1. Introduction

1.1. Scope of Document

The amount of installed Permanent Magnet (PM) motors will increase over the coming years. Many technicians have experience with induction motors (IM) but not with the new PM technology. When it comes to selecting, installing and the commissioning of. PM motors, still many questions arise. This note provides basic PM motor information and explains how to select the right VLT$^®$ drive for a given motor.

1.2. Target Group

This document is intended for all people who would like to use PM motors combined with a Danfoss VLT$^®$ frequency converter. It covers information for engineers, consultants, system designers, and commissioners. Beside basic PM knowledge information regarding design and commissioning PM motors are included.

It is expected that the reader has basic knowledge in the field of electrical motors and frequency converters. This includes sizing, wiring, installation, and programming. Information about these topics is available in the drive-related documentation and in separate guidelines.

All relevant paragraphs in the corresponding product manuals and local and international regulations and safety recommendations must be applied.

1.3. Discussed Drives

There are different control strategies are available in Danfoss VLT$^®$ drives for operating PM motors: U/f, VVC^{PLUS} PM and FLUX. U/f is a basic way to control PM motors. The required voltage at a certain frequency must be programmed. VVC^{PLUS} PM and FLUX provides better efficiency at different loads. Therefore U/f is not described in depth. The following table indicates which advanced control strategy is available in the different drives of the VLT$^®$ series.

| Series	Control strategy	Software
VLT$^®$ AutomationDrive	FLUX	1.00 or newer
VLT$^®$ AutomationDrive	VVC^{PLUS} PM	Not available
VLT$^®$ HVAC Drive	VVC^{PLUS} PM	3.72 or newer (EE ≥3.30)
VLT$^®$ AQUA Drive	VVC^{PLUS} PM	Not available

PM Motor control strategies implemented in different VLT$^®$

This note is only referring to VVC^{PLUS} PM. A separate note describing the configuring procedure for FLUX is available.

2. PM Motors in General

2.1. Salient and Non-salient PM Motor Constructions

Various constructions of PM motors are available on the market. Highly efficient are PM motors with sinusoidal commutation. They can be divided in motors with rotors where the magnets are mounted on the surface (non-salient magnetic field) or interior (salient magnetic field). Motors with interior magnets have a better performance in field weakening due to the salient magnetic field. The following sketches are for basic illustration and understanding. Technically, the inductances Ld and Lq give the difference between salient/non-salient (see technical literature e.g. Schröter or Chiasson)

Interior Mounted Magnets
(Salient Magnetic Field)

Surface Mounted Magnets
(Non-salient Magnetic Field)
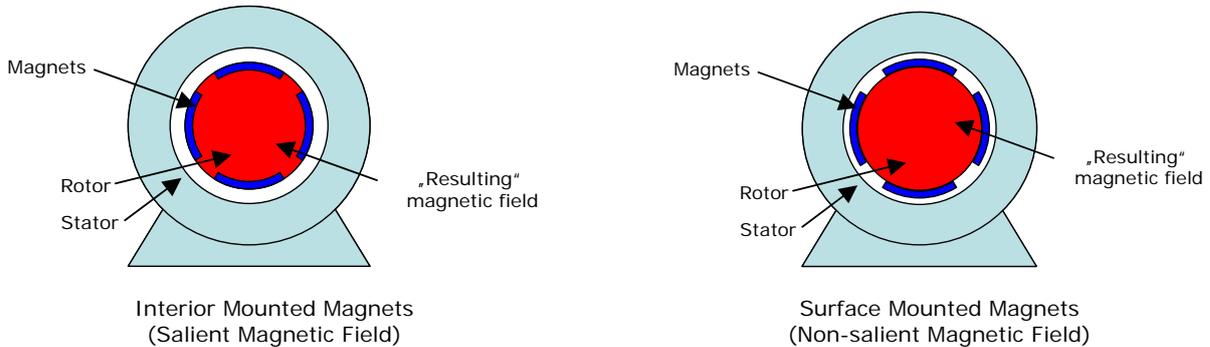
The most common are surface mounted magnets. If the nameplate does not provide values for Lg and Ld, contact the motor supplier for a data sheet to determine the motor type. Currently Danfoss supports non-salient motor types only.

2.2. PM motor for starting direct on mains (DOL)

PM motors that can start direct on mains (DOL) are available on the market. These motors typically have a squirrel cage included in the rotor in addition to the magnets. This results in a lower efficiency and cos φ (bigger drive required) compared to PM motors without DOL. Only the name plate or data sheet provides the information, if the motor is a DOL type or not.

2.3. BackEMF

When the shaft of a PM motor is turned, the motor produces a voltage at its terminals. This voltage is called BackEMF, and describes an important characteristic of the motor. The higher the voltage, the better is the motor efficiency. Unfortunately a high BackEMF is limiting the max speed of the motor (see section 3.3 and 3.4).

For optimum control of this motor type, the controller must match the supply voltage waveform as closely as possible to the waveform of the back EMF. Sinusoidal commutated PM motors are easier to implement from a structural perspective, but they have more complex control circuitry. Producing a square-wave back EMF is more difficult, but the structure of the control circuitry is simpler.

However, due to square-wave commutation torque ripple is worse and iron losses are higher. In addition, the current is 1.22 times as large as with sinusoidal because it is distributed over two phases instead of three.

3. PM Motor selecting Criteria's

Many selecting criteria for PM motors are similar to IM (induction motors), especially when using motors in IEC standard dimensions. The standardized mechanical dimensions make it easy to design these motors into new and existing appliances.

Beside the mechanical adaption, the motor must be suitable for the environmental conditions (dust, temperature, moisture,…) and for the mains voltage (insulation). The following part describes technical details to consider with regards to PM motors.

3.1. Motor Speed

The number of poles and the frequency of the feeding mains determine the speed of electrical motors with rotating magnetic fields.

$$n = \frac{f \times 60}{p}$$

n = Speed [RPM]
f = Frequency [Hz]
p = number of pole pairs (1 pole pair = 2 poles)

Induction motors are designed for operation direct on mains. The combination of typical numbers of motor poles and the most common mains frequencies (50/60 Hz), results in typical speeds of the magnetic field in the motor stator. The speed of the motor shaft is lower than the speed of the magnetic field, due to the motor slip.

	2 poles (p=1)	4 poles (p=2)	6 poles (p=3)
50 Hz	3000 RPM	1500 RPM	1000 RPM
60 Hz	3600 RPM	1800 RPM	1200 RPM

Typical synchronous speeds of magnetic fields in induction motor stators

PM motors are driven by frequency converters; therefore the feeding frequency is not tied to the mains frequency. This means that a nominal speed of e.g. 1500 RPM can also be achieved by a 6 pole PM motor at 75 Hz. To reduce torque ripples and electrical noise, higher numbers of pole pairs are used in PM motors.
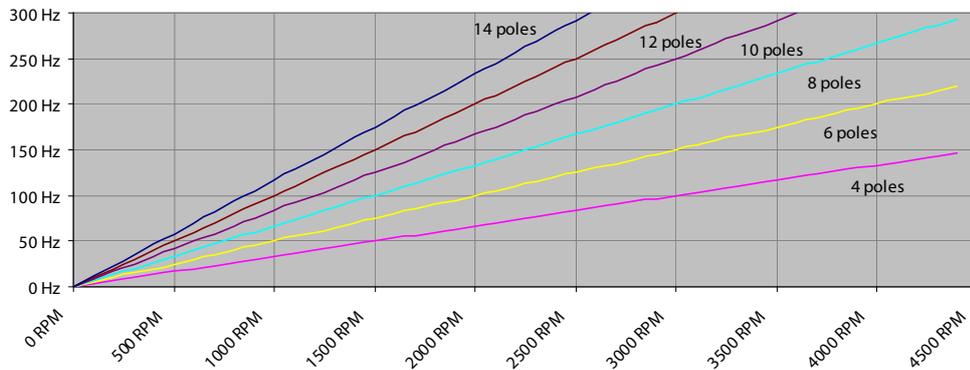
Relation between actual motor frequency, number of poles and resulting speed (50 Hz oriented)
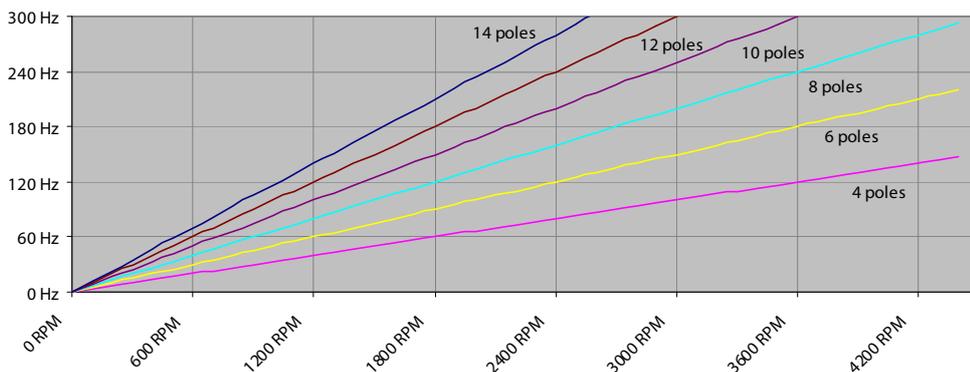
Relation between actual motor frequency, number of poles and resulting speed (60 Hz oriented)

3.2. Motor Torque

The torque of a PM motor is proportional to the motor current, and its speed is proportional to the frequency. The resulting power can be calculated when speed and torque are given.

$$T \sim I$$

$$P = \frac{T \times n}{9550}$$

P = Power [kW]
T = Torque [Nm]
n = Speed [RPM]
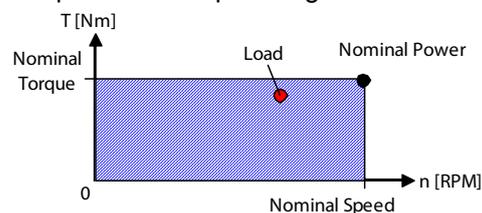
At nominal torque and speed, a certain voltage is required. If the frequency converter can deliver a higher voltage, the speed can be increased further. This results in a higher power at constant torque.

3.3. Speed Range

A PM motor can be operated above the nominal speed range at the same torque when the frequency converter can provide enough voltage (see section 3.2). When the voltage has reached an upper limit, the motor enters the field weakening area. All VLT® drives offering PM motor control (see section 1.3) can operate PM motors in field weakening. Only certain frequency converters available on the market offer this functionality. For information about the critical speed shown in the drawing, refer to section 3.4.

The required voltage at the nominal load point is typically below the supplied mains voltage (e.g. 320V on 400V mains) for many PM motors. Therefore many PM motors can be operated above the nominal power rating.
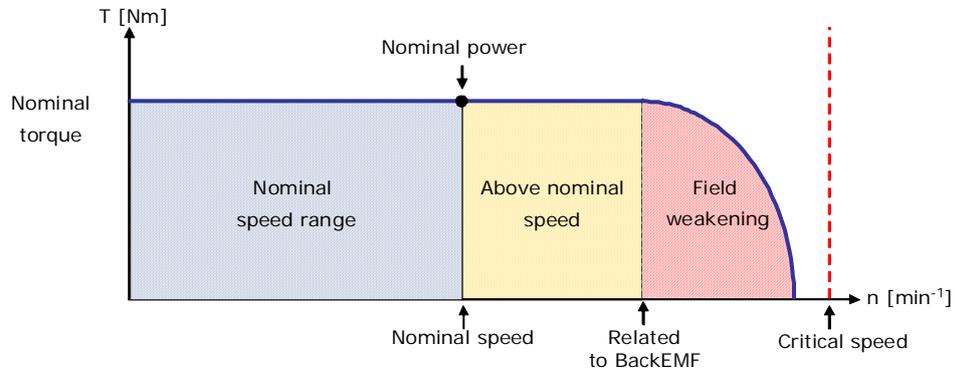
Another possibility for extending the speed range, is to change the star configuration of a motor to delta, if the motor provides this feature. Similar to induction motors, a delta connection results in a higher voltage on the windings, because it is not reduced by 1.73 like in star.

3.4. Field weakening

The biggest risk in field weakening operation is switching off the motor control at too high speed, as it can destroy the frequency converter. This critical speed (see drawing in 3.3) depends on the BackEMF of the motor, and the voltage the drive is designed for. Typical value for motors with BackEMF of 200V at 400V mains is 3200 RPM. Consider a brake chopper when operating at higher speeds or if the frequency converter does not limit the max speed. Be aware that VLT® HVAC drive limits the maximum speed, but the VLT® AutomationDrive does not. Use brake resistors when the VLT® AutomationDrive is operated above the critical speed.

3.5. Efficiency

The efficiency of PM motors is typically higher than for IM motors. Also at lower speeds the efficiency of a PM motor is higher than for a comparable IM, as the efficiency decreases less with lower speeds. Efficiency in field weakening decreases fast.
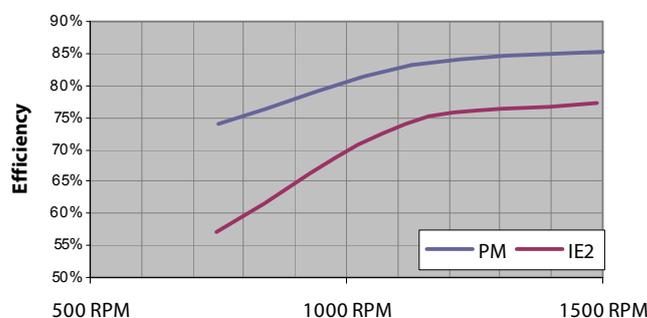
Shown efficiency curves are measured on a 1,1 kW PM and IE2 motor at VT (variable torque) load.

At higher power sizes the efficiency values become better but the principle shape is comparable.

3.6. Choosing PM Motor in Smaller Frame Size?

PM motors have a higher energy density than induction motors. Therefore PM motors with the same power rating as induction motors can be built in a physically smaller frame size. When using these smaller frame sizes, it must be ensured, that the mechanical design of the motor is suitable for the mechanical requirements of the application. Check dimensioning of motor bearings and motor shaft.

3.7. Risks of Demagnetising the PM Motor by a Drive

The risk of demagnetising a motor depends mainly on the used magnetic material. Motors using neodymium (NeFeB) magnets have a high energy density, a low risk of demagnetisation but a high price. When ferrites are used as magnetic material, the risk of demagnetisation is higher. This material is cheaper and has a lower energy density. However, high current at high temperatures can lead to demagnetisation of the magnets. A situation where both preconditions appear for a longer time is a stall situation (locked rotor with high current). Typically, demagnetising is not an issue in normal operation, not even in field weakening.

3.8. Drive Powered on at Disconnected Mains

PM motors produce voltage when the rotor shaft is turned (see section 2.3). The generated voltage is fed back into the connected frequency converter. When the voltage level is high enough, the motor can generate enough energy to power up the frequency converter, even when it is disconnected from mains. The required voltage for powering the frequency converter depends on the mains voltage the frequency converter is designed for.

Example: A VLT® for 400V mains requires about 320 – 340V in the DC link for powering up. When the motor is feeding the drive, the inverter is acting as a rectifier. Therefore a voltage of about 230V AC produced by the motor is required. This means that a motor with a BackEMF of 200V @ 1000 RPM must turn > 1150 RPM to power up the frequency converter.

This technical fact must be considered when designing the system. Evaluate if a motor in generative mode can cause dangerous situations by powering up the frequency converter when the user does not expect it to. If yes, take suitable actions like additional switch/relay between frequency converter and motor or forced stop signals to the frequency converter. A situation as described can arise in fan applications by wind milling, but also emergency stop situations must be considered.

4. Selecting the VLT®

4.1. Control Strategies

Danfoss provides two advanced control strategies for operating PM motors. Which strategy to use for which application depends on the required dynamic performance.

FLUX
This control is only available in the VLT® AutomationDrive and can be used in all applications.
- Programming of motor data is similar to VVC+ PM
- High dynamic performance is possible
- Direct access to speed controller (Group 7-0x) for optimizing performance
- Open loop and Closed loop (supported encoders: TTL, SinCos, Resolver, Hiperface, Endat…)

A separate application note explaining commissioning of FLUX is available. Refer to this note for further information.

VVC^PLUS *PM*
The robust control is intended for applications that do not require high dynamic performance like pumps, fans, and conveyors etc.
- Dedicated parameter group (1-14) for optimizing performance
- Open loop (without speed control feedback)
- Power range limited to 22 kW
- Max. motor frequency: 300 Hz

VVC^PLUS PM is implemented in the VLT® HVAC Drive only. Implementation in other drives is planned.

	FLUX		VVC+
	Open Loop	Closed Loop	Open loop
Speed control range	1:100	1:1000	1:100
Speed accuracy	± 0,5 %	Encode related	± 0,5 %
Acceleration torque	100 - 150 %	100 - 150 %	80 - 130 %
Reaction speed change	10 - 100 ms	5 - 50 ms	50 - 300 ms
Reaction torque change	0,5 - 5 ms	0,5 - 5 ms	20 - 50 ms

Typical achievable motor performance in FLUX and VVC+.

4.2. Sizing: Power and Current must fit

VLT$^®$ design guides state the current (A) and the apparent power (kVA) a frequency converter can provide related to different voltage ranges. Further a typical power rating (kW) for induction motors (IM) is noted. When selecting a frequency converter for a dedicated PM motor, ensure that the frequency converter delivers the required current and has sufficient power rating (kW).

It is more accurate to select the drive by current and the apparent power. Because many motor manufacturers do not provide this information in the technical documentation, the value must be calculated:

Calculation based on voltage and current

When current and voltage are known, apparent power can be calculated: $S = \sqrt{3} \times U \times I$

Motor current is typically noted on the motor nameplate or in the technical documentation. Attention must be paid to the motor voltage. At the nominal load point is the voltage at many PM motors is below the supplied mains voltage (e.g. 320V on 400V mains).

Calculation based on power, cos φ, and efficiency
If the motor nameplate or technical documentation do not provide values for cos φ and efficiency, use this method to estimate the values with a good accuracy. See typical values in the following equation.

$$S = \frac{P}{\eta \times \cos\varphi}$$

cos φ non salient motors: 0,95 … 0,97
cos φ salient motors: 0,7 … 0,77
Efficiency ɳ   ≥ IE3 efficiency according IEC/EN 60034-30

When a PM motor is operated above the nominal speed, the power is increasing as long as the torque is constant. Consider this when sizing the system. The frequency converter must be able to provide the required power and current in all operation conditions. Due to the high motor inductances of PM motors, higher current ripple can arise in the frequency converter. Therefore, size frequency converters > 7.5kW operated constantly at 100% load with sufficient safety margin.

4.3. Sizing example for nominal power rating

PM-motor size: 1,5 kW / 2,9 A
Mains: 3 x 400 V
Drive Series: VLT$^®$ HVAC Drive

Technical Data VLT$^®$ HVAC Drive

Drive	Typical [kW]	Typical [hp] at 460V	Continuous [A] (3x380-440 V)	Intermitted [A] (3x380-440V)	Continuous [A] (3x441-480 V)	Intermitted [A] (3x441-480V)	Continuous [kVA] (3x380-440 V)	Continuous [kVA] (3x441-480 V)
P1K1	**1,1**	1,5	**3**	3,3	2,7	3,0	**2,1**	2,1
P1K5	**1,5**	2,0	**4,1**	4,5	3,4	3,7	**2,8**	2,7

Source: Design guide VLT$^®$ HVAC Drive MG11BA02

Method 1 – Drive selected by power and current

	Motor	Drive 1,1 kW	Drive 1,5 kW
Power	1,5 kW	1,1 kW	1,5 kW
Current	2,9 A	3 A @ 400V	4,1 A @ 400V

Selected drive: P1K5

Method 2 – Drive selected by apparent power and current
Apparent power must be calculated by estimating values for cos φ (0,95) and efficiency (85.3% = IE3 efficiency 1.5kW – 4 pole motor)

$$S = \frac{P}{\eta \times \cos \varphi} = \frac{1,5kW}{85,3\% \times 0,95} = 1,85kVA$$

|	Motor	Drive 1,1 kW	Drive 1,5 kW
Apparent power	1,85 kVA	2,1 kVA	2,8 kVA
Current	2,9 A	3 A @ 400V	4,1 A @ 400V

Selected drive: P1K1

5. Information about Required Motor Data

Unfortunately, often only limited amounts of the required data for programming a VLT$^{®}$ are available on the motor nameplate. This section describes some details the user must be aware of, when programming the motor data, and how the required data are calculated or measured. However, in some cases the user must contact the motor manufacturer, to get all necessary data. The description is valid for VVC^{PLUS} PM and FLUX.

5.1. BackEMF Value

The voltage generated by the motor when the shaft is turned, is an important parameter for controlling PM motors. VLT$^{®}$ frequency converters are optimized for motors which provide a sinusoidal BackEMF (see also 2.3). Unfortunately, motor manufacturers state the value of the BackEMF differently.

Danfoss convention
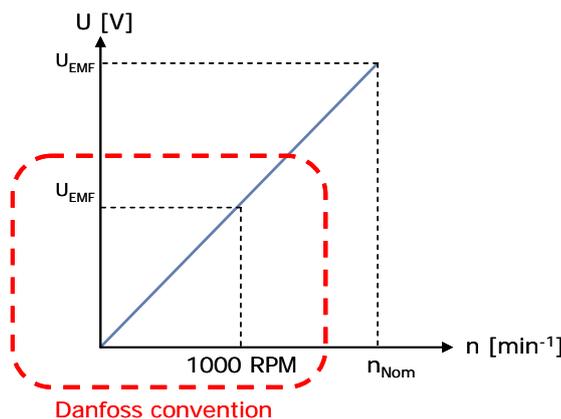
$$U_{RMS} = \frac{U_{Peak}}{\sqrt{2}}$$

Some manufactures provide BackEMF peak values. In this case the voltage must be divided by two in order to get the RMS value.

All Danfoss VLT$^{®}$ frequency converters require the BackEMF as phase to phase (also called line to line) RMS value related to 1000 RPM. Some manufacturers provide a factor (ke) for calculating the voltage. This factor must be multiplied with a speed factor (typically 1000) to get the required value at 1000 RPM.

It is also possible to measure the BackEMF. To do so, the motor must be turned externally @ 1000 RPM. Then the voltage can be measured between two terminals of the frequency converter. When the motor is turned with a lower speed, the BackEMF must be interpolated linearly to 1000RPM.

5.2. Motor Resistance and Inductance

There are several ways of noting if motor resistance and inductance are common for PM motors. Typically the values are given phase/phase or phase/star.
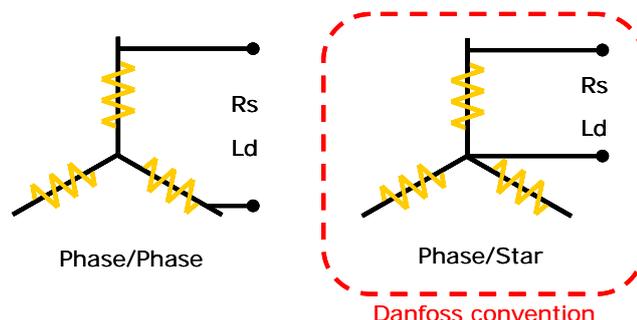
Danfoss VLT$^{®}$ frequency converters always require these values as phase to star data. This convention has the advantage, that motor resistance, and inductance can easily be measured or verified with an ohm- and inductance meter. Independent of the motor configuration (star or delta) the measured value must be divided by 2. This procedure can also be used to verify if the motor nameplate/data sheet provides phase/phase or phase/star values.

Recommendation for long motor cables

Pay special attention to long motor cables. Their resistance can affect the internal calculation of the frequency converter. The effect of long cables can be compensated by measuring the total resistance of the cable and motor. As described above, the resistance must be measured between two phases and divided by 2.

5.3. Torque, Speed and Number of Poles

Several data can easily be calculated from information stated on the nameplate or in the data sheet.

Power/Torque and speed relation:

$$P = \frac{T \times n}{9550} \qquad\qquad T = \frac{P \times 9550}{n} \qquad\qquad n = \frac{P \times 9550}{T}$$

P = Power [kW] / T = Torque [Nm] / n = Speed [RPM]

Number of pole pairs/speed and frequency relation

$$n = \frac{f \times 60}{p} \qquad\qquad p = \frac{f \times 60}{n} \qquad\qquad f = \frac{n \times p}{60}$$

n = Speed [RPM] / f = Frequency [Hz] / p = number of pole pairs (1 pole pair = 2 poles)

It is also possible to determine the number of poles practically. For this procedure, the frequency converter must be programmed to asynchronous motor (parameter 1-10). Then DC-hold must be activated in the stop function (parameter 1-80). Now the number of poles can be counted when turning the shaft manually.

To avoid personal injury, ensure that the motor cannot start when turning the shaft!

Adjust the DC current in *2-00 DC-hold Current* if the applied DC current is too high to turn the shaft, or too low to notice the poles.

High DC-hold currents applied for a longer time at zero speed can damage the motor and/or the magnets.

After the poles have been counted, the stop function should be programmed to its original value. For verifying if the correct numbers of poles are entered in the drive, the motor speed can be measured at a certain frequency. The value must correspond to the motor speed shown in the display.

6. Relevant Parameters

6.1. Enabling VVC^{PLUS} PM Motor Mode

For activating the VVC^{PLUS} PM mode, only one parameter must be considered. Parameter 1-10 must be programmed to the used PM motor type. Currently only non-salient motors are supported.

Par.	Name	Setting	Comment
1-10	Motor type	PM, non salient	Operation of salient motors can not be guarantied

6.2. Required Motor Data

Programming of the motor data is essential for PM motor operation. After selecting PM motor in parameter 1-10, the PM motor-related parameters in group 1-2x, 1-3x, and 1-4x are active. Following parameters must be programmed in the listed order and fit the PM motor.

Par.	Name	Comment
1-24	Motor current	Refer to nameplate / data sheet
1-26	Nominal torque	Refer to nameplate / data sheet (see also 5.3)
1-25	Nominal speed	Refer to nameplate / data sheet (see also 5.3)
1-39	Motor poles	Refer to nameplate / data sheet (see also 5.3)
1-30	Resistance Rs	Phase/star value required (see also 5.2)
1-37	Inductance Ld	Phase/star value required (see also 5.2)
1-40	BackEMF	Phase/phase RMS value at 1000 RPM required (see also 2.3/5.1)

If the correct motor data are programmed, the VLT® can operate almost every non-salient PM motor. Wrong motor data can result in motors not starting and/or strong shaft movement. Therefore, