High power electrical drive systems

Solution guide

- low voltage and medium voltage solutions
- powers of over 100 kW
- asynchronous cage motors
Electrical drive systems in industry and infrastructures

Electrical drive systems are widely used in industry, the tertiary sector and infrastructures.

The types of motors and drives vary considerably and rotary machine powers range from a few to several thousand kW.

This Solutions Guide is intended to present Schneider Electric’s low and medium voltage solutions for typical drive systems, limiting its scope to powers of over 100 kW and asynchronous cage motors.

Document objectives

This guide has the following objectives:

- providing basic knowledge to guide drive solution selection,
- positioning the various solutions,
- guiding towards the most appropriate solution.

Applications covered by this guide

The above diagram shows the applications covered by this guide in terms of power/speed and voltage.

In particular we will look at:

- applications and mechanical loads,
- various starting modes: direct, reduced voltage, variable speed drive
- the equipment used in each solution:
  - the electric motor,
  - electromechanical and electronic equipment used for starting and control.
Expertise in interconnecting the electrical and mechanical world

The choice of a global drive system solution results from the following considerations:

- mechanical criteria such as torque, speed, cycle repetitiveness, speed rise time, etc.,
- electrical network characteristics: voltage, frequency, short circuit power,
- environmental constraints: dimensions, temperature, humidity, standards, etc.

The technical solution must conform to the required operating and performance levels of the driven machine, have a non-disturbing connection to the network, and must satisfy economic objectives in terms of investment, operating and maintenance costs.
**Panorama of solutions**

**Direct motor feeders**

### Disconnecting and short-circuit protection

**Low voltage**
- GS1 or Compact NS

**Medium voltage**
- Motorpact FVNR or MCset contactor

### Control

**Low voltage**
- LC1 F or V or CV1, CV3, LC1 B

**Medium voltage**
- SM6 or MCset contactor

### Relay

**Low voltage**
- LR9 F or LT6 or TesysU

**Medium voltage**
- Sepam

### Specifications

<table>
<thead>
<tr>
<th></th>
<th>Low voltage</th>
<th>Medium voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ue max</strong></td>
<td>400 - 690 V</td>
<td>3.3 - 7.2 kV</td>
</tr>
<tr>
<td><strong>P max</strong></td>
<td>900 kW (1)</td>
<td>4000 kW</td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td>–</td>
<td>■</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>–</td>
<td>Modbus</td>
</tr>
<tr>
<td><strong>User-machine dialog</strong></td>
<td>■</td>
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</tr>
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<td>■ operation</td>
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</tr>
<tr>
<td>■ diagnosis</td>
<td>–</td>
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</tr>
<tr>
<td>■ event logging</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>■ disturbance recording</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

(1) P limited to 800 kW for a combined circuit breaker-contactor with coordination.

When the control frequency is low, we can use a single-device solution for disconnecting and control: Compact NS250 to NS800 circuit breaker, equipped with a Micrologic electronic control unit.
**Progressive motor feeders**

### Star - Delta

| GS1 or Compact NS | LC1 F or LC1 B | LR9- or LT6 or TesysU controller |

### LV soft starter

| Compact NS |

### MV soft starter

| Motorpact RVSS (Softstart™) |

### MV Autotransfo.

| Motorpact RVAT |

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<table>
<thead>
<tr>
<th>400 - 690 V</th>
<th>400 - 690 V</th>
<th>3.3 - 7.2 kV</th>
<th>3.3–7.2-kV</th>
<th>2.3–</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 kW–(1)</td>
<td>1200 kW–(2)</td>
<td>4000 kW-</td>
<td>4000 kW</td>
<td>2200 kW</td>
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<tr>
<td>Modbus</td>
<td>Modbus</td>
<td>Modbus</td>
<td>Modbus</td>
<td>Modbus</td>
</tr>
</tbody>
</table>

*(2) P limited to 950 kW for a combined circuit breaker-contactor with coordination.*

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Schneider Electric - Electrical Drive Systems Solution Guide
Motor feeders with **speed variation**

*Low voltage*

ATV 38/68/71/78

- 400 - 690 V
- 1500 kW
- Modbus/Ethernet
Asynchronous motors

An asynchronous motor comprises a stator (fixed part) and a rotor (rotary part). It is an induction machine, in other words the currents in the rotor are induced by the rotary flow generated in the stator.

There are two possible technologies:

- **the so called squirrel cage asynchronous motor**
  - In this type of motor, the rotor windings are designed to be in short circuit.
  - The rotor currents are only induced currents.

- **the wound rotor asynchronous motor**
  - In this type of motor, the rotor windings are accessible on rings. The currents induced in the rotor can be adjusted using variable resistors placed outside of the motor.
  - The squirrel cage asynchronous motor is more widely used and we will only look at this one in this document.

### Asynchronous cage motors

In this type of motor, the power consumed in the stator is transformed into:

- power transmitted to the rotor which will be used to provide the effective mechanical power
- power dissipated in the form of losses due to the motor's design and its usage mode:
  - Joule losses,
  - iron losses,
  - mechanical losses,
  - losses due to ventilation.

The motor's efficiency is the ratio between the effective mechanical power and the power consumption.

In addition, the energy absorbed in the stator is split into:

- active energy used to produce the torque (active current),
- reactive energy which is used to magnetize the rotor (reactive current).

The phase angle between the active current and the reactive current defines the motor's power factor ($\cos \phi$).

### Asynchronous motor operating curves

The torque characteristics of an asynchronous motor are based on 3 intrinsic values:

- the starting torque $C_{d}$,
- the maximum torque $C_{\text{max}}$,
- the nominal torque $C_{n}$.

During the starting phase, the torque varies as shown in the graph opposite.

The driven mechanism has a resistive torque and, amongst other considerations, its motion is determined by the following condition:

$$C_{\text{motor}} > C_{\text{resistive}}$$

The difference between the motor torque and the resistive torque is the acceleration torque.

### Asynchronous motor characteristics

The asynchronous motor is characterized by:

- electrical parameters,
- mechanical parameters,
- thermal parameters.

Knowing these parameters allows us to calculate and select the appropriate motor every time we are looking for a drive system solution.

*These parameters are listed in appendix 1.*
Low and medium voltage solutions

Over 100 kW, we can use both LV and MV motors. The power of low voltage motors is limited by the magnitude of the current, which becomes high as power increases: sizing the motor, the switchgear, cables, etc.

Example: a 1500 kW motor at 690 V draws around 1500 A in steady state.

Low voltage motors
LV motors are single-phase (for low powers) or three-phase motors, supplied power at voltages of between 220 and 690 V.
Up to 355 mm shaft height (i.e. around 200 kW for a 2-pole motor and 300 kW for a 4-pole motor), these motors are grouped into standard ranges from an electrical and mechanical point of view.

Medium voltage motors
MV motors are generally three-phase and are supplied power at voltages of between 2.2 kV and 13.8 kV.
There is no real standard, each manufacturer offers his own ranges of motors.

