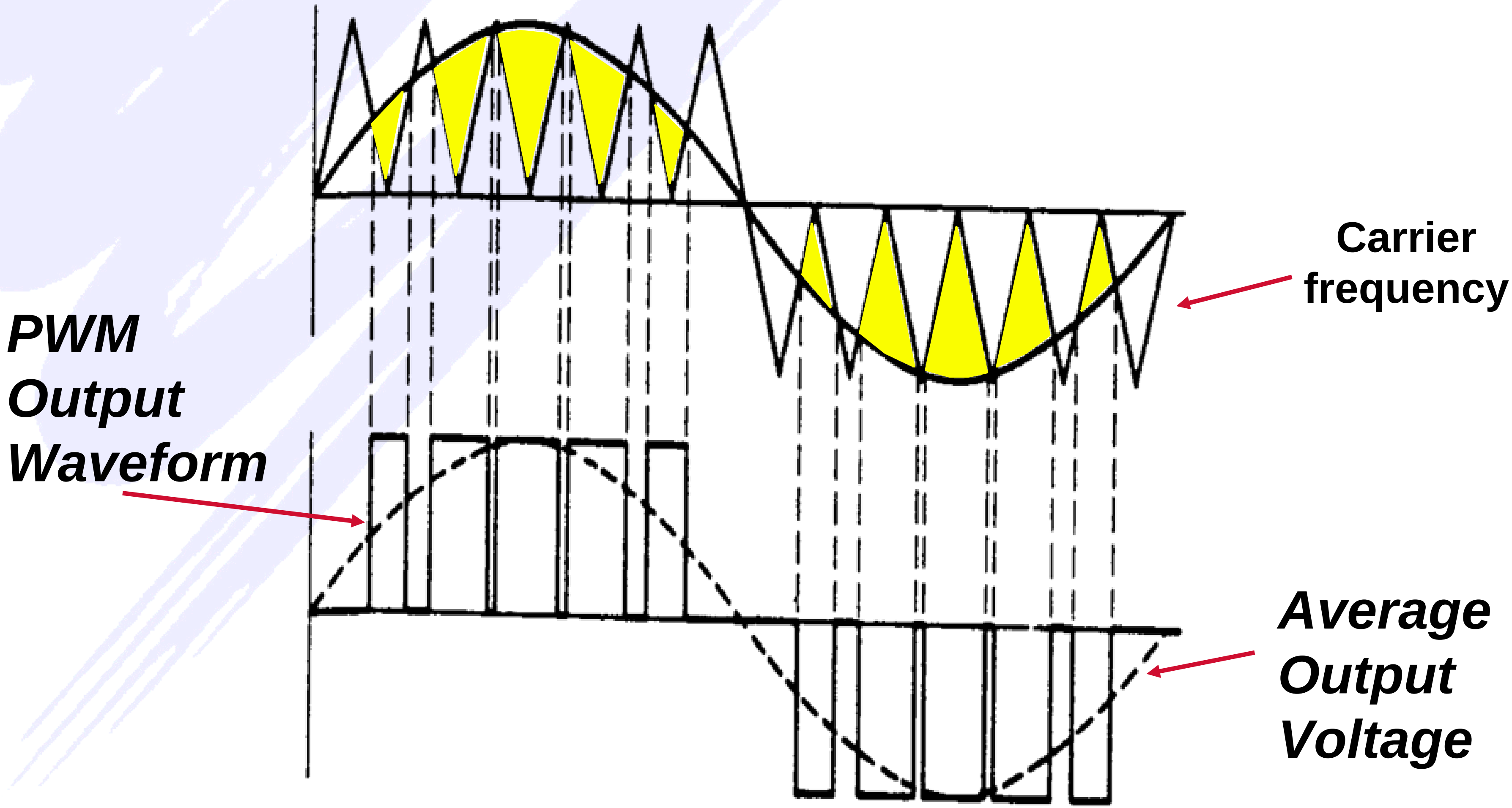
# How to get 3 Phases Output




Position of the switches

# Pulse Width Modulation



# Selection of Inverters

**Most important:**

- **Motor nominal voltage**
- **Motor nominal current**
- **Application: Depending on application it might be that not the full motor current is needed or that over torque (current) for specific time is needed**

# Yaskawa Inverter Type Code 7 Series

**CIMR- F7 (C) C 4 7P5 1 A**


| Type |
|---|
| E7 |
| F7 |
| G7 |
| J7 |
| V7 |

Operator / Fin only J7 and V7

| Fin | Operator | |
|---|---|---|
| yes | with poti | A |
| yes | no | B |
| yes | w/o poti | C |
| no | with poti | R |
| no | no | S |
| no | w/o poti | T |

| Region | |
|---|---|
| Japanese Spec. | A |
| Chinese Spec. | B |
| European Spec. | C |
| USA Spec. | U |
| Asia Spec. | T |

| Input Voltage | |
|---|---|
| 1 ~ 230 V | B |
| 3 ~ 200 V | 2 |
| 3 ~ 400 V | 4 |

| Max. Appl. Motor | |
|---|---|
| 0.55 kW | 0P4 |
| 4.0 kW | 4P0 |
| 7.5 kW | 7P5 |
| 11 kW | 011 |
| 45 kW | 045 |
| 110 kW | 110 |
| 160 kW | 160 |
| 300 kW | 300 |

| | |
|---|---|
| IP00 | 0 |
| IP20/NEMA1 | 1 |
| IP54/NEMA2 | 2 |

| Version | |
|---|---|
| 1st | A |

# Yaskawa Inverter Type Code 1000 Series

**CIMR- J C B A 0001 B A A**

| Version | |
|---|---|
| 1st | A |

| Type | |
|---|---|
| J1000 | J |
| V1000 | V |
| A1000 | A |

| Region | |
|---|---|
| Japanese Spec. | A |
| Chinese Spec. | B |
| European Spec. | C |
| USA Spec. | U |
| Asia Spec. | T |

| Input Voltage | |
|---|---|
| 1 ~ 230 V | B |
| 3 ~ 200 V | 2 |
| 3 ~ 400 V | 4 |

| Customer Spec. | |
|---|---|
| Standard | A |

| Rated Current ND | |
|---|---|
| 1.2 Amps | 0001 |
| 1.9 Amps | 0002 |
| 3.3 Amps | 0003 |
| 4.1 Amps | 0004 |
| 5.4 Amps | 0005 |
| 6 Amps | 0006 |
| 6.9 Amps | 0007 |
| 8.8 Amps | 0009 |
| 11.1 Amps | 0011 |
| 12 Amps | 0012 |
| 19.6 Amps | 0020 |

| Fin, Filter, Enclosure | | | |
|---|---|---|---|
| Fin | Filter | Protection level | |
| Standard | no | IP00 | A |
| Standard | no | IP20 w/o top cover | B |
| Standard | no | NEMA Type 1 | F |
| no | no | Finless (IP20) | J |

| Environmental Spec. | |
|---|---|
| Standard | A |
| Moisture humidity)/dust proof | M |
| Oil proof | N |
| Salt proof | C |
| Vibration proof | S |
| Gas proof | K |
| Moisture and vibration proof | P |
| Oil and vibration proof | Q |
| Gas and vibration proof | B |
| Oil proof double coating | D |
| Moisture double coating | E |

# V/f Control

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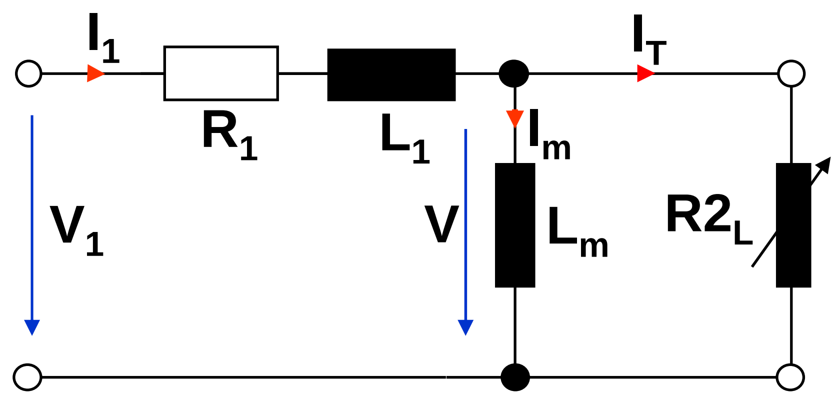
$$T \propto \Phi \cdot I_2$$




**For No Load ($I_T$=0), R1=0**

$$V_1 = 2 \cdot \pi \cdot f_1 \cdot (L_1 + L_m) \cdot I_1$$

$$V_1 = 2 \cdot \pi \cdot f_1 \cdot (L_1 + L_m) \cdot I_m$$

$$I_m = \frac{1}{2 \cdot \pi \cdot (L_1 + L_m)} \cdot \frac{V_1}{f_1}$$

$$\mathrm{Im} \propto \frac{V_1}{f_1}$$

$$T \propto \frac{V_1}{f_1} \cdot I_2$$

**That means the $I_m$ and Flux is constant, when we keep the ratio $V_1$/f constant during frequency change.**

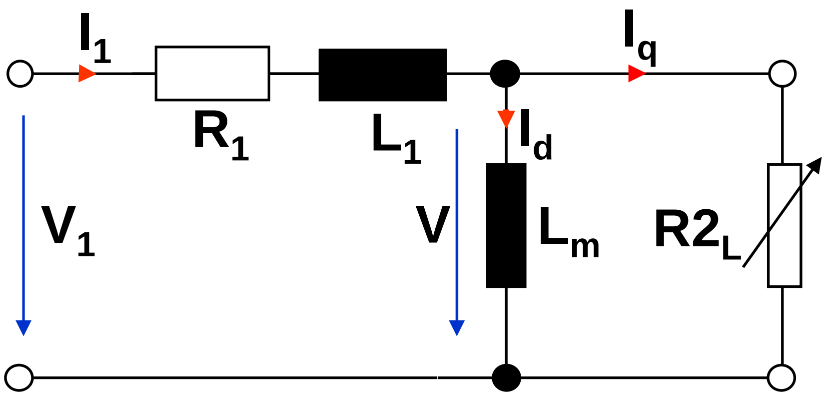
# V/f Control

YASKAWA

$$T \propto \Phi \cdot I_2$$

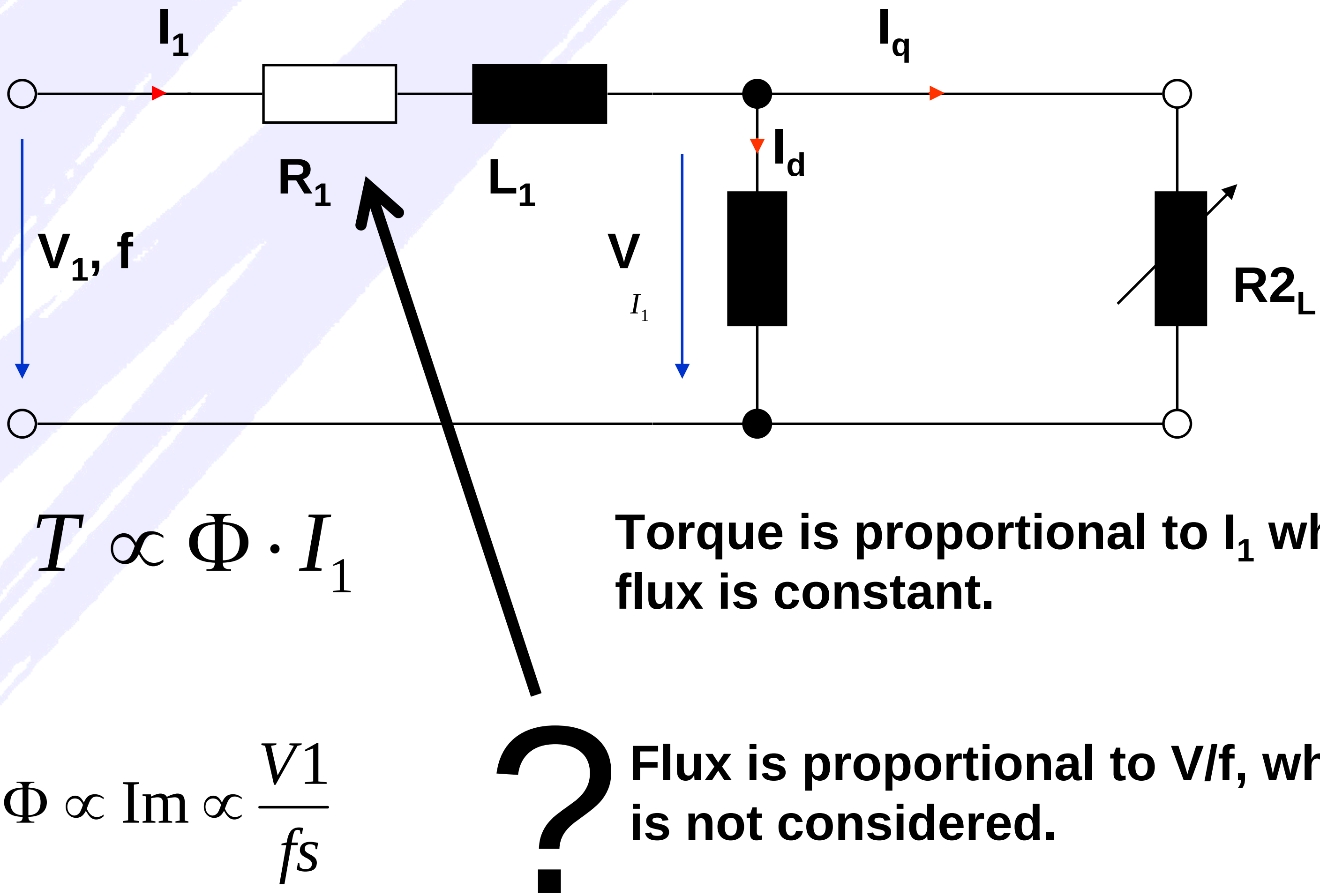
For $R_1$=0 and $I_t$ is prop. to $I_1$

$$T \propto \frac{V_1}{f_1} \cdot I_1$$




That means if we keep the ratio $V_1$/f constant, the torque is proportional to $I_1$ during frequency change

# Voltage Boost



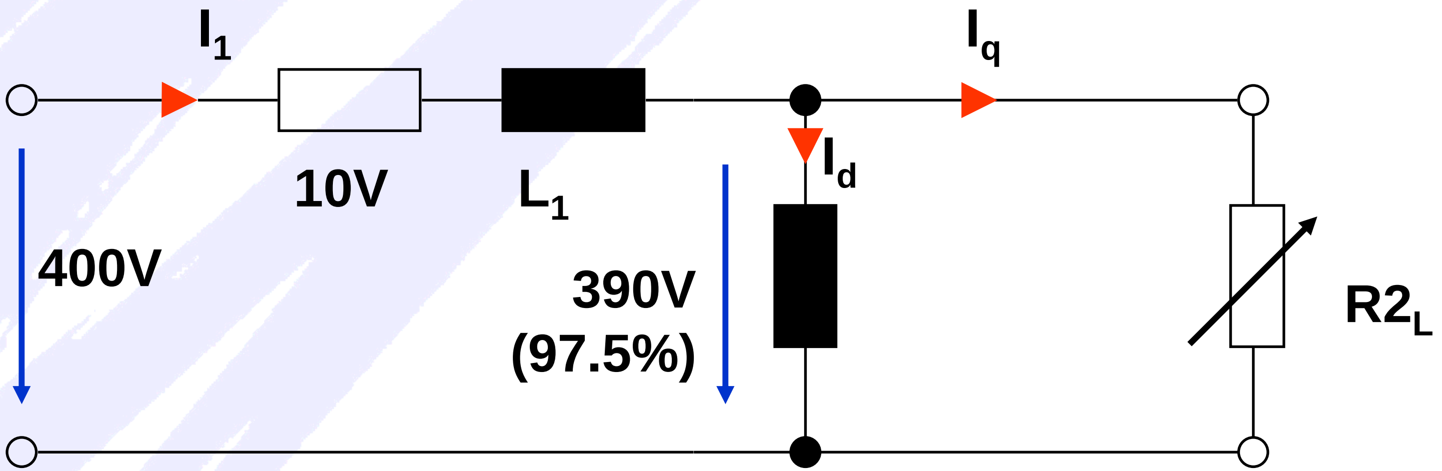

$$T \propto \Phi \cdot I_1$$

Torque is proportional to $I_1$ when flux is constant.

$$\Phi \propto \mathrm{Im} \propto \frac{V1}{fs}$$

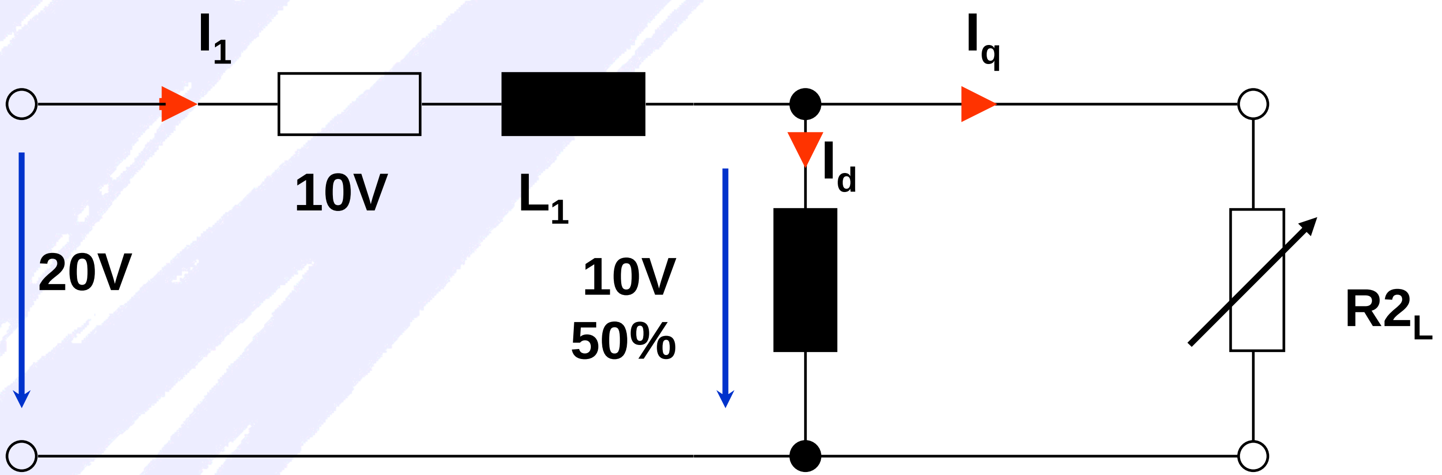
Flux is proportional to V/f, when $R_1$ is not considered.

# Voltage Boost



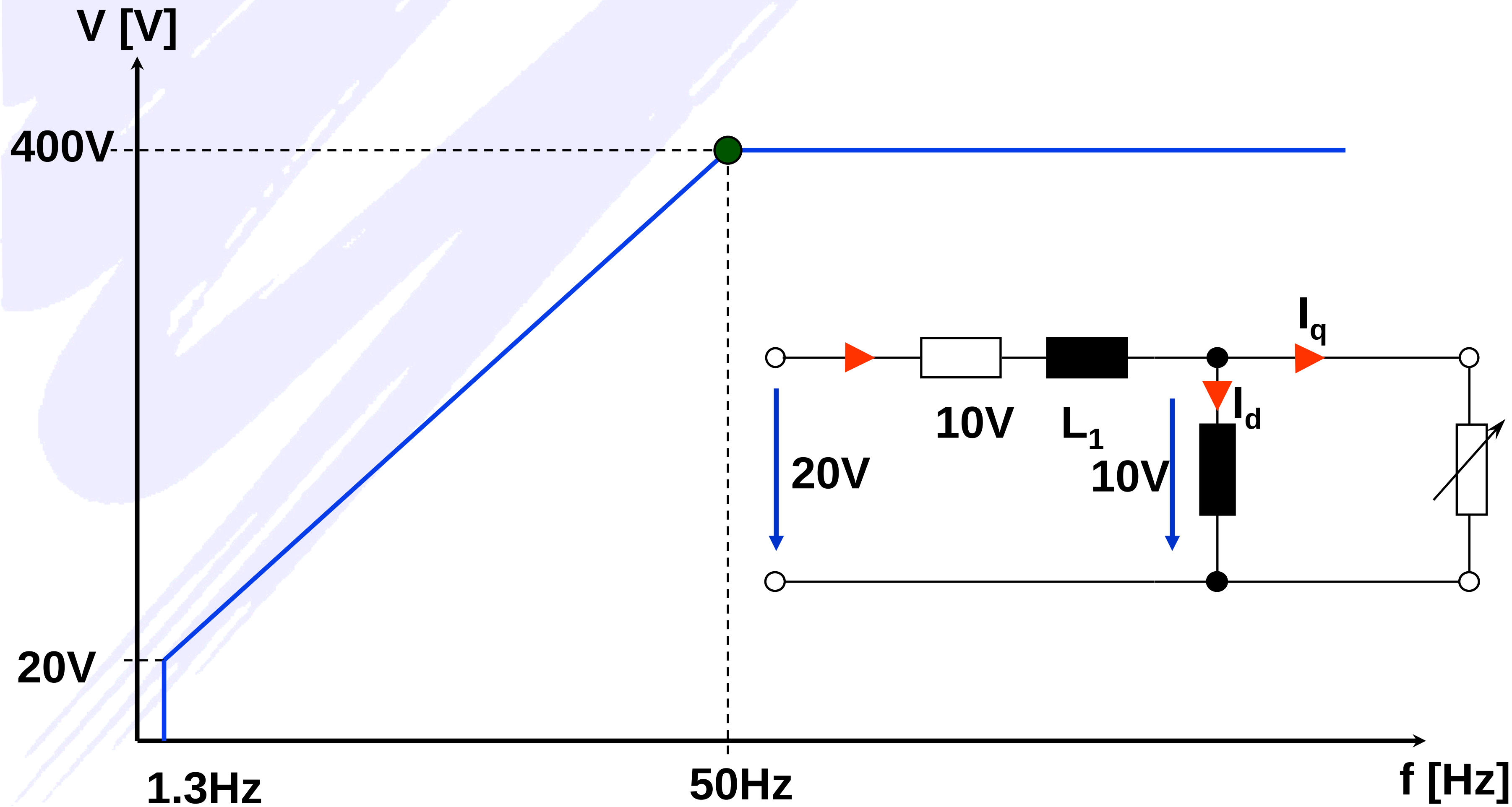

**The effect of R1 by high voltage, high frequency.**

# Voltage Boost

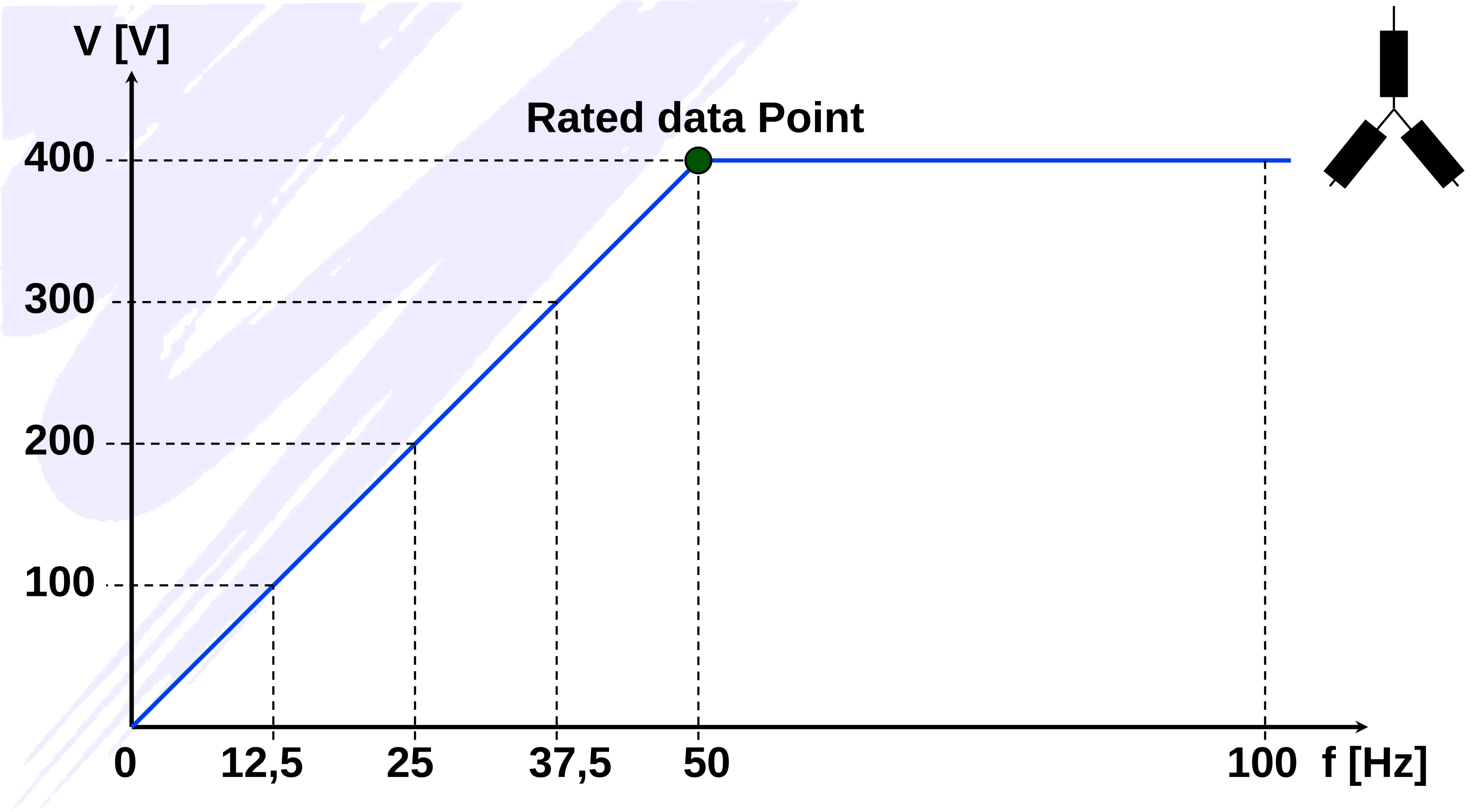



**The effect of R1 by low voltage, low frequency, same load**

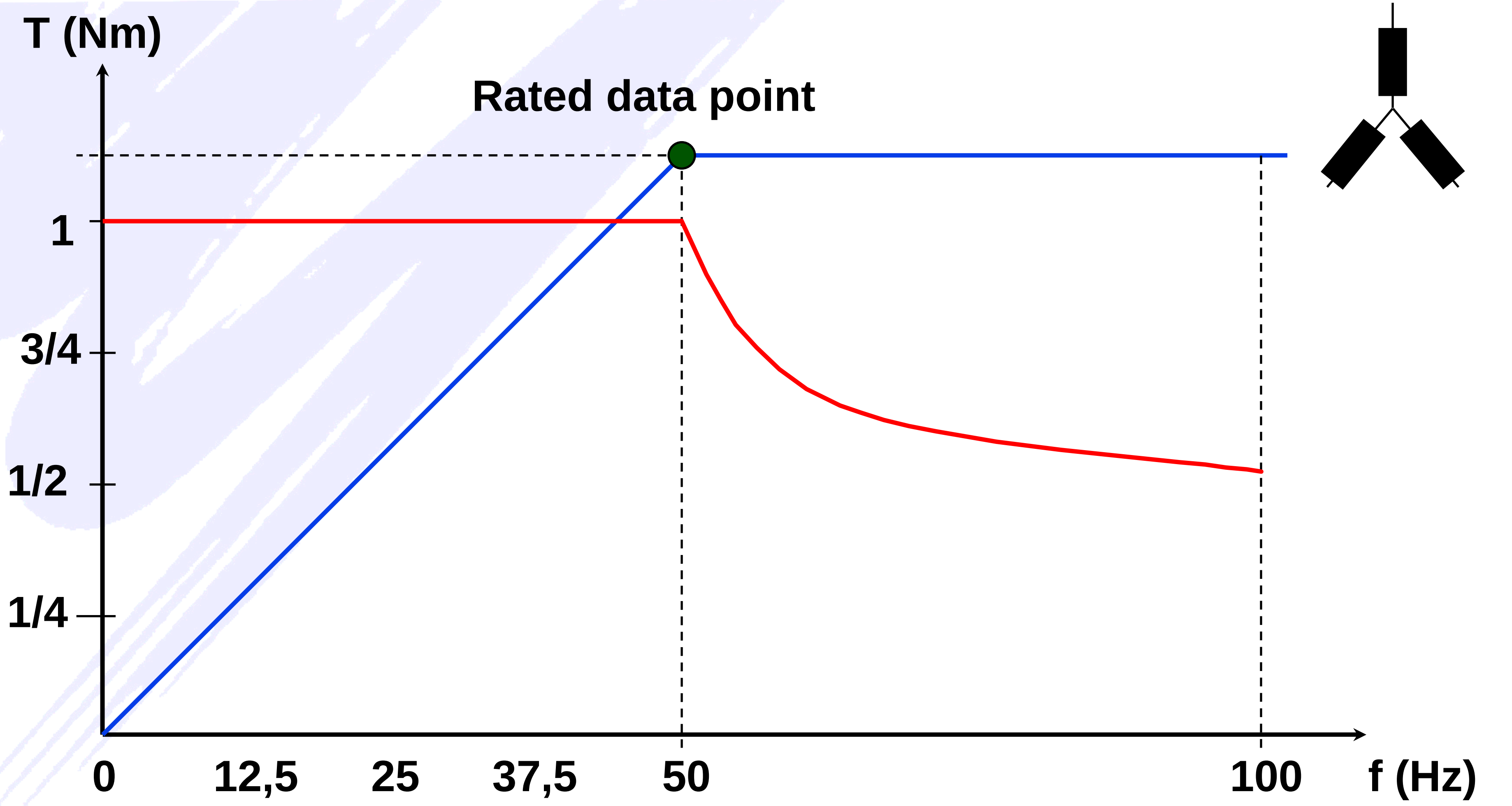
# Voltage Boost



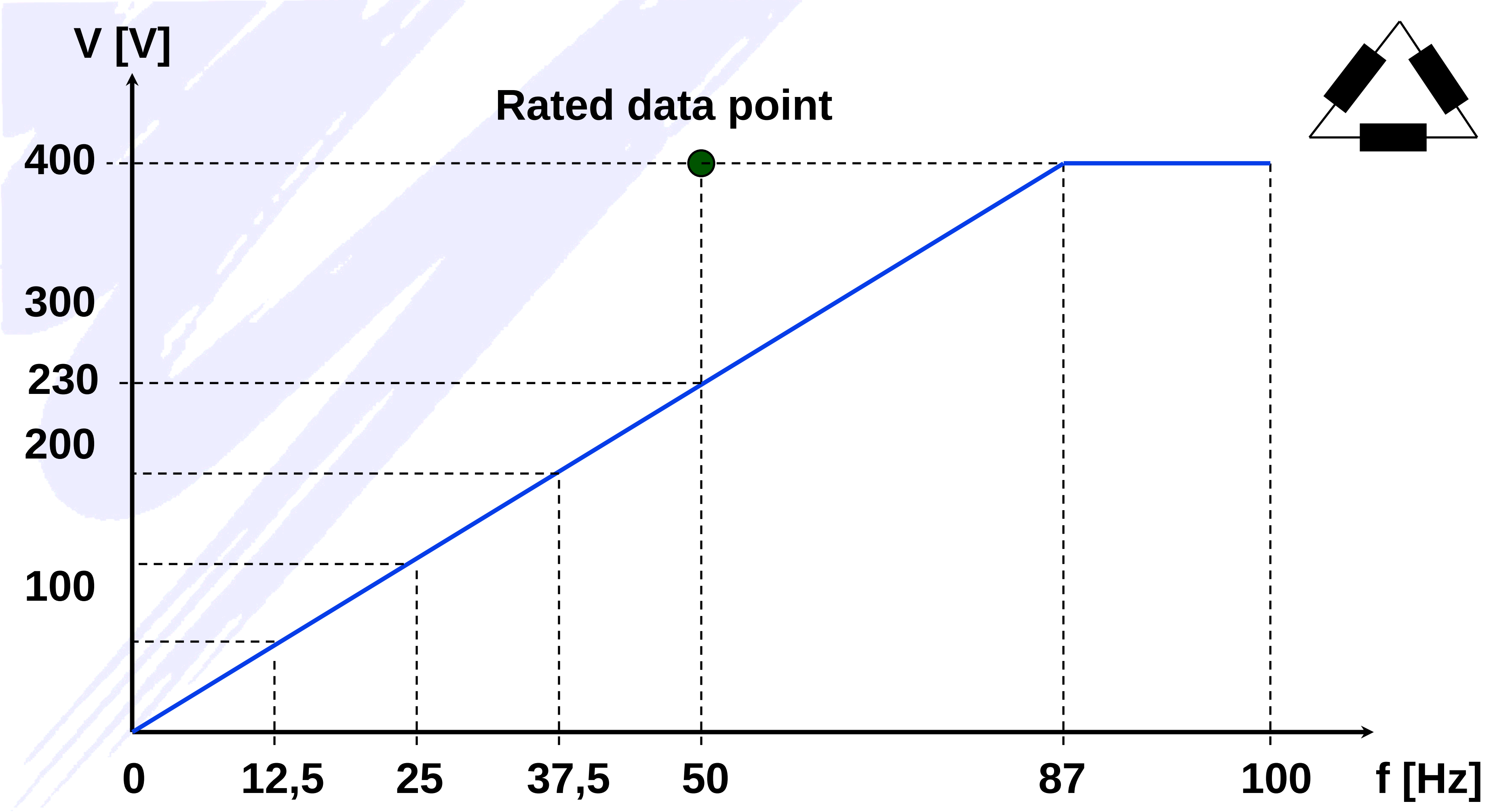
# V/f Pattern



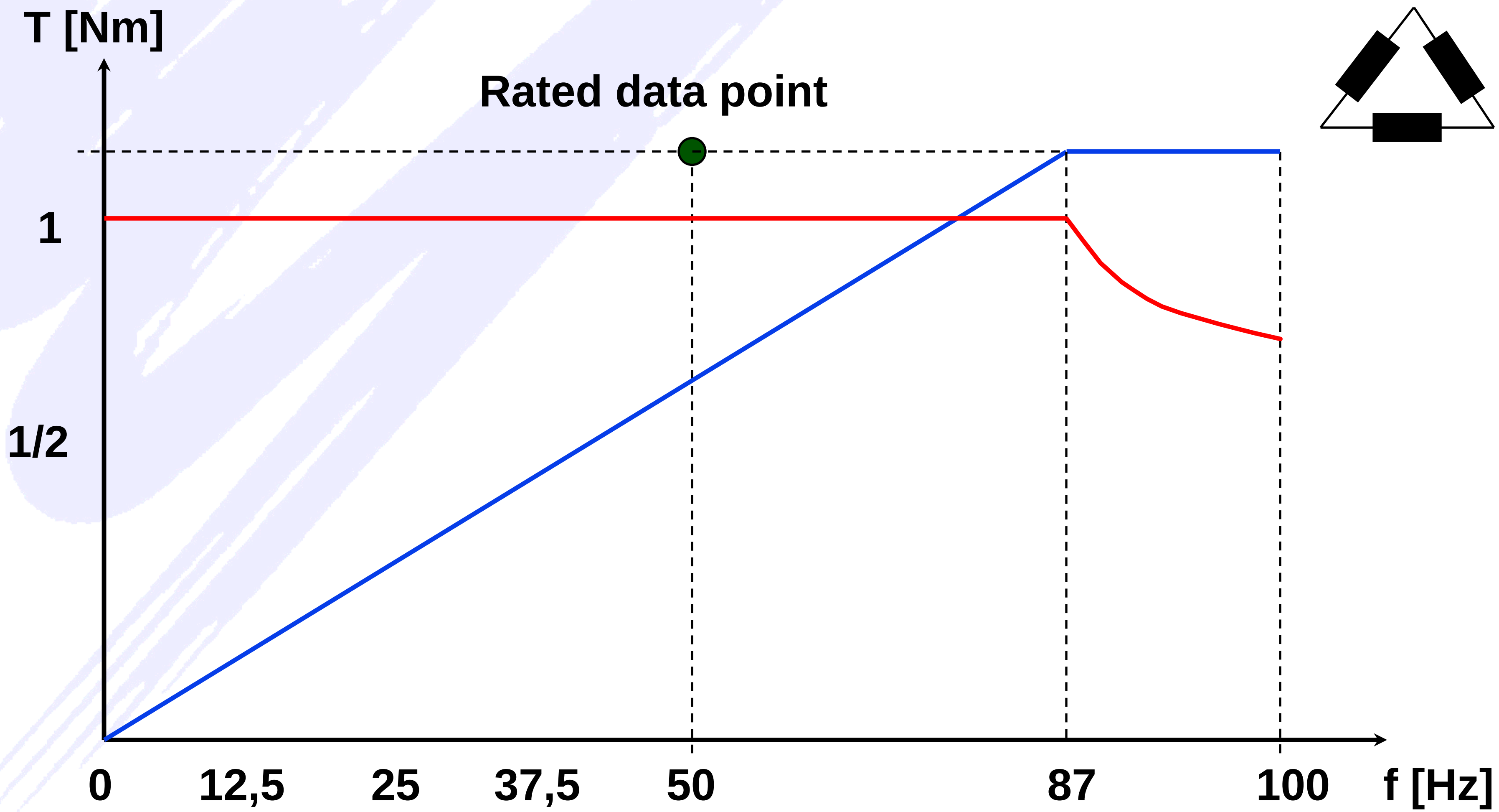
# V/f Pattern



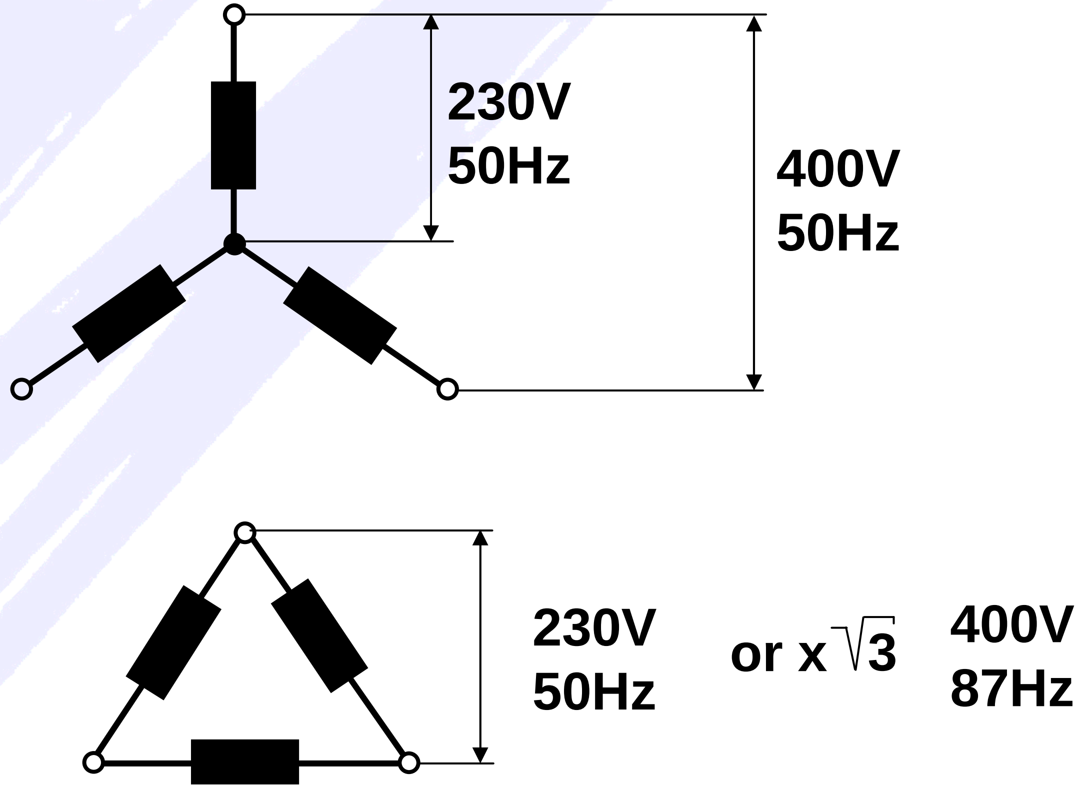
# V/f Pattern Delta



# V/f Pattern Delta



# Star-Delta-Connection

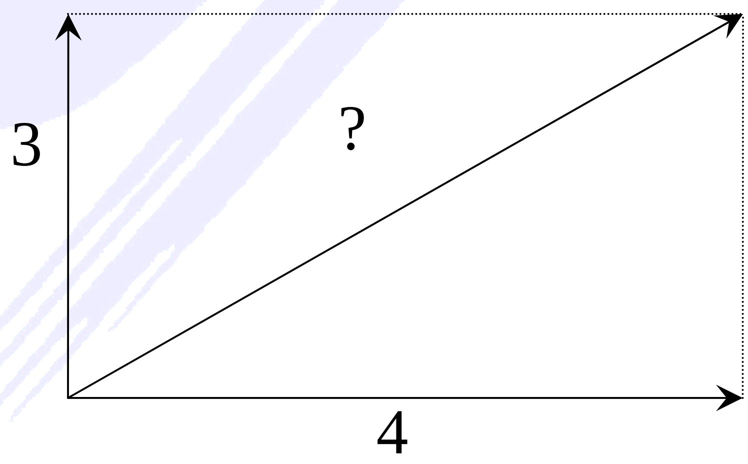



**In delta connection the current is also $\sqrt{3}$ (1,73) times higher.**
**Please refer to the motor name plate**

# Vector in General

**Definition of the word "VECTOR" !**

**A vector is described as a quantity having both magnitude and direction. If the lengths of the x and y components are known, the length can be determined by using the Pythagorean theorem.**



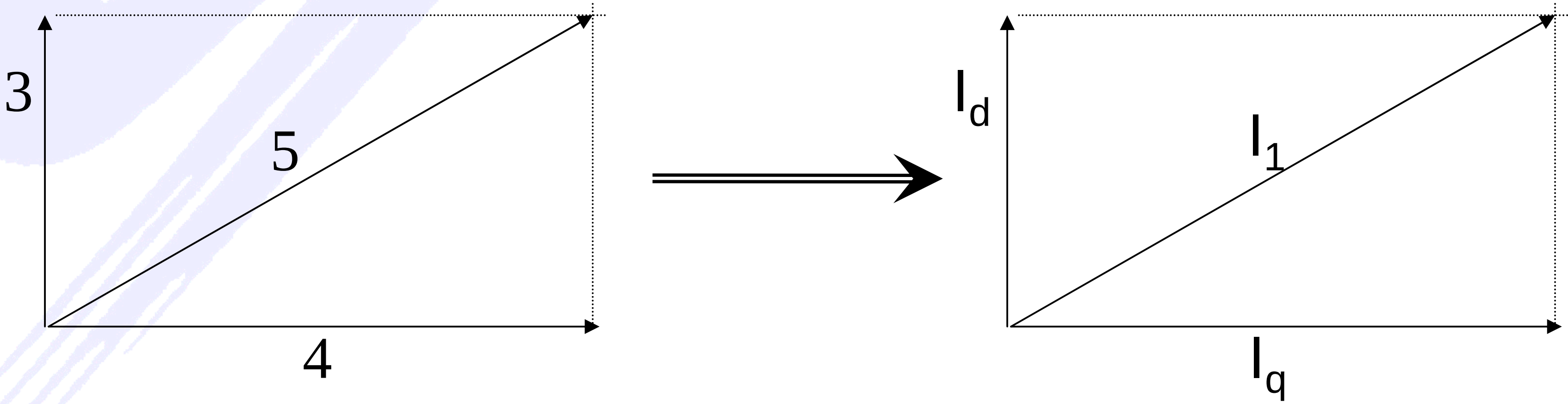

$$? = \sqrt{3^2 + 4^2}$$

$$? = 5$$

# Vector in General

## Vector and Current Vector

**From the previous example, a relationship between the magnetising current ($I_m$ or $I_d$), torque producing current ($I_t$ or $I_q$), and the resultant ($I_1$) is established.**

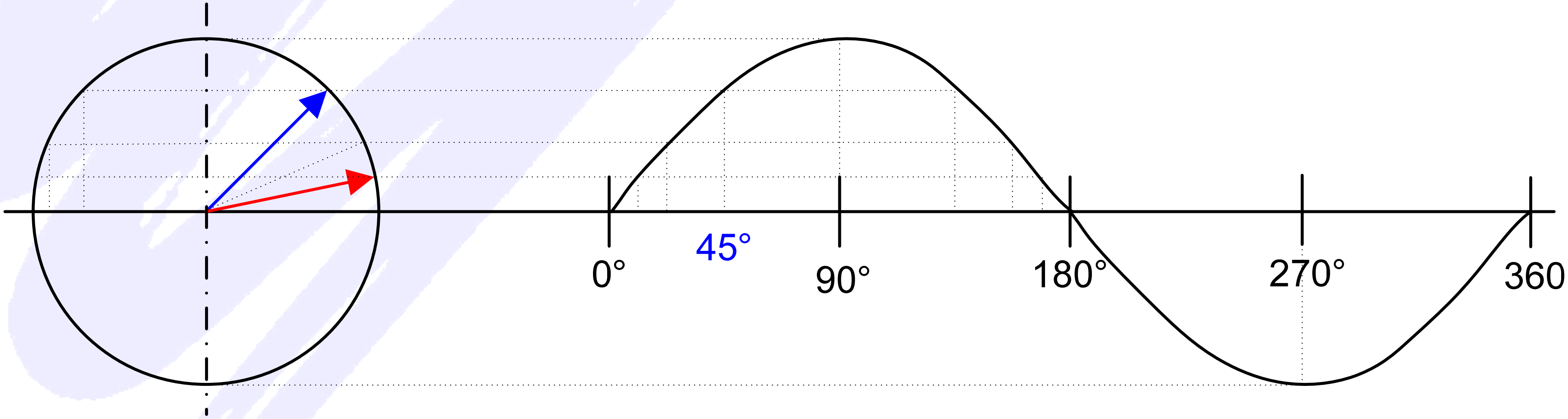



$$5 = \sqrt{3^2 + 4^2}$$

$$I_1 = \sqrt{I_d^2 + I_q^2}$$

# Vector in General

## Relationship between a circle, a sinus, and a vector




**Vector just means that there is a quantity having a magnitude and a direction.**

**For example: - Speed in fact is a vector !**

**- Force is a vector as well !**

# Vector Control Modes

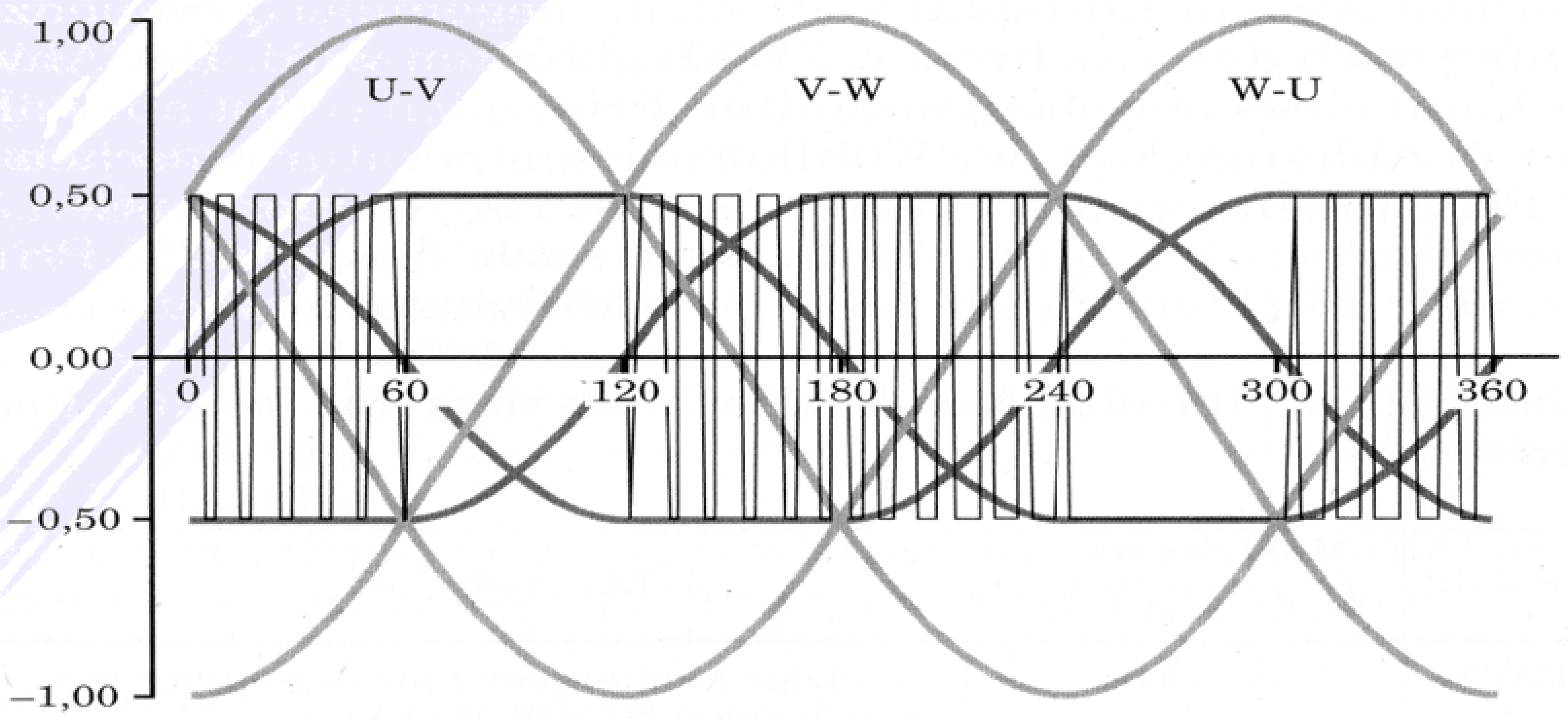
A vector drive can be controlled by :

- Voltage Vector
- (Flux Vector)
- Current Vector

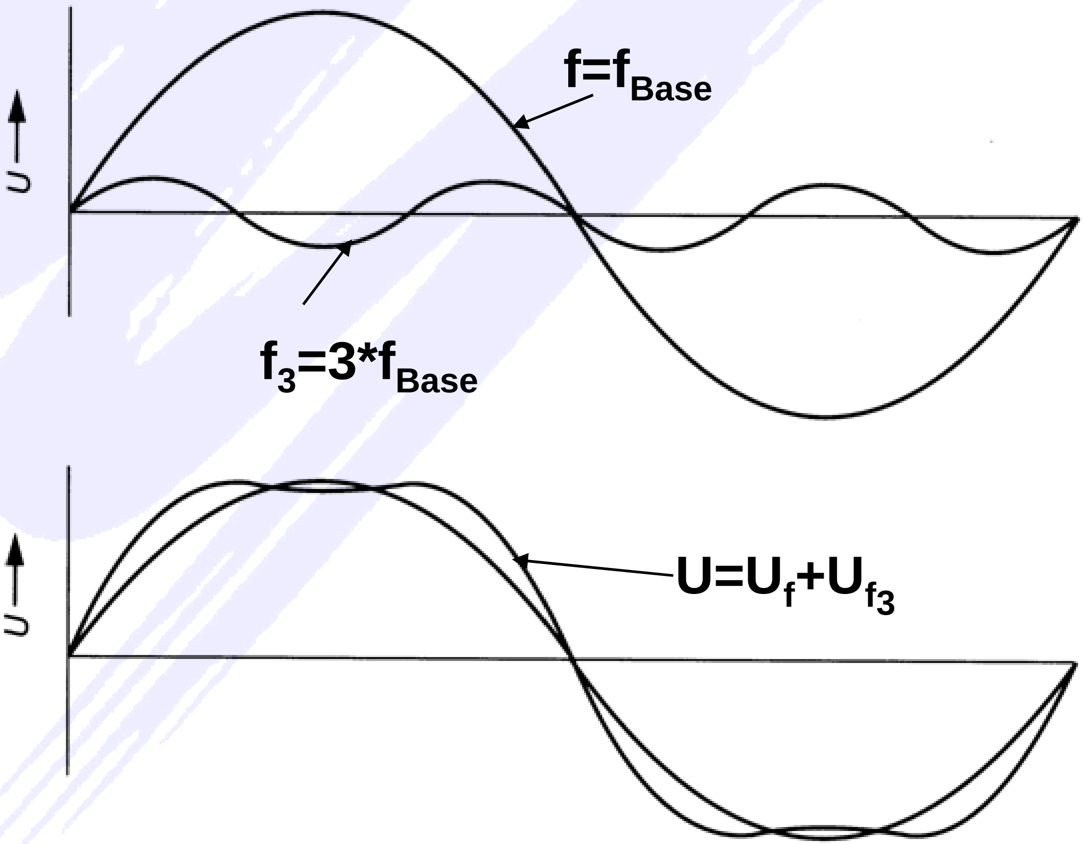
# Voltage Vector Control

**Voltage block from 60° to 120° and from 240° to 300°**

**Advantages : $U_{output}$ can reach the average value of $U_{input}$**



# Voltage Vector Control



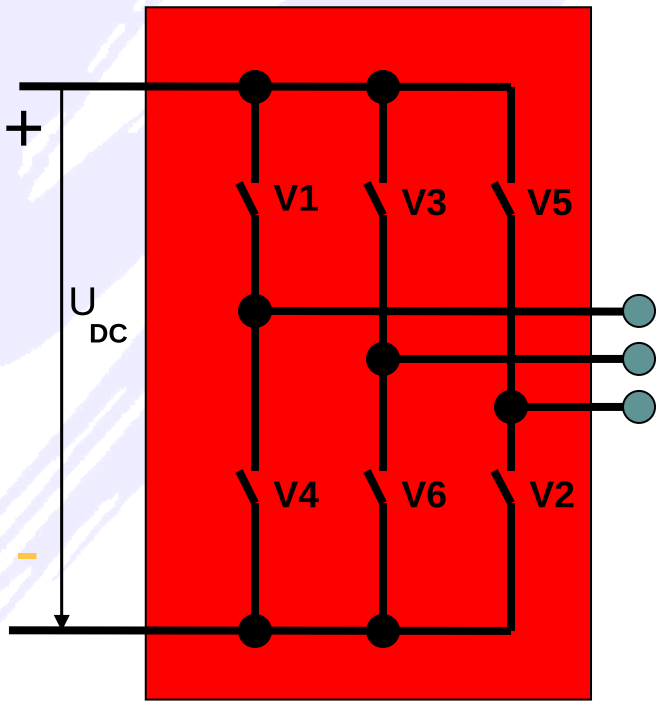

**A third harmonic is added to the base frequency.**

**Advantages :**
**$U_{output}$ can reach the average value of $U_{input}$**

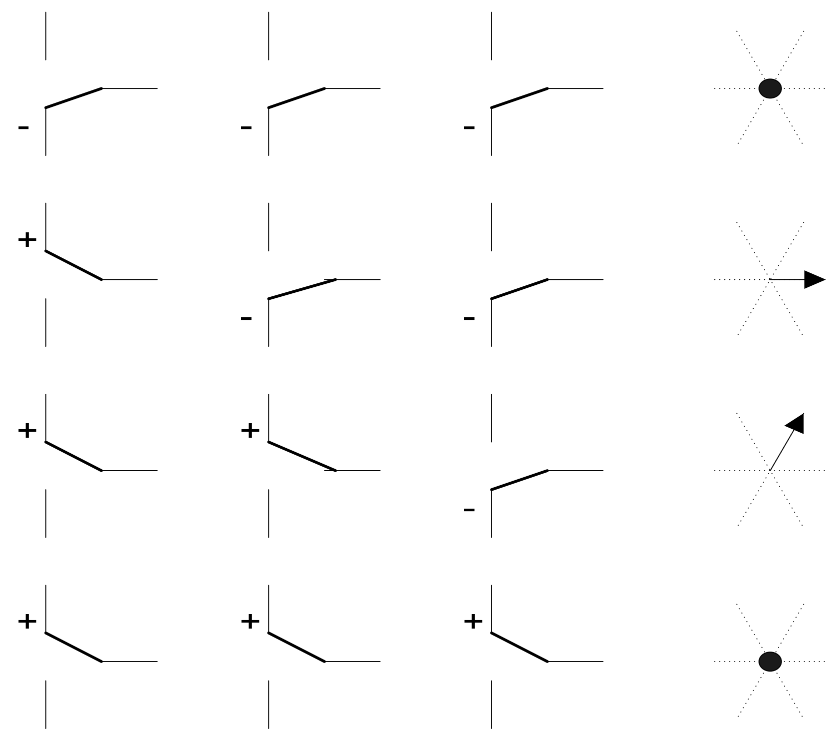
# Inverter Output

## How it switches !

Inverter



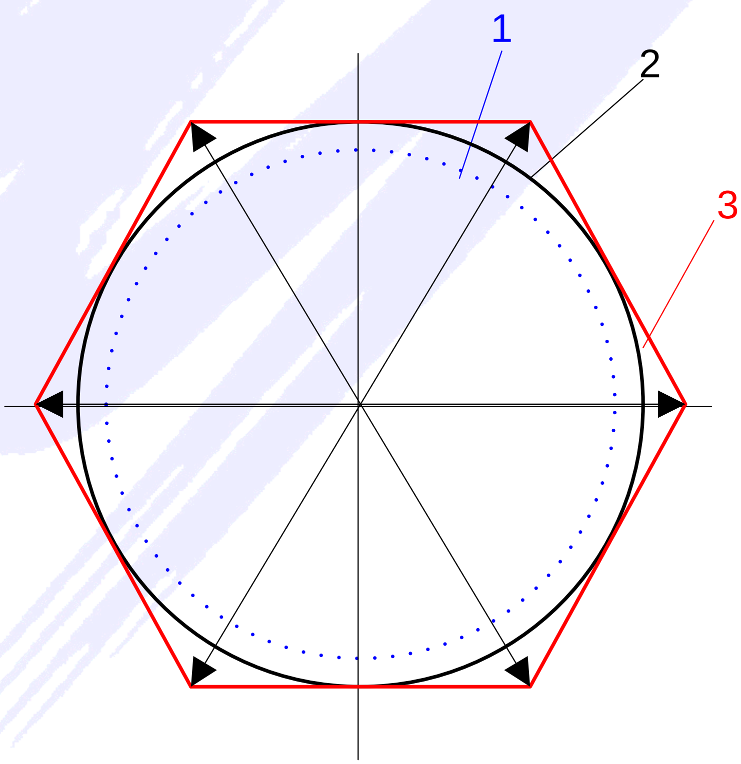

V1/V4 V3/V6 V5/V2




**All together there are eight combinations possible !**

# Output Voltage Phase to Neutral

## Different Control Modes



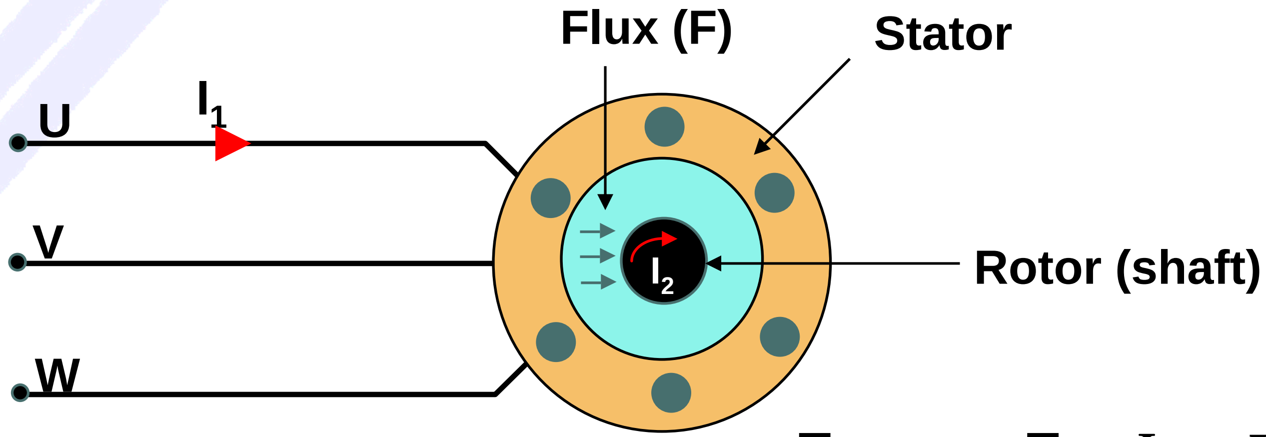

**1 = Curve for Sin-PWM**
**(average voltage ~ 85%)**

**2 = Voltage Vector Curve**

**3 = max. Voltage Curve**

# Flux Vector Control

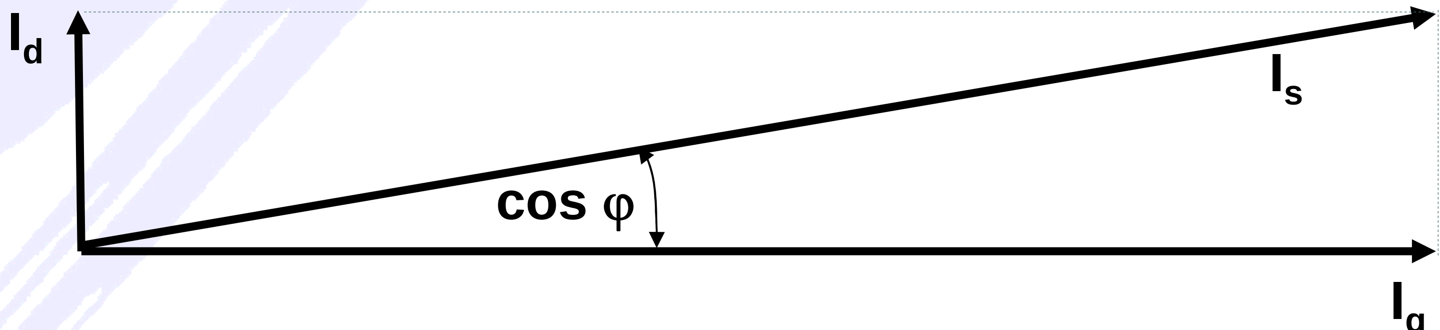
In a Flux Vector inverter, voltage is applied to the U,V,W- leads of the motor ($U_1$). This voltage produces a current that breaks into two components, an d value (magnetising current) and a q value (torque producing current). Magnetising current is required to make flux. The torque producing current will change with the load.




Torque : $T \propto \Phi \bullet I_2$

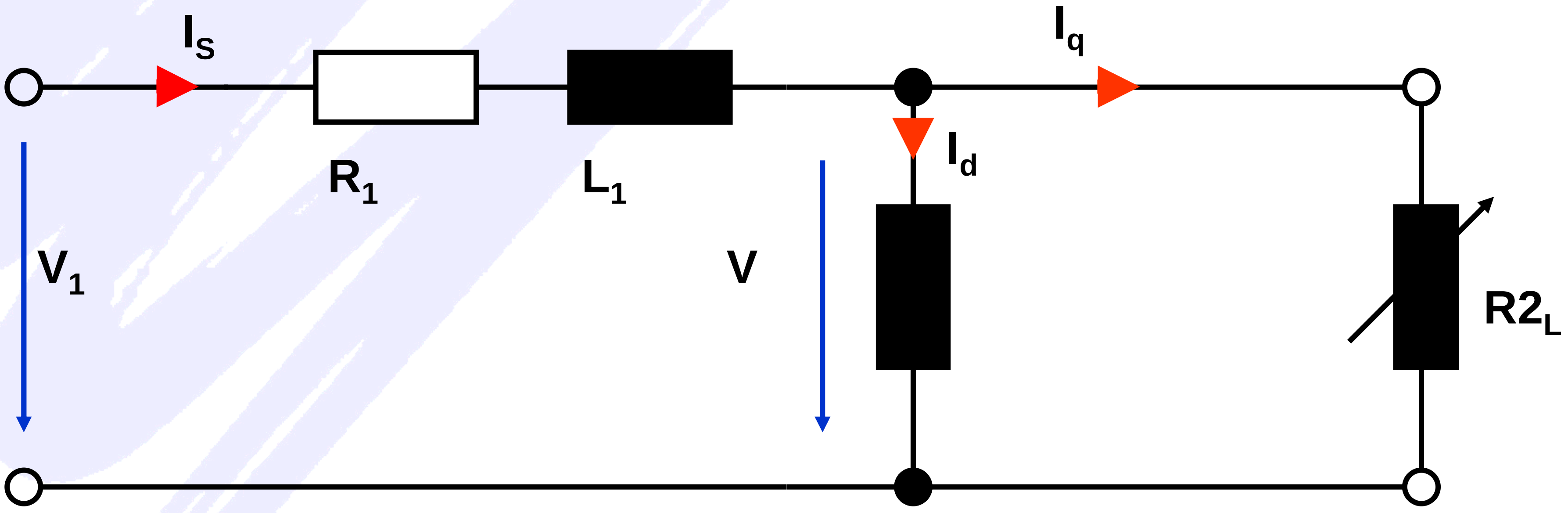
# Current Vector Control

The angle between the torque producing current ($I_t$) and the magnetising current (Id) is held at 90º to produce maximum torque. Torque is proportional to Id  x  Iq  x  Sine of 90º. The Sine of 90º =1. If the angle is greater than or less than 90º, the Sine of the angle would be less than 1.




The angle between summery current ($I_s$) and torque producing current is mentioned at the motor name plate as cos φ. The cos φ depends on load of the motor.

# Equivalent Circuit Diagram of an Asynchronous Motor




$I_d$ = magnetising current → flux

$I_q$ = torque producing current → secondary current

# Auto Tuning

To support the motor data with exact data, the YASKAWA inverter provides an Auto Tuning function which measures the motor data automatically. Only the basic data (mentioned on the motor name plate) have to be set by parameter.

Motor data to be set by parameter

- Rated Voltage
- Rated Current
- Rated Frequency
- Rated Speed
- No. of Poles

During auto tuning the inverter measures resistance of stator and rotor, main inductance, leakage inductance of stator and rotor, saturation coefficient, and saturation coefficient during field weakening, no load current, and slip.

# Why to Use Auto Tuning

The inverter needs motor equivalent circuit data for internal calculations to achieve maximum motor performance

There are 3 ways of getting the motor equivalent circuit data:

- Ask the manufacturer – Needs time and often the information is poor
- Manually calculation – By using the name plate data the necessary equivalent circuit data can be calculated but it is impractical
- Auto tuning – only input name plate data, rest is done by inverter

There are 3 different auto tuning modes available

- Rotating Auto Tuning
- Non Rotating Auto Tuning
- Terminal Resistance

# Terminal Resistance Tuning Mode

Available in all control modes (V/f, V/f w. PG, Vector)

Inverter detects Terminal Resistance

- The Inverter applies a DC voltage to the motor and detects the resulting current.
- Terminal Resistance can be calculated easily.
- Motor does not rotate in terminal resistance tuning mode.

Result:

- By knowing the resistance the motor internal voltage drop and motor temperature influence can be compensated.
- When using long motor cables, the voltage drop at the cable resistance can be compensated by the inverter.

# Rotating Auto Tuning

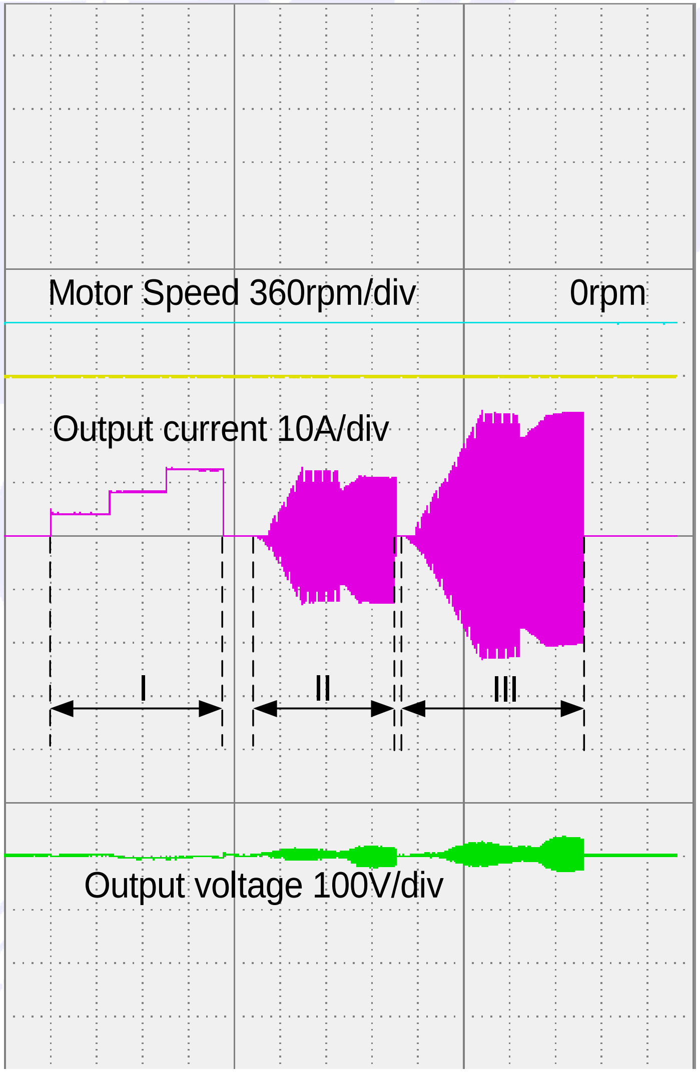
- Available in Open Loop Vector and in Close Loop Vector mode
- Inverter determines
  - Terminal Resistance,
  - Leakage Inductance
  - No Load Current
  - Core Saturation Coefficient
  - Rated Slip Frequency
- Result:
  - By knowing the exact motor equivalent data the inverter can calculate the $I_d$ and $I_q$ values very accurate.
  - Maximum speed and torque accuracy can be achieved.
- The motor is rotating while auto tuning with 80% of nominal speed
  - Not usable at applications, where load and motor can not get disconnected

# Non Rotating Auto Tuning

Available in Open Loop Vector and Closed Loop Vector mode

- 1.) Non rotating part
  - Terminal resistance, leakage inductance
  - The values for no load current and motor rated slip are taken from an inverter internal motor data table (based on Yaskawa standard motors).
- 2.)Test mode
  - First run of the motor with min. 30% of rated speed. Speed agree must be detected.
  - Real values of No Load Current and Rated Slip are detected during test mode. Low load during test mode gives the most accurate result.
- Result:
  - By knowing motor equivalent data $I_d$ and $I_q$ can be calculated very accurate.
- Advantage: Motor does not has to rotate while auto tuning. Therefore it is possible to use auto tuning with coupled load

# How Non Rotating Auto Tuning Works




I The inverter applies DC voltage to the motor, detects the resulting current and calculates the terminal resistance.

II First 50% of motor rated current with 15Hz is applied to the motor, after that 50% of rated current with 30 Hz is applied to the motor. Leakage inductance is detected while this procedure.

III Step II is repeated with 100% of motor rated current.

**Phase voltages while step II and III:**

$$V_U = -\tfrac{1}{2} V_W$$

$$V_V = -\tfrac{1}{2} V_W$$

(phase angle is the same in all 3 phases)

**Hence the motor does not rotate.**

# Different Control Modes

YASKAWA

## V/f

**The motor has to follow the V/F pattern of the inverter**

## Voltage Vector Control VVC: (not at Yaskawa)

**There is no feed back from motor to the inverter, but the motor get full voltage. Therefore the motor must follow the inverter**

## Open Loop Vector Control OLV:

**Internal current feed back. The inverter calculates cos $\varphi$ , $I_d$ and $I_q$ for optimal magnetising.**

## Closed Loop Vector Control:

**Pulse Generator and PG-card is needed.**

**The inverter knows the real motor speed. Through internal current feed back and PG feed back the inverter can calculate the current in magnitude and direction which is needed in order to have a optimised operation.**

# Summary for Auto Tuning:

In case that there is no problem to disconnect the load it is recommended to use rotating auto tuning. It is more accurate.

The Non Rotating Auto Tuning gives us the opportunity to use Vector Control with a very high performance even at applications, where an auto tuning was not possible in the past.

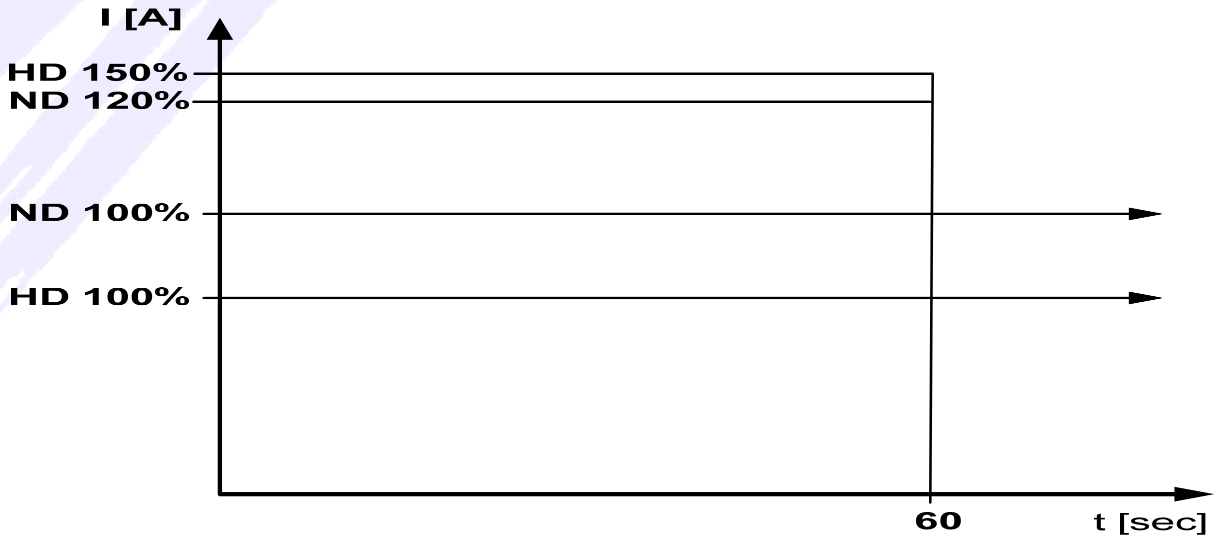
Examples:

- Centrifuges
- Industrial Washing Machines
- Applications with Gear Motors
- Lifts

# Dual Rating

**Yaskawa inverter 1000 series have dual rating**
**It is selectable by parameter C6-01. The carrier frequency changes together with with C6-01 settings. (Depends which type)**

- **Normal Duty (ND) 120% overload capability for 60 sec**
- **Heavy Duty (HD) 150% overload capability for 60 sec**

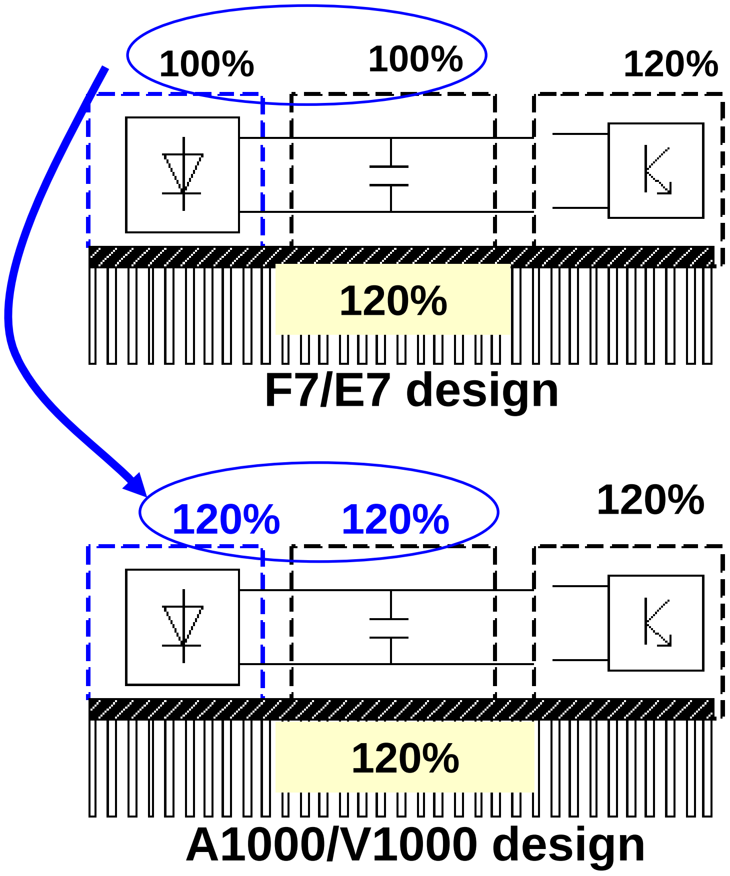


# Dual Current Ratings I

Each Drive has 2 current ratings:

- Heavy Duty (default, like F7):
  - nominal output current
  - 150% overload for 1 minute
  - 2 kHz carrier frequency as default (fixed)
  - high starting torque

- Normal Duty:
  - higher output current
    motor size one frame size bigger
  - 120% overload for 1 minute
  - 2kHz swing PWM (low noise)




➔ Up to one frame size smaller drive possible
for Normal Duty applications

# Handling 1000 Series Digital Operator

YASKAWA

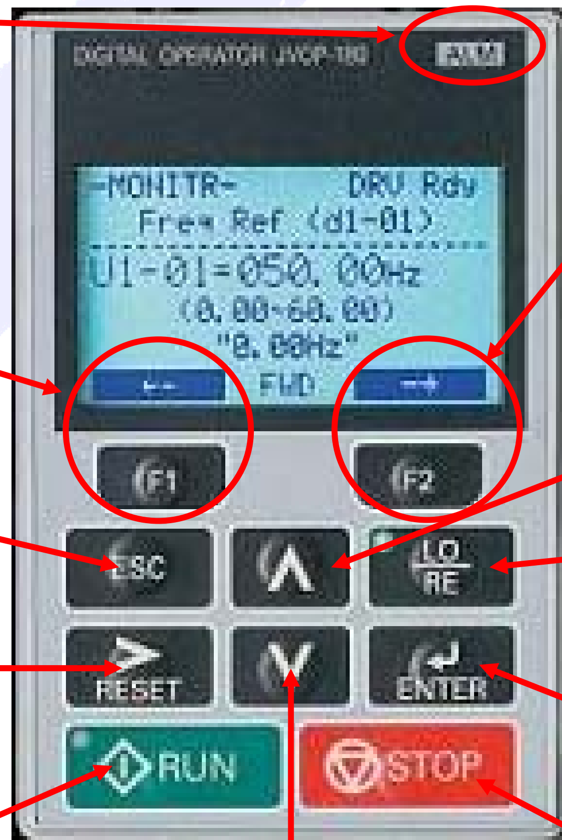
On when inverter is tripped

Display tells the function of this key (here one step left)

Close without saving

One digit right or reset after fault message

Start the drive




Display tells the function of this key (here one step right)

One step up or one number higher

Select local or remote operation

Open or save the parameter

Stop the drive

One step down or one number lower

# Menu Tree

YASKAWA

**Drive Mode**

Inverter can be operated and status can be displayed

| | |
|---|---|
| U1 | Status Monitor Constants |
| U2 | Fault Trace |
| U3 | Fault History |

**Quick Programming Mode**

Minimum required constants can be set or monitored

**Advanced Programming Mode**

All constants can be set or monitored

| | |
|---|---|
| A1-A2 | Setup Settings |
| b1-b8 | Application Constants |
| c1-c6 | Tuning Constants |
| d1-d6 | Reference Constants |
| E1-E4 | Motor Constants |
| F1/F6 | Option Card Constants |
| H1-H6 | Terminal Function Con. |
| L1-L8 | Protection Function Con. |
| n1-n3 | Special Adjustments |
| o1-o3 | Digital Operator Constants |

**Verify Mode**

Constants changed from factory setting can be monitored

**Auto Tuning Mode**

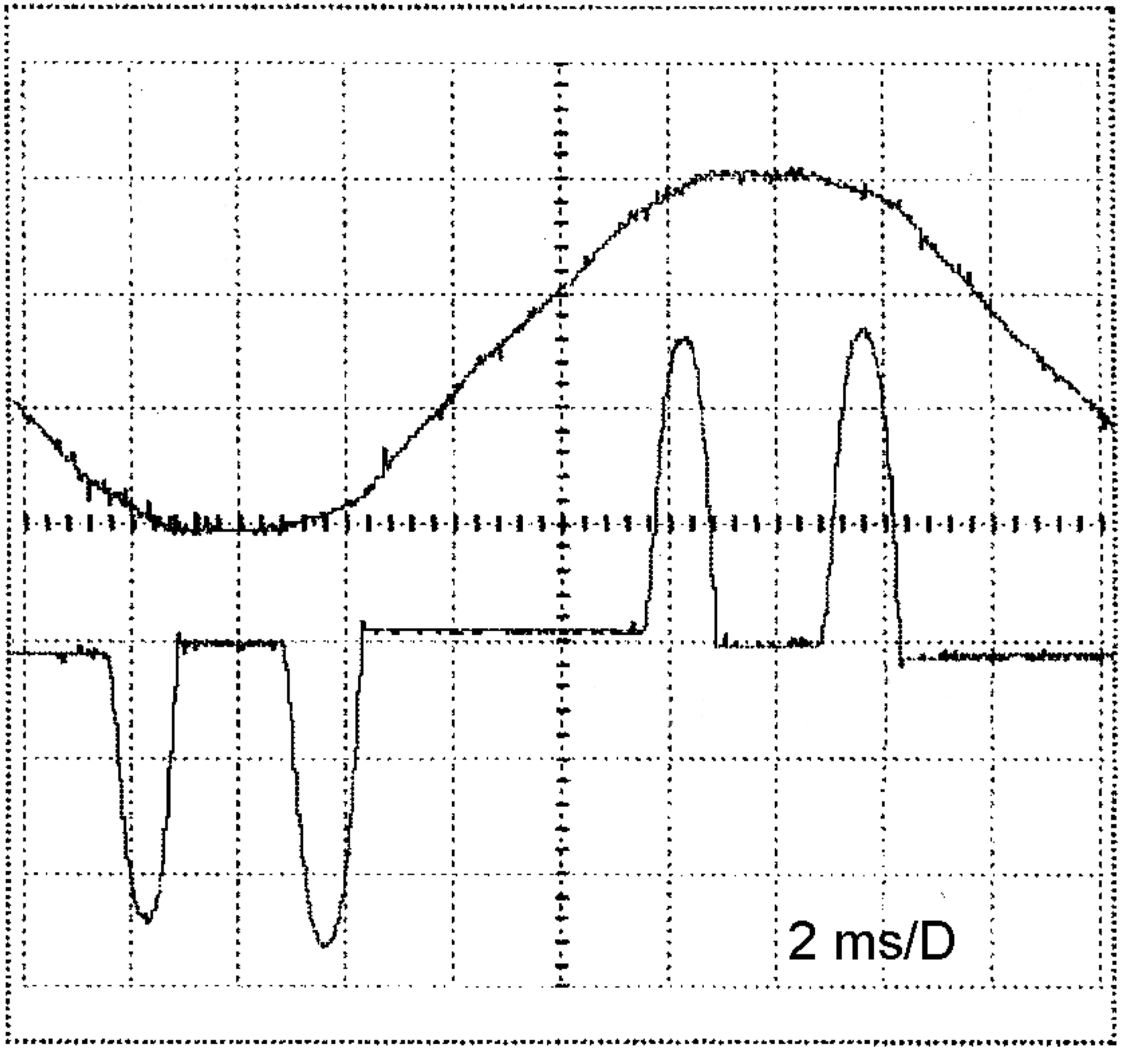
Automatically sets motor constants

| | |
|---|---|
| T1 | Motor Auto-Tuning |

# Input Voltage and Current

Voltage

Current 80% THD



# Total Harmonic Distortion (THD)

YASKAWA

There are 4 possible ways to reduce the Harmonic distortion

Without countermesure there are 80 % THD

With AC reactor at input side there are 50 % THD (max 25%)

With DC reactor at DC bus there are 50 % THD (max 25%)

With 12 pulse input there are 12 % THD

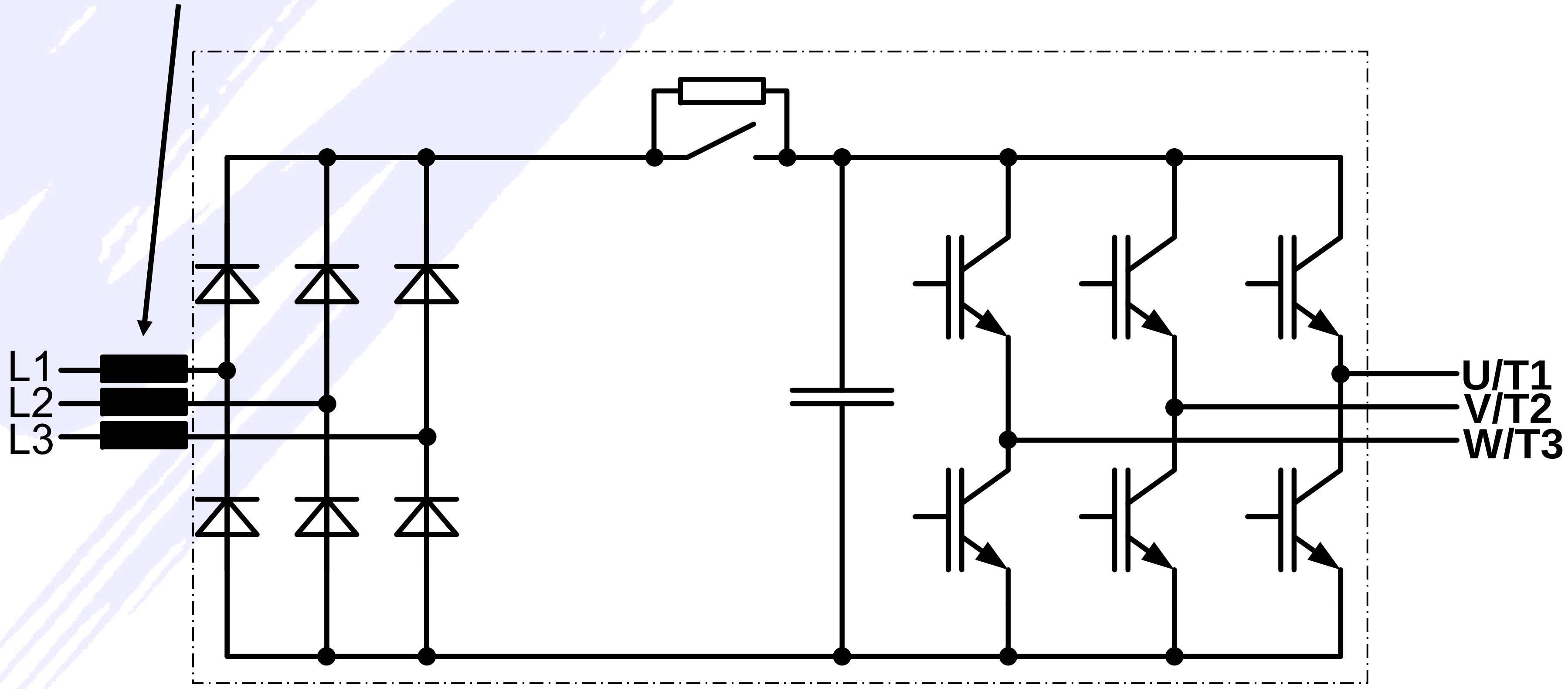
With active front end inverter there are 8 % THD

With Yaskawa Matrix Converter there are 6 % THD

# AC Reactor

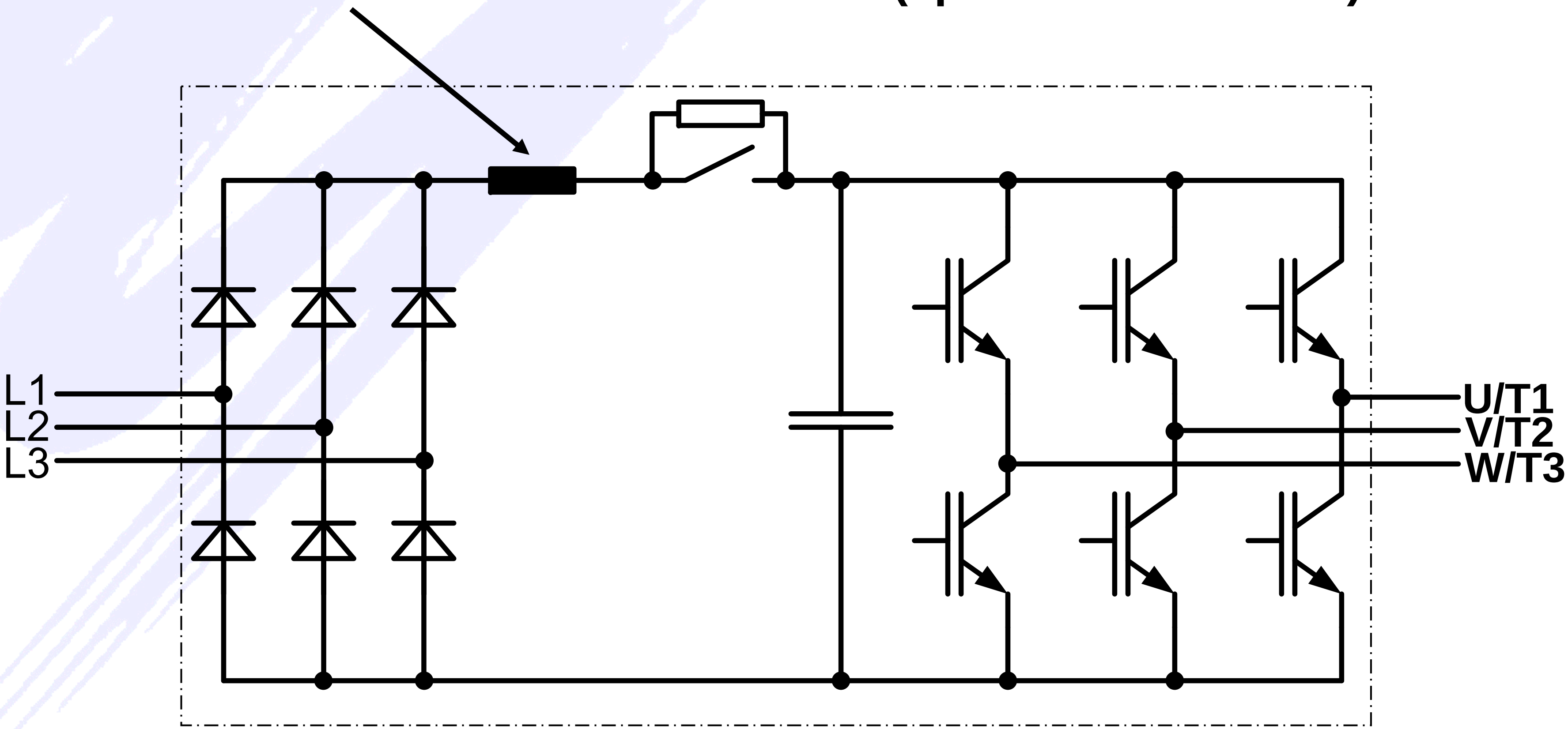
YASKAWA

AC reactor reduces THD to 50 % (special reactor 25%)



# DC Reactor

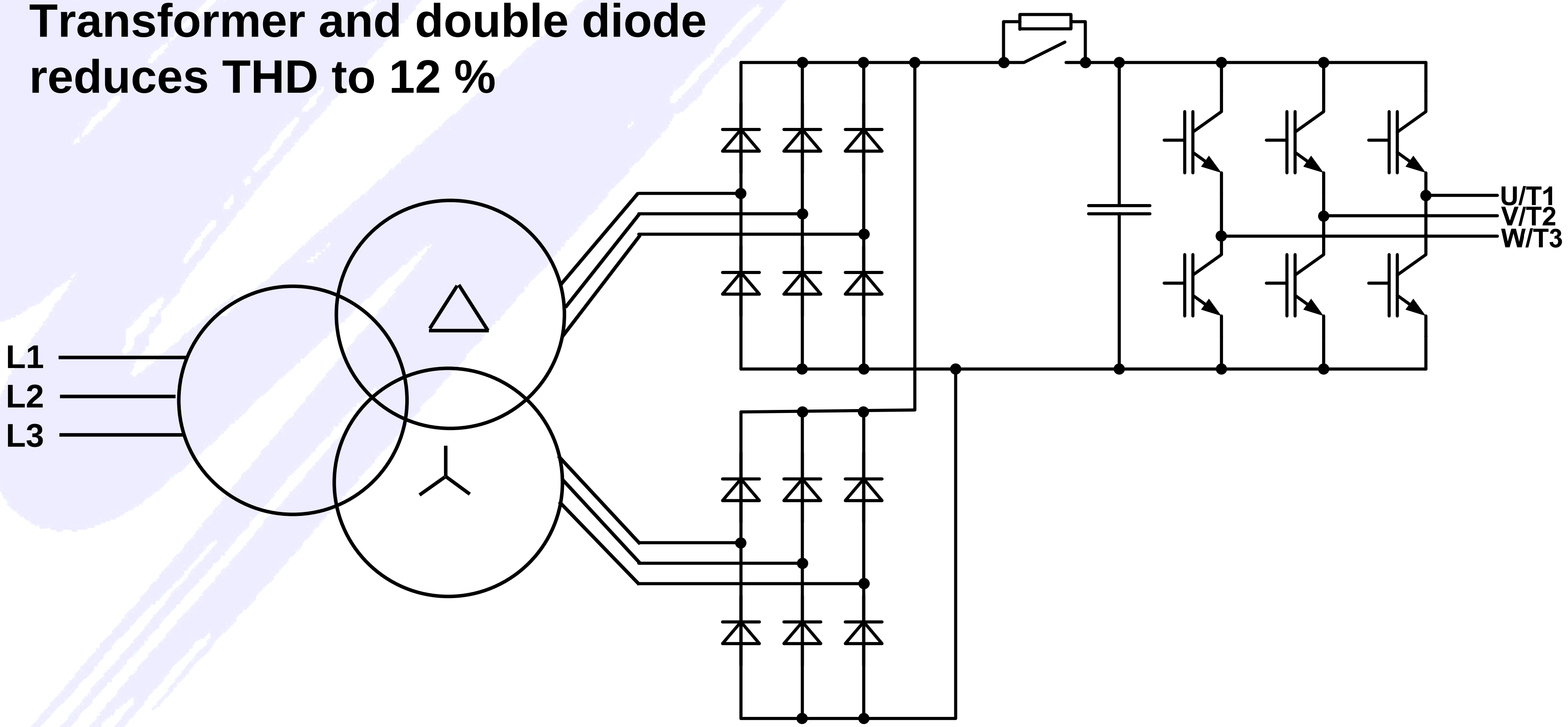
DC reactor reduces THD to 50 % (special reactor 25%)




**If the DC reactor is outside of inverter the risk of additional EMC problems is high.**

# 12 Pulse Input

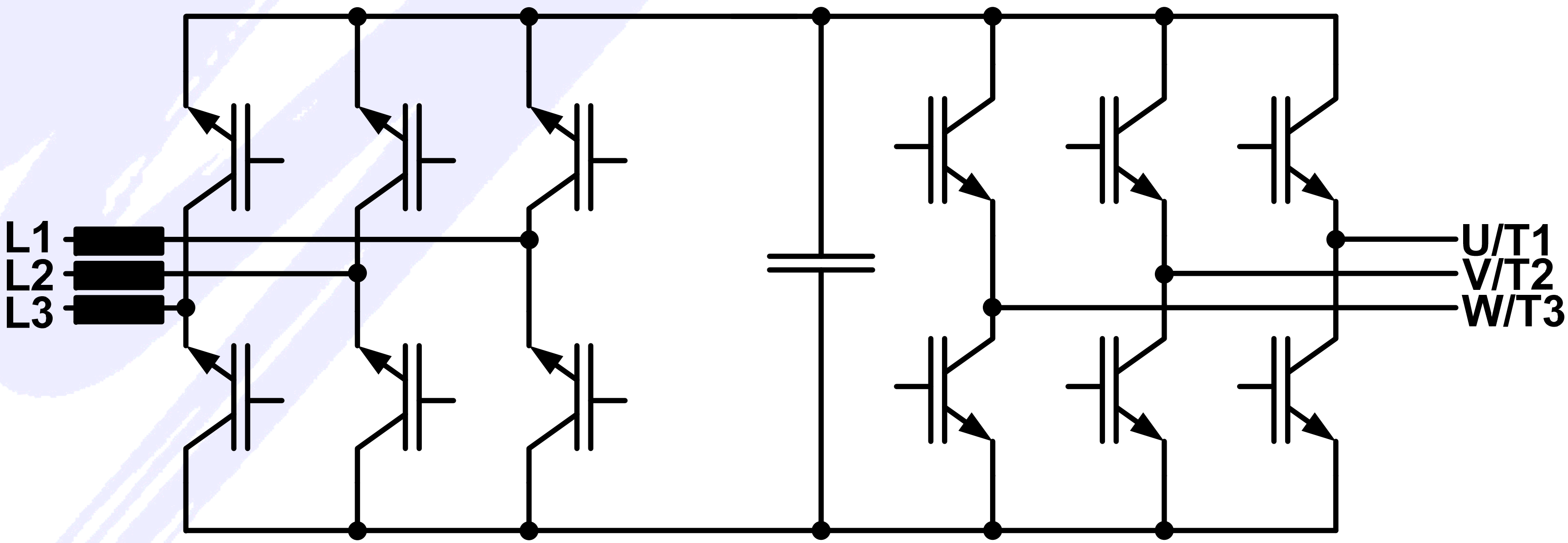
**Transformer and double diode reduces THD to 12 %**



# Active Front End Inverter

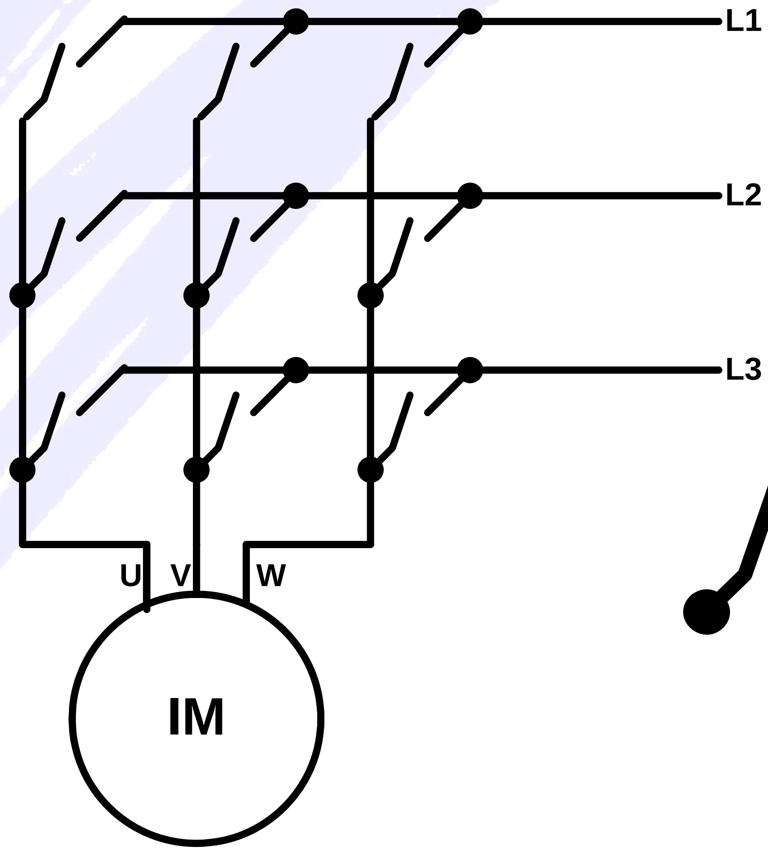
YASKAWA

## Active front end reduces THD to 8 %

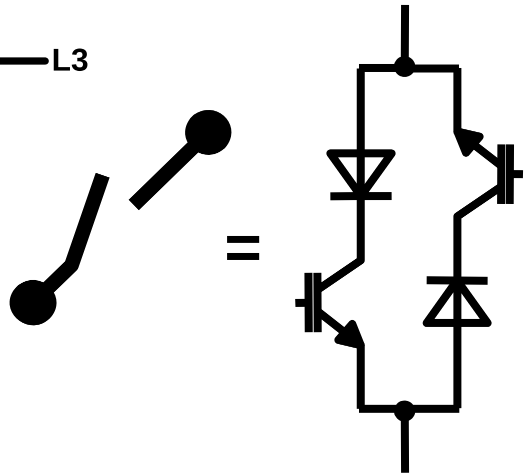


# Matrix Converter

Matrix Converter have only 6 % THD

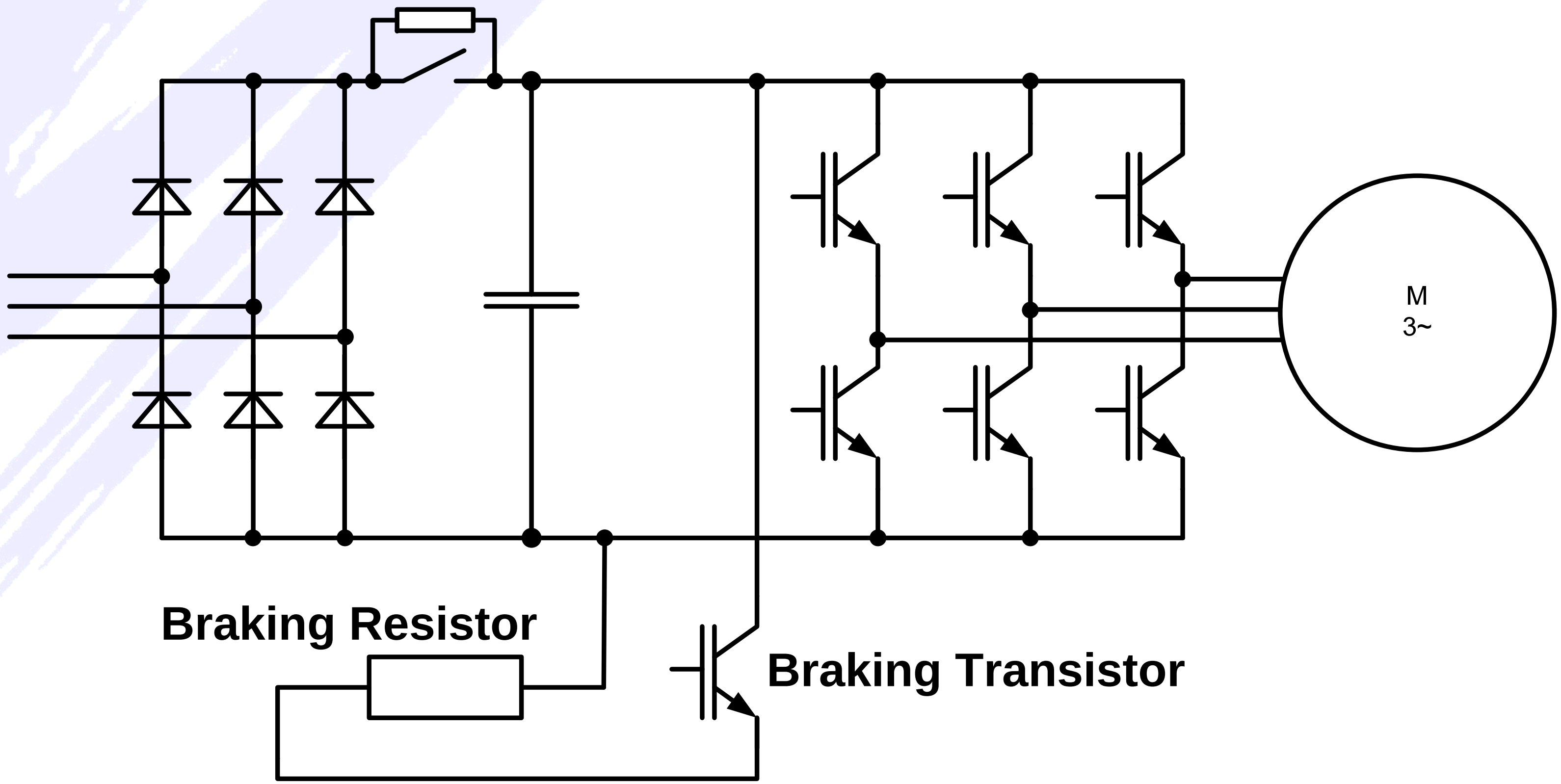



Each switch consists of 2 IGBTs with diodes



# Braking

In case of regenerative operation the energy will be given back to the inverter. To protect the capacitors against high voltage and to shorten the braking time a braking transistor and a braking resistor is needed.



# Braking

Braking resistors have the disadvantage that they generate heat. The regenerated energy can not be used for others.

Matrix converters or active front end inverters have the possibility to bring the regenerated energy back to main power supply.

Braking without braking resistor is possible with High Slip Braking or Overexitation Braking. The braking torque with braking resistors is higher.