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The choice between LV and MV solutions
Choosing between an LV and an MV solution depends on:
- the geographical zones (customers, standards); in IEC-influenced zones the trend is to go as high as possible using LV solutions, whereas in NEMA influenced zones, the trend is to go as low as possible using MV solutions,
- specific habits in a sector (oil, chemicals, etc.),
- the presence of skilled or unskilled staff,
- implementation of control equipment,
- availability of the solution in LV and/or MV,
- economic criteria.

The choice between an LV and MV solution is the result of considering many other criteria explained below in this guide.
Choosing an electrical motor and its starting system must take account of constraints imposed by various phenomena and result in a technical solution that is in conformity with the operating and performance requirements of the driven mechanical system. The choice must satisfy economic objectives in terms of investment, operating and maintenance costs.

To engineer and design a global drive system solution, we have to take account of certain aspects that have an impact on our choice.

The electrical network
The choice of components must take account of the electrical network characteristics:
- voltage, frequency,
- short circuit power,
- existing harmonics levels,
- disturbance level (voltage drops, micro-outage, lightning, etc.).

Starting mode
The motor starting mode, a prime factor for correct operation, must take into account:
- the starting current,
- the available torque during the starting phase,
- the repetitiveness of starting operations over time,
- the starting time.
The starting mode must take into account:
- the acceptable thermal stresses for the motor,
- the acceptable mechanical stresses for the motor, the coupling system and the driven load.

Application and mechanical load
Application: grinding, laminating, ventilation…, is the action on the product to be processed (see diagram opposite). The mechanical load strain causes a reaction in the motor and therefore on the electrical network i.e.:
- varying the load torque leads to a variation in the motor current,
- the inertia of the motor and the load influence the starting time,
- the rotary speed of the load can require adjustment of the motor speed,
- etc.

Process-related constraints
The application is often part of a global process. The processes are characterized by performance criteria:
- speed of execution,
- repetitiveness of cycles,
- precision.
Satisfying these criteria will influence the design requirements for the motor and its drive system.

Environmental constraints
Lastly, we need to know the environmental constraints:
- ambient temperature,
- dust,
- type of atmosphere (explosive gases, etc.),
- altitude,
- hygrometry,
- vibration and impact, …
**Starting modes**

**Direct starting**

This is the simplest and most economical starting mode if:
- the load allows a high starting torque,
- the network allows a starting current of up to 10 times the rated current.

It is best suited to starting:
- low power motors,
- low inertia machines.

**Specificities**

**Electrical network**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting current</td>
<td>5 to 10 x In</td>
</tr>
<tr>
<td>Voltage drop</td>
<td>High (depends on network Psc)</td>
</tr>
<tr>
<td>Harmonic disturbance</td>
<td>High during starting, zero in steady state</td>
</tr>
<tr>
<td>Power factor</td>
<td>Low during starting</td>
</tr>
<tr>
<td>Controlled electrical consumption</td>
<td>No</td>
</tr>
</tbody>
</table>

**Motor**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of successive starting operations</td>
<td>Limited</td>
</tr>
<tr>
<td>Available torque</td>
<td>Maximum (abrupt starting)</td>
</tr>
<tr>
<td>Thermal stress</td>
<td>Very high (rotor)</td>
</tr>
<tr>
<td>Protection device calibration</td>
<td>Depends on manufacturer data</td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

**Mechanical load**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupling stress</td>
<td>Very high</td>
</tr>
<tr>
<td>Suitable load types</td>
<td>Low inertia load</td>
</tr>
<tr>
<td>Critical speed</td>
<td>No impact</td>
</tr>
<tr>
<td>Pulsing torque</td>
<td>No impact</td>
</tr>
<tr>
<td>High inertia starting</td>
<td>Special motor design</td>
</tr>
</tbody>
</table>

**Process**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed control</td>
<td>No</td>
</tr>
<tr>
<td>Performance</td>
<td>On/off operation</td>
</tr>
<tr>
<td>Reliability/Availability</td>
<td>High</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Good</td>
</tr>
<tr>
<td>User-machine dialog</td>
<td>Simple operation. Possibility of a digital UMI and communication network</td>
</tr>
</tbody>
</table>
**Electrical drive system engineering**

**Starting modes**

**Star-delta starting**

A simple and economical starting mode if:
- the load allows a starting torque of 1/3 nominal torque,
- the network allows an overcurrent on changing the bus connection.

It is particularly suited:
- to starting low power LV motors < 150 kW,
- to low inertia loads which therefore have a quadratic torque type (e.g.: centrifuge pumps).

**Specificities**

**Electrical network**

- Starting current: 2 to 3 x In
- Voltage drop: High when changing above connecting
- Harmonic disturbance: High when starting, zero in steady state
- Power factor: Reduced during starting
- Controlled electrical consumption: No

**Motor**

- Number of successive starting operations: 2 to 3 times higher than direct mode
- Available torque: 3 times less during starting
- Thermal stress: Less than direct mode
- Protection device calibration: Depends on manufacturer data
- Others

**Mechanical load**

- Coupling stress: Lower than direct mode
- Suitable load types: Pumps, fans, compressors
- Critical speed: No impact
- Pulsing torque: No impact
- High inertia starting: No

**Process**

- Speed control: No
- Performance: On/off operation
- Reliability/Availability: Good
- Maintainability: Good
- User-machine dialog: Simple operation. Possibility of digital UMI and network communication
Starting modes
Autotransformer starting

This starting mode is used particularly:
- in LV for powers > 150 kW,
- in MV.

It is best suited:
- to starting high power motors,
- for low inertia mechanisms whose torque characteristics can withstand a drop in motor torque of between 0.4 and 0.85 of the motor Cd.

Specificities

**Electrical network**
- Starting current: \( k \times I_d \) (\( k \) = transformation ratio)
- Voltage drop: Low
- Harmonic disturbance: Low
- Power factor: Reduced during the transient phase
- Controlled electrical consumption: No

**Motor**
- Number of successive starting operations: 2 to 3 times higher than direct mode
- Available torque: \( k^2 \times Cd \) (0.4 to 0.85 \( Cd \))
- Thermal stress: Lower than direct mode
- Protection device calibration: Depends on manufacturer data

**Mechanical load**
- Coupling stress: Lower than direct mode
- Suitable load types: Depends on the inertia and torque profile
- Critical speed: No impact
- Pulsing torque: No impact
- High inertia starting: No

**Process**
- Speed control: No
- Performance: On/off operation
- Reliability/Availability: Good
- Maintainability: Good
- User-machine dialog: Digital protection and control relay, with a UMI and a communication network
Starting modes
Soft starter starting

A high performance starting mode enabling gentle starting and stopping. It can be used:
- with current limitation: the current is set at a value of 3 to 4 x In during the starting phase, the starting torque is therefore limited. This mode is particularly suited to “turbomachines” (centrifuge pumps, fans, etc.)
- with torque regulation: the torque performance level is optimized. This mode is more particularly suited to centrifuge pumps and constant torque machines, or machines with a high resistive torque when starting.

Specificities

Electrical network
- Starting current: Depends on the control mode
- Voltage drop: Limited
- Harmonic disturbance: High during starting
- Power factor: Reduced during starting
- Controlled electrical consumption: No

Motor
- Number of successive starting operations: Considerably increased
- Available torque: Depends on the control mode and on the level of current limitation
- Thermal stress: Reduced
- Protection device calibration: Depends on manufacturer data
- Others

Mechanical load
- Coupling stress: Limited
- Suitable load types: Depends on the control mode
- Critical speed: No impact
- Pulsing torque: No impact
- High inertia starting: Yes with torque regulation

Process
- Speed control: No
- Performance: Very good
- Reliability/Availability: Good
- Maintainability: Very good - integrated diagnosis and measurement tools
- User-machine dialog: Digital UMI and communication network
Starting modes
Speed variation using a frequency converter

A high performance starting mode used whenever it is necessary to control the speed. Amongst other things it enables:

- starting of high inertia loads,
- starting high loads on a low short circuit capability network,
- optimizing electrical power consumption according to speed on turbo machines.

Usable on all types of machines.

Specificities

**Electrical network**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting current</td>
<td>Limited according to the load (1.5 In)</td>
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<tr>
<td>Voltage drop</td>
<td>Very limited</td>
</tr>
<tr>
<td>Harmonic disturbance</td>
<td>Needs a filtering device</td>
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<tr>
<td>Power factor</td>
<td>&gt; 0.95 throughout the speed range</td>
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<tr>
<td>Controlled electrical consumption</td>
<td>Yes</td>
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</tbody>
</table>

**Motor**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of successive starting operations</td>
<td>Not limited</td>
</tr>
<tr>
<td>Available torque</td>
<td>Adjustable up to 1.5 to 2 Cn</td>
</tr>
<tr>
<td>Thermal stress</td>
<td>Very limited</td>
</tr>
<tr>
<td>Protection device calibration</td>
<td>Depends on manufacturer’s data</td>
</tr>
<tr>
<td>Others</td>
<td>Motor-converter distance &lt; 50 m</td>
</tr>
</tbody>
</table>

**Mechanical load**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coupling stress</td>
<td>Very limited</td>
</tr>
<tr>
<td>Suitable load types</td>
<td>All</td>
</tr>
<tr>
<td>Critical speed</td>
<td>Can be concealed</td>
</tr>
<tr>
<td>Pulsing torque</td>
<td>Requires a shaft study for very high powers</td>
</tr>
<tr>
<td>High inertia starting</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Process**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed control</td>
<td>Yes</td>
</tr>
<tr>
<td>Performance</td>
<td>High – depends on the regulation mode</td>
</tr>
<tr>
<td>Reliability/Availability</td>
<td>Good (can be improved by redundant systems)</td>
</tr>
<tr>
<td>Maintainability</td>
<td>Very good – integrated diagnosis and measurement tools</td>
</tr>
<tr>
<td>User-machine dialog</td>
<td>Digital UMI and communication network</td>
</tr>
</tbody>
</table>
Applications and mechanical loads

In order to determine the best drive system solution, we have to:
- identify mechanical parameters,
- identify expected performance levels,
- characterize the mechanical transfer chain.

Mechanical parameters

Inertia
This increases with the mass of the load and opposes a change in motion. It is characterized by the moment of inertia $J$, which is expressed in kg$m^2$.

Torque
This defines the force that the mechanical load opposes to maintain its motion. It is expressed in Newton meters (Nm). Each type of mechanism can be categorized according to its torque/speed characteristic (see graphs on the following page):
- constant torque,
- linear torque,
- quadratic torque...

The initial torque and transient torque values are parameters to be identified for the correct drive system design.

Speed
This qualifies the movement of a load with a certain inertia that is subject to torque. For electric motors, it is expressed in revolutions per minute (Rev/min).

Expected performance levels

These are generally constraints of the application and process which set the drive system performance level. They concern the torque and speed parameters for the load and are characterized by:
- static precision: the difference between the value expected by the process and the actual value of these parameters in steady state.
- dynamic precision: the difference between the value expected by the process and the actual value of these parameters in transient state.
- response time: the time taken for the drive system to stabilize these parameters to steady state following a transient state.

The mechanical transfer chain

The coupling of the motor shaft to the driven mechanism can be:
- direct,
- via a speed step-up or step-down gear system:
  - pulley - belt,
  - cogs - chain,
  - coupling device...

This transfer chain has an impact on the transfer of inertia and torque between the load and the motor. In addition it penalizes the global efficiency of the drive system.

The notion of quadrants

This notion allows us to identify the load’s operating mode. It is shown in the torque-speed chart opposite.

Amongst other things, it allows us to differentiate between resistive loads (opposed to the movement) and driving loads (which encourage the movement). Operation in all 4 quadrants is required for applications with energy recovery.
# Applications and mechanical loads

The table below gives an overview of the various machines concerned by this document. It only shows machines equipped with motors likely to have a power of over 100 kW. Centrifuge pumps, fans and centrifuge compressors (turbo-machines) represent over 70% of applications.

Key:
- **torque laws:** see curves opposite.
- **indicated speed range:** average ratio between the minimum speed and the maximum speed (when using a variable speed drive).
- **columns Q1 to Q4:** operating in these quadrants.
- **columns LV and MV:** showing the feasibility in one or other of the voltage ranges: low voltage or medium voltage.

![Torque-Speed Graph](image)

<table>
<thead>
<tr>
<th>Machine types</th>
<th>Business sectors</th>
<th>Laws</th>
<th>Speed ranges</th>
<th>Power in kW</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>LV</th>
<th>MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conveyors</td>
<td>Cement - Quarries - Agri-food</td>
<td>C</td>
<td>1 to 10</td>
<td>0.37 to 500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Rotary</td>
<td>Printing</td>
<td>C</td>
<td>1 to 10</td>
<td>10 to &gt; 200</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Volumetric and dispensing pumps</td>
<td>Chemicals - Pharmaceuticals - Agri-food</td>
<td>C</td>
<td>1 to 10</td>
<td>0.37 to 200</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Centrifuge pumps</td>
<td>Water - Chemicals - Agri-food</td>
<td>kN²</td>
<td>1 to 5</td>
<td>0.37 to 5000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Two-phase pumps</td>
<td>Oil - Gas</td>
<td>kN²</td>
<td>1 to 5</td>
<td>200 to 2000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Fans</td>
<td>HVAC - Ovens - Infrastructures</td>
<td>kN²</td>
<td>1 to 5</td>
<td>0.1 to 1500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Blowers</td>
<td>Test rigs</td>
<td>kN²</td>
<td>1 to 10</td>
<td>2.2 to 50-000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Compressors</td>
<td>Gas - Petrochemicals</td>
<td>kN²</td>
<td>1 to 10</td>
<td>2.2 to 50-000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Ovens</td>
<td>Cement</td>
<td>C</td>
<td>1 to 10</td>
<td>100 to 1500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Extruders</td>
<td>Petrochemicals - Plastics - Agri-food</td>
<td>C-P</td>
<td>1 to 10</td>
<td>10 to 2500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Mechanical presses</td>
<td>Engineering - Automotive</td>
<td>C</td>
<td>1 to 10</td>
<td>50 to 700</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Winder - unwinder</td>
<td>Iron and steel - Paper</td>
<td>C-P</td>
<td>1 to 20</td>
<td>3 to 300</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Pulp making machines</td>
<td>Paper</td>
<td>C</td>
<td>1 to 10</td>
<td>500 to 2000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Sectional machines</td>
<td>Iron and steel - Paper</td>
<td>C</td>
<td>1 to 10</td>
<td>10 to 700</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Test rigs</td>
<td>Automotive - Aeronautical</td>
<td>C-P</td>
<td>1 to 100</td>
<td>10 to 500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Grinding machines</td>
<td>Cement - Quarries - Agri-food</td>
<td>C</td>
<td>1 to 10</td>
<td>10 to 1000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Mixers</td>
<td>Chemicals - Pharmaceuticals - kN Agri-food</td>
<td>1 to 5</td>
<td>30 to 300</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td></td>
</tr>
<tr>
<td>Kneaders</td>
<td>Chemicals - Rubber</td>
<td>C-P</td>
<td>1 to 10</td>
<td>&lt; 1000</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Centrifuge machines</td>
<td>Chemicals - Pharmaceuticals</td>
<td>kN²</td>
<td>1 to 10</td>
<td>10 to 200</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>Lifting machines</td>
<td>Buildings - Infrastructures</td>
<td>C</td>
<td>1 to 100</td>
<td>10 to 500</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
</tbody>
</table>

- **C** = Constant torque  
  - **kN²** = Quadratic torque  
  - **C-P** = Constant torque and constant power  
  - **kN** = Linear torque

Schneider Electric - Electrical Drive Systems Solution Guide
Applications and mechanical loads

Example: centrifuge pump

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power range</td>
<td>From 0.37 to 5000 kW</td>
</tr>
<tr>
<td>Voltage range</td>
<td>LV or MV according to the power</td>
</tr>
<tr>
<td>Speed range</td>
<td>From 1 to 10</td>
</tr>
<tr>
<td>Starting mode</td>
<td>Direct: Acceptable (possible ram effect)</td>
</tr>
<tr>
<td></td>
<td>Limited voltage: Possible</td>
</tr>
<tr>
<td></td>
<td>Soft starter: Good solution</td>
</tr>
<tr>
<td></td>
<td>Variable speed: Good solution</td>
</tr>
</tbody>
</table>

Specific features of centrifuge pumps

In a centrifuge pump:
- the flow rate is proportional to speed,
- the pressure is proportional to the square of the speed,
- the power is proportional to the cube of the speed.

Mechanical characteristics

Torque/Speed

Centrifuge pumps have one specific characteristic: the resistive torque varies proportionally to the square of the rotary speed (quadratic torque).
This means that at nominal speed $N_n$, the resistive torque is equal to the nominal torque $C_n$, and at $N_n/2$, $C_r = C_n/4$.
The resistive torque of the pump opposes the motor torque.
In addition, the direction of rotation of a centrifuge pump cannot be inverted.
Therefore this sort of machine operates in quadrant Q1.

Inertia

The inertia of a centrifuge pump can be considered low and with little impact on the speed rise time.

Operating mode

“On/off”
Most centrifuge pumps work permanently at constant speed and are started and stopped at regular intervals.

“Flow regulation”
Pressure or flow rate regulation of a pump can be achieved in two ways:
- traditionally using mechanical systems such as motorized valves or by-pass systems. These systems are called "Load loss" systems.
- A motorized valve enables the cross section of the pipe to be reduced from fully open to a degree of closure acceptable by the pump.
- One of the intrinsic characteristics of these pumps is that the flow rate is proportional to the rotary speed. Flow rate or pressure control can also be achieved by varying the pump speed.

Impact on the drive system solution

The choice of motor is directly related to the power consumed by the pump at its nominal operating point (flow rate – pressure) for a given network load curve. Generally, this power is set by the pump manufacturer.
The starting mode and sizing are determined by the type of network on which the pump is working (mains water, over-pressure, distribution, etc.) and depend in particular on the required performance levels in terms of pressure or flow rate regulation.
Applications and mechanical loads

Example: fan

<table>
<thead>
<tr>
<th>Torque (C)</th>
<th>Speed (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = kN²</td>
<td></td>
</tr>
</tbody>
</table>

- **Power range**: From 0.1 to 50-000 kW
- **Voltage range**: LV or MV according to the power
- **Speed range**: From 1 to 10
- **Starting mode**
  - Direct: Acceptable (possible mechanical stress)
  - Reduced voltage: Difficult if high inertia
  - Soft starter: Good solution
  - Variable speed: Good solution

**Specific features of centrifugal or helicoidal fans**

In a centrifugal or helicoidal fan:
- the flow rate is proportional to the speed,
- the pressure is proportional to the square of the speed,
- the power is proportional to the cube of the speed.

**Mechanical characteristics**

**Torque/Speed**

Fans have one specific characteristic: the resistive torque varies proportionally to the square of the rotary speed. This means that at nominal speed Nn, the resistive torque is equal to the nominal torque Cn and at Nn/2, Cr = Cn/4.

The fan’s resistive torque opposes the motor’s torque during acceleration phases. Through its inertia, the fan “drives” the motor during deceleration phases. The rotational direction of a fan is only rarely inverted. Therefore this sort of machine generally works in quadrants Q1 and Q2.

**Inertia**

According to the flow rate that they have been designed for, certain fans, and particularly helicoidal fans, have very high moments of inertia. This parameter has an impact on the speed rise time for the machine according to the power that is involved.

**Operating mode**

“On/off”

Most fans work permanently at constant speed and are started and stopped at regular intervals.

“Flow regulation”

Flow regulation for a fan can be achieved in two ways:
- traditionally using mechanical systems such as flaps and baffles. These systems are called “load loss systems”.
- one of the intrinsic characteristics of fans is that the flow rate is proportional to the rotary speed. Flow rate control can therefore be achieved by varying the fan speed.

**Impact on the drive system solution**

The choice of motor is directly related to the power consumed by the fan at its nominal operating point (flow rate – pressure) for a given load curve. Generally, this power is set by the fan manufacturer. The motor sizing will take into account the rotor inertia and the fan inertia. The Jr/Jv ratio must be greater than 1.

The starting mode and sizing are set by the type of system that the fan is working in (extraction, injection, circulation, etc.) and particularly by the performance levels required in terms of pressure or flow rate regulation.

Certain applications have to withstand high fluid temperature variations, which lead to significant load variations.
Applications and mechanical loads

Example: grinder

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power range</td>
<td>From 50 to 1000 kW</td>
</tr>
<tr>
<td>Voltage range</td>
<td>LV or MV according to the power</td>
</tr>
<tr>
<td>Speed range</td>
<td>From 1 to 10</td>
</tr>
<tr>
<td>Starting mode</td>
<td>Acceptable (high mechanical stress)</td>
</tr>
<tr>
<td>Direct</td>
<td>No</td>
</tr>
<tr>
<td>Reduced voltage</td>
<td>Possible</td>
</tr>
<tr>
<td>Soft starter</td>
<td>Good solution</td>
</tr>
<tr>
<td>Variable speed</td>
<td></td>
</tr>
</tbody>
</table>

Specific features of grinders

There are several types of grinders:
- blade/cutter grinders,
- roller/hammer grinders, …

They are generally part of a production line, whether in cement or agri-food industries. Their function is to produce processed material from unprocessed material, generally defined in terms of particle size criteria.

Mechanical characteristics

Torque/Speed

Grinders have one specific characteristic: the resistive torque is constant whatever the rotary speed. The resistive torque of a grinder opposes the motor torque during acceleration and deceleration phases. The rotary direction is virtually never inversed. Therefore this sort of machine operates in quadrant Q1. A specific feature of the torque is that the grinder starts under load in the starting phase (i.e. after a power cut). This initial torque can be 1.5 to 2 times the nominal torque. In addition, major transient torques can appear during operation.

Inertia

Depending on the type of grinder, inertia should be taken into consideration, especially for hammer grinders.

Operating mode

"On/off"

In quarries, mines and agri-food sectors, grinders generally work at constant speed. Considering the high torques that are involved, the mechanisms must be strong and have protective electrical and mechanical systems.

"Flow regulation"

Flow regulation for a grinder allows account to be taken of the loading and unloading throughputs. In addition, the operator can act directly on the product's particle size by varying the speed.

Impact on the drive system solution

The motor, and its starting system, must especially take account of initial and transient torques, which can be very high. This generally leads to over-design in terms of drive power. Speed variation gives a good compromise between starting under load and over-design, due to a higher available torque on starting.
**Applications and mechanical loads**

**Example: lifting machine**

<table>
<thead>
<tr>
<th>Power range</th>
<th>From 50 to 1000 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage range</td>
<td>LV</td>
</tr>
<tr>
<td>Speed range</td>
<td>From 1 to 100</td>
</tr>
<tr>
<td>Starting mode</td>
<td>(determined by the required performance levels)</td>
</tr>
<tr>
<td>Direct</td>
<td>Possible</td>
</tr>
<tr>
<td>Reduced voltage</td>
<td>Possible</td>
</tr>
<tr>
<td>Soft starter</td>
<td>Good solution</td>
</tr>
<tr>
<td>Variable speed</td>
<td>Good solution</td>
</tr>
</tbody>
</table>

**Specific features of lifting machines**

There are many different types of these machines:

- hoists, cranes, lifting beams, traveling cranes...
- lifts, elevators...

Their function is to move loads from level 1 to level 2. They are subject to very strict safety standards, even more restrictive when they involve moving people instead of material.

**Mechanical characteristics**

**Torque/Speed**

Lifting machines have one specific characteristic: the resistive torque is constant whatever the rotary speed. When lifting, the resistive torque opposes the motor torque. When lowering, the rotary direction is inversed and the load tends to drive the motor which has to hold the load in order to maintain a constant lowering speed. The motor becomes a generator.

Lifting machines work in four quadrants Q1, Q2, Q3 and Q4 depending on the operating phase.

**Inertia**

According to the type of lifting to be performed, inertia will have to be considered (winding drum diameter). However, it is frequent to use a mechanical gearing system, mounted between the motor and this drum in order to reduce inertia (which is then divided by the square of the gearing ratio).

**Operating mode**

The wide variety of these machines means that they involve all of the operating mode types:

- for a simple hoist, the operating mode is on/off,
- for an elevator used in an “automatic store”, will use a positioning function,
- for control of a container loading crane, we will use sophisticated regulation functions: position, indexing, slack-control, etc.

**Impact on the drive system solution**

Sizing in terms of power is closely related to the above mentioned mechanical characteristics. Over-design is the consequence of safety margins imposed by standards. The choice of starting mode depends on the performance levels required by the application.
Processes

Whether transitic, utilities or process applications, processes involve one or several standard or specific machines carrying out the identified operations, linked together according to a predefined scenario.

The process comprises the basic function, i.e.: grinding, mixing, lifting, pumping. Generally speaking this function involves the motion of a mechanism which transforms the energy that it receives into a very precise action on the processed product. This action is controlled in terms of intensity and time by the process control system.

Auxiliary functions are involved in order to carry out more complex operations, generally involving optimizing the basic function, and are activated according to various operating cycles. They therefore enhance the process performance and make it more flexible.

Example: in polyethylene pellet manufacture, the main function is an extrusion process. The necessary auxiliary functions include filling (loading the material) and pellet cutting (cutting the finished product at the extrusion die exit). The loading – extrusion – pellet cutting sequence represents the production process.

Process control is managed by an automation and monitoring system. Especially in continuous processes, process availability and productivity are closely related to the electrical power network quality: micro-outage, brown outs, voltage fluctuation, phase imbalance… Drive systems in these processes have to withstand these transient events within set limits. In certain cases, non-quality of the network may require us to opt for process control involving deteriorated mode operation or secure stoppages.
Characterizing the process
According to their complexity, the various processes involve precise operating modes. Whether controlling operations using on/off, flow, throughput, cycle, position, indexing or synchronization, this always involves an automatic control solution. The drive system used for each operation must meet the specific performance criteria for this operation.

Electronic speed variation in processes
Apart from on/off control, as soon as we look at more sophisticated processes, electronic speed variation becomes essential. Its performance levels give us the flexibility, precision, variability and repetitiveness that are needed by the process in which it is used.

The use of variable speed drives is said to be **structural** when related to machine performance. This is the case in production processes such as bottling lines, machining, assembly and sectional lines (e.g. paper, cardboard, iron and steel industry).

In **transitic** applications, other than its performance levels, speed variation is used for safety functions.

When **pumping** or **ventilation** applications are considered as stand-alone processes, speed variation is fully justified.

The advantages of electronic speed variation
This is the most sophisticated and highest performance solution for electrical motor starting and control systems. Frequency converters are now recognized as the best solution for asynchronous cage motors. Today, thanks to power electronics technologies and advances in digital techniques, this equipment meets the most advanced application's requirements. Electronic speed variation is a mature technical solution with industrial experience in a very wide range of applications (references). It gives:

- high reliability and availability,
- operating flexibility and high adaptability,
- natural integration in existing automatic control systems (digital interface),
- very sophisticated user-machine dialog:
  - integrated parameter setting and self-adjustment tool,
  - integrated diagnosis tool,
- easy and low cost maintenance.
Batch and continuous processes

**Processes**

Batch processes

As their name suggests, these processes comprise several machines, each carrying out a specific operation. The changing from one step to another involves storing or accumulating the product during the production process. Process control can be simple since each step is independent of the previous step.

Continuous processes

What differentiates a continuous process from a batch process is the fact that the phase between steps involves a transfer facility which takes account of the upstream step and the downstream step conditions. Whilst for batch processes we can assimilate the operating mode with an on/off type operation, at least concerning each step, in continuous processes process control must manage regulation and synchronization between the operations carried out at each step and the transfer phases. Modulating production throughout is possible by acting on the rate at which each operation is executed.

“Sectional line” type continuous processes

This is the most complex case that we find in applications in paper and cardboard production industries. It is also representative of rolling mills in the iron and steel industry, drawing machines and certain textiles machines. The product processed in a sectional line, whether it is paper or a length of steel, represents a mechanical link between the different steps (sections). To simplify our explanation of such a system, we could say that the “upstream section” pushes the product towards the downstream section which itself “pulls” the product to be processed through and “pushes” it on to the next section.
Transitric applications include all systems used to move materials or people. These include:

- **handling machines** (conveyor belt, conveyor, etc.),
- **people moving equipment** (lift, escalator, walkway, cable car, etc.),
- **lifting systems** that we can split into 4 categories:
  - simple machines such as hoists or winches,
  - cranes used in building construction,
  - specific mobile cranes used in the following areas:
    - handling of dangerous loads (nuclear industry, etc.),
    - handling devices in port infrastructures (iron and steel, aluminum, etc.),
  - handling devices in port infrastructures:
    - container storage cranes,
    - quayside cranes.

Most of these systems have performance level requirements that demand electronic speed variation. For drive systems that are attached to the lifting movement, the **energy recovery** function is required on the network (4 quadrants).

Automatic control and regulation functions are essential for these drive systems:

- synchronization for translational movements,
- position for lifting movements.

Even more sophisticated control functions can be used:

- for example slack control.

In lifting applications, variable speed drives provides safety functions (braking, load holding, etc.).

It would not be possible to give a full presentation of high power drive systems without including applications related to **transport**. These include electrical drive systems in:

**Marine propulsion systems**

- several thousands of kW, main propulsion systems
- and several hundreds of kW, side propulsion systems:
  - naval,
  - submarine,
  - merchant navy,
  - cruise liners, car ferries.

**Rail propulsion systems**

- high power propulsion:
  - electric motor systems,
  - TGV (over 8 x 1100 kW for each train),
  - metro/RER (1500 kW per train),
- light propulsion systems:
  - tram,
  - trolley bus…
Electrical drive systems in the Utilities sector represent almost 70% of the installed motor equipment base. Utilities implies all of the functions used around industrial and infrastructure processes. In certain cases the pumping, ventilation or compression function can be considered a process in itself. The powers involved can be very high. Utilities represent the highest electrical consumption in industry.

## Ventilation

Ventilation has applications in many functions either for injection, extraction or circulation (of air or gases):
- closed area ventilation: underground stations, car parks, metro systems, road and rail tunnels...
- heat exchange and air conditioning: clean rooms...
- combustion: ovens, incinerators...
- test rigs: blowing systems, wind tunnels...

## Pumping

Pumping has applications involving flow or pressure regulation of the processed liquid in functions such as:
- mains water,
- distribution,
- spraying,
- irrigation,
- over-pressure,
- circulation: swimming pools, heat exchangers...
- immersed pumping: water, oil, etc.

## Compression

There are many types of compressors:
- centrifugal compressors: they have \( kN^2 \) torque characteristics,
- volumetric compressors: they have constant torque characteristics:
  - screw or piston compressors,
  - lobe compressors,
  - “pigtail” compressors.

Compressors are used to compress air or other gases.
We find them in:
- refrigeration,
- chemicals, petrochemicals industries...
- for certain manufacturing and metallurgical applications.
For machines that do not necessarily require such a solution, the use of variable speed drives depends on economic considerations. This is the case in Utilities. It is justified by factors such as:
- starting a machine on a low short circuit power network,
- starting a machine with high inertia.
In both of these cases, speed variation avoids peak currents due to directly starting asynchronous motors on the network. Moreover, the use of speed variation is justified when substituting for load loss systems in applications using pumps, centrifugal fans and compressors. It helps control electrical consumption according to operating modes.

### Electronic speed variation applied to ventilation

In conventional ventilation systems which work with fixed speed electrical motors, control of the air flow rate is achieved using so called “load loss” type mechanisms, such as flaps or baffles. The graph opposite shows that with flaps placed upstream of the ventilator with the opening angle corresponding to a flow rate of 50%, the electrical power consumption remains at 60% (blue line). If we obtain the same flow rate by varying the fan’s rotary speed, we can see that electrical consumption is reduced to 30% (orange line).

In the second graph opposite, we can observe that there is an even more significant difference between regulation carried out with flaps downstream and the use of speed variation. It should be noted that for cost reasons, flaps positioned downstream are often used.

Besides energy considerations, speed variation gives perfect control of the air flow rate according to outside parameters, e.g.:
- in a clean room to:
  - maintain perfect air quality depending on the usage rate,
- in a closed area such as a car park or a tunnel in order to:
  - maintain air quality according to the pollution level,
- provide “hygienic flushing” in a period of low usage,
- provide fume extraction functions.

### Electronic speed variation applied to pumping

Just like fans, flow rate or pressure regulation is conventionally carried out with load loss devices such as a bypass or a downstream valve. At an operating point of 50% of the nominal flow rate, the graph opposite shows a major difference of over 40% in electrical power consumption.

### Electronic variable speed drives in Utilities

Naturally, the large installed motor equipment base in the Utilities sector is a major field of application for speed variation. However, it should never be forgotten that each application has to be subject to a specific study taking account of all mechanical parameters of the pump or the fan, as well as the air or water system characteristics and operating constraints.

With this approach, the drive system will be correctly designed.
Communication and user-machine dialog

Using Schneider Electric architectures and communicative products provides:
- quicker process commissioning,
- easier operation,
- fewer unwanted stoppages,
- savings on maintenance costs and time.

TCP/IP and the Web

Schneider Electric has many products designed around new communication technologies to enhance production facility performance levels. Integrating TCP/IP Ethernet and Web technologies, they allow you to produce high performance architectures:
- uniform automatic control solutions that can be directly integrated in production management systems,
- easy starting and diagnosis functions with display on monitors, screens, display terminals (integrated in the products or located remotely),
- real time access to data on the motors, the automatic control functions and the electrical power supply, from any point in the system.

Transparent Ready™ solutions use the following standards: Ethernet TCP/IP, PC, Web browser. Transparent Ready™ therefore allows you to make major savings in wiring, maintenance or training.
Schneider Electric
Power & Control solutions

Schneider Electric's Transparent Ready™ solutions integrate Ethernet and Web technologies in products to make them "transparent". Transparent Ready™ gives authorized users simple, quick and secure access to data, wherever and whenever they need it.

A universal network
The Ethernet TCP/IP network has messaging services that are suited to industrial automatic control. Ethernet TCP/IP can be used at any point in the system.

Local or remote data access
Internet technologies make it easier and reduce costs to access information remotely. Authorized people can react under all circumstances if they are on line.

A simple Web browser
Data access is via a simple internet browser on a PC, via integrated Web servers in the product. There is no longer any need for software licenses for users and maintenance teams.
Sizing and implementation

Incorporating a drive system solution is the result of various stages presented in the previous chapters. The following pages give recommendations on sizing in 3 examples: direct starting, soft starter, the use of electronic speed variation.

The quality of the incorporation stage will partly determine:
- the performance levels and durability of equipment,
- the achieving of objectives set by the operator. Maintenance conditions are closely related to this. These concern:
- equipment location,
- on-site installation,
- power and control connection,
- commissioning,
- testing.

**Equipment location**

Equipment location must take account of:
- distances between devices (cable calibration),
- "indoor" or "outdoor" installation (selecting the IP protection index),
- type of location (ambient air qualified in terms of temperature, dust, salt, presence of corrosive or explosive gases, etc.),
- standards applicable on the site.

**Site installation**

Installation of equipment must take account:
- dimensions and weight of equipment:
  - accessibility of premises,
  - handling and lifting devices,
- environmental constraints:
  - noise levels (motor, variable drive ventilation etc.),
  - vibration transmission (type of motor base),
  - assessment of energy losses,
  - safety of operating staff,
- access to equipment for operation, safety and maintenance.

**Power and control connections**

- Position of the motor terminals,
- Accessibility of the connector terminals,
- Cable routes: mixing of power and control cables in the same cable route is not recommended due to electromagnetic radiation problems (EMC),
- The need to use shielded cables or not for power and/or for control,
- Earthing considerations.

**Commissioning**

Commissioning is an important stage in the incorporation operation:
- it involves customizing settings of the equipment involved in the drive system:
  - setting parameters to adapt the system to the drive mechanism load (torque, speed, inertia),
  - setting parameters related to process performance levels,
  - setting parameters related to protection devices and drive safety devices, (overload, overcurrent, overvoltage, etc.),
  - configuring control and dialog information.

**Testing**

Commissioning ends with a series of tests which allow us to qualify the installation relative to the original set specifications.
Functional tests, no-load and load tests lead to the acceptance test for production. Successfully passing this series of tests depends on the quality and the methodical work that has been carried out beforehand. Optimizing their duration depends on the trust between the drive system supplier and the operator.
Example: direct starting

Impact on the electrical network
The most important impact is in the starting phase. It depends on the motor’s ld/in parameter. The starting current can reach up to 10 times the rated current. According to the supply network’s short-circuit power, starting causes varying degrees of voltage drop. The electrical network must be able to withstand this constraint, with an acceptable voltage drop.

Consumption of reactive power is directly related to the motor’s power factor and to the load. Example for a 300 kW motor:
- at 100% load, the power factor is equal to 0.95,
- at 50% load, the power factor is equal to 0.93.

Impact on the motor’s operation
Various network parameters have to be considered:
- the pre-existing level of harmonics disturbances
  All odd harmonics disturbances (5, 7, 11, 13, etc.) tend to overheat the motor which must then be de-rated in order to supply its nominal torque.
- the level of imbalance of supply voltages
  The motor characteristics are given by the manufacturer for a balanced supply voltage. Any imbalance causes an increase in phase currents and consequently overheating of the motor, reduction in the effective torque and causes the appearance of pulsing torque.

Transformer sizing
In this starting mode, the transformer is not a critical component in the chain. It can be standard, but has to withstand the above mentioned constraints. In addition, its thermal design must be adapted to the number of starting operations per hour, and the speed rise time of the motors (S) that it supplies power to.

Protection devices
The protection devices used depends on the strain placed on the motor: thermal, electrical and mechanical strains.

Thermal strains
These can be due to supply voltage variations, to voltage imbalances, to the repetitiveness of starting operations, to the failure of the ventilation system, to an ambient temperature that is too high, to overloads, etc.
In order to measure the impact of these strains, the motor can be equipped with temperature sensors placed on the stator.

Electrical faults
These are mainly insulation faults due to excessive dielectric strain. They are seen in terms of strike-over between phases, earthing of a coil...
Protection devices that act on the circuit breaker or the contactor placed upstream of the motor should detect these various faults.

Mechanical strains
These are particularly high on the motor’s bearings. These are the radial and axial loads caused by the mechanical coupling devices and the load. They are directly related to the driven mechanism and can generate high-amplitude transient over-torque and/or pulsing torque (critical speeds). These strains are seen in vibrations that can be measured using sensors.

Motor sizing
The motor is sized thermally and electrically according to:
- the electrical supply network: voltage, frequency,
- the mechanical load to be driven: torque, speed, inertia,
- the usage cycle (service): continuous, start-stop, repetitiveness of starting conditions.
The choice of technology is defined according to environmental constraints: ambient temperature, altitude, degree of hygrometry and type of atmosphere (dust, acid, explosives, marine, etc.).
Sizing and implementation

Example: soft starter

Impact on the electrical network
By adjusting the firing delay angle on thyristors making up the power bridge, the soft starter is intrinsically a disturbing system. The impact on the network can be seen in terms of:

- a high level of harmonic disturbance during the starting phase,
- a deterioration in the power factor during the same phase.

Constraints related to the soft starter
At the end of the starting operation, the soft starter supplies full voltage to the motor. However, although the thyristors that make up the power bridge have a relatively low voltage drop, it is sufficient to generate temperature rises which can be a disadvantage in certain applications, notably when included in cabinets or control units.

The solution involves using a bypass switch at the end of start up which allows us to combine the advantages of the electronic starter during the starting phase with a lack of temperature rise during steady state. In this case, the bypass is a simple current switch and the motor's thermal protection is provided by the soft starter.

Transformer sizing
In this type of starting mode, the transformer is not a critical component in the chain. It can be a standard transformer but must withstand the above mentioned constraints. In addition its thermal sizing must take account of the number of starting operations per hour and to the speed rise time of the motor that it supplies power to:

- Back-up generator:
  If the network can be backed up by a generator set, it is recommended to check that it is capable of withstanding the harmonic level generated during the starting phase.

Protection devices
Full motor protection devices are integrated in the soft starter's protection and control unit:

- thermal overload,
- phase imbalance,
- underload,
- starting time too long,
- blocked rotor,
- etc.

Back-up bypass
The use of a back-up bypass should take account of:

- automatic control of the device by the soft starter itself,
- calibration of protection devices related to the bypass branch.

Calibration will be carried out on the same basis as those used for direct starting modes of the supplied motor.

Specific use of the soft starter
It is possible to delta connect the starter to the motor. This type of connection provides gains in terms of starter current sizing of a factor of root 3.

Motor sizing
For a motor of equal size, this configuration enables it to withstand 2 to 3 times the number starting operations per hour than in direct starting mode.

(\*) According to the network short circuit power (network impedance) harmonic currents are transformed into harmonic voltages. It is these harmonic voltages which can have an impact on the network and other electrical devices connected to the same network (additional losses, overheating).
Example: variable speed drive starter

**Variable speed drive**
Here we will look at the “voltage source” type frequency converter comprising a diode rectifier type network bridge (6-pulse six-phase or 12-pulse twelve-phase) and an IGBT voltage inverter type motor bridge controlled using Pulse Width Modulation (PWM). These characteristics represent the majority of equipment that is currently used. For other types of variable speed drives, the recommendations below are not applicable as they stand.

**Impact on the network**
- Low reactive power consumption whatever the motor's operating speed and load (power factor > 0.95).
- Production of harmonic current according to the rectified configuration (6-pulse or 12-pulse).

**Transformer sizing**
The frequency converter is a “non linear” load, in other words, as opposed to a so-called “linear” resistive load, it consumes a current which is not sinusoidal. The rectifier on the network side is generally of 6-pulse type, the consumed current is polluted with harmonics, in particular those of rank 5 and rank 7. These harmonics cause additional losses in the transformer and therefore overheating. The transformer sizing must take account of this.

**Harmonic filtering**
Harmonic filtering can be dealt with by:
- configuring the 6-pulse or 12-pulse rectifier combined with an appropriate transformer (secondary with a single winding or double star delta winding).
- setting up of the use of a reactor of the right size upstream of the converter.
- using “active” filters, but this remains expensive.
- using a controlled sinusoidal sampling rectifier.
- The 12-pulse solution eliminates harmonics 5 and 7.
This ideal solution also has the advantage of making the equipment reversible (4 quadrants) in other words capable of managing dynamic braking by eliminating braking energy from the supply network.

**Electromagnetic compatibility (EMC)**
The system must be designed in accordance with usual practices and according to EMC related standards (“conducted” or “radiated” disturbance phenomena).
- quality of wiring and connections, shielding, radio frequency filters, earthing strategy (isolated neutral system)…

**Variable speed drive - motor connection**
The frequency converter generates a motor current that is virtually sinusoidal. As opposed to this, the produced voltage has a very high “dV/dt” characteristic (very steep voltage ramp in a very short time).
The cable used between the variable speed drive and the motor is characterized by:
- the longer the cable, the higher the losses related to its resistance and the higher its “parasite capacitance”,
- as a general rule over 50 to 100 m we should analyze the impact of the cable on the correct operation of the drive system. Including reactors at the variable speed drive output limits the impact of the parasite capacitance.
An appropriate regulation mode enables line losses to be compensated.
For certain applications, the use of a “sine wave filter” can prove necessary:
- limiting pulsing torque,
- eliminating voltage ramp effects (dV/dt).

**Motor sizing**
The motor is sized according to the driven mechanical load. The manufacturer must be informed of the fact that it is supplied power through a frequency converter (impact of the voltage wave and “dV/dt” ramp on the motor stator winding). In certain cases power derating may be necessary (5 to 10%). In applications requiring long operating times at low speed (< 50% of the rated speed), “motorized ventilation” of the motor could be considered. The use of variable speed drives on “qualified” motors (in terms of temperature, flame retardant, etc.) will lead to these motors losing their qualification. A “global qualification” approach could then be considered.

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Appendices
Asynchronous motor characteristics

Mechanical characteristics
- Body type (cast iron, aluminum, machine-welded, etc.),
- Shaft height,
- Number of pole pairs,
- Rotary speed,
- Assembly form IM..
- Protective index IP.
- Flame retardant (ADF) EExd, EExde...
- Type of bearings,
- Type of bearing mechanisms,
- Balancing - Class N, R, S,
- Cooling mode:
  - motorized ventilation,
  - heat exchanger...
- Coupling type:
  - permissible radial loads,
  - permissible axial loads,
  - Isolation class,
  - Temperature rise class,
  - Available shaft torque,
  - Rotor moment of inertia,
  - Noise level,
  - Weight.

Electrical characteristics
- Voltage,
- Frequency,
- Rated current,
- Available power,
- Power factor,
- Efficiency,
- Starting current (Id/In),
- Starting torque (Cd/Cn),
- Maximum torque (Cm).

Accessories fitted to the motor
- Winding temperature sensors,
- Bearing temperature sensors,
- Bearing vibration sensors,
- Rotation sensor,
- Speed sensor,
- Type of paint,
- Type of terminal plate,
- Reheating resistance.

Limits of usage - Derating according to:
- Service conditions (S..),
- Ambient temperature,
- Altitude.

Each motor manufacturer offers ranges of machines that meet each type of operating condition. Catalogues can be used as selection guides to help users to select the most appropriate motor for their application. Accurate data for each parameter will give the best solution.
Warning
The broad scope of this subject involves knowledge on:
- alternating current machine technology,
- modeling these machines with a view to their control,
- electromechanical breaking device technology,
- power semi-conductors,
- static converter technology and their control,
- Electronic variable speed drives.

The bibliography on these subjects is very wide ranging and often only found in a university environment. However, certain works are available, of which a very limited list is given below.

Schneider Electric works
Cahiers techniques:
- CT 152 - 183 - 202 on harmonics
- CT 204 - LV protection and variable speed drives (frequency converters)
- CT 206 - Energy savings in the building sector
- CT 207 - Electrical motors... for better control and protection
- CT 208 - Electronic starters and variable speed drives

We also refer you to the many Scatalogues for motor monitoring, control and protection and to the variable speed drive catalogue.

Other works
- EDF and GIMEC - La Vitesse Variable: L'électronique maîtrise le mouvement
  (Variable speed: Electronics to control movement)
  TECHNO-NATHAN Paris 1992
- Jean BONAL and Guy SEGUIER - Entraînements électriques à vitesse variable
  (Electrical variable speed drive systems) - Volume 1
- Jean BONAL and Guy SEGUIER - Entraînements électriques à vitesse variable
  (Electrical variable speed drive systems) - Volume 2
- Jean BONAL and Guy SEGUIER - Entraînements électriques à vitesse variable
  (Electrical variable speed drive systems) - Volume 3
- Jean BONAL - L'utilisation industrielle des moteurs à courant alternatif
  (Industrial use of alternating current motors)
  Technique et Documentation Lavoisier Paris 2001
- R. CHAUPRADE - F. MILSANT - Commande électronique des moteurs à courant alternatif
  (Electronic control of alternating current motors)
- CFE theme dossier – La variation électronique de vitesse – Guide d'utilisation
  (Electronic variable speed drives - User's guide).

Photographs
Our thanks to the motor manufacturer Weg, for providing the application photographs.
Notes
As standards, specifications and designs develop from time to time, always ask for confirmation of the information given in this publication.

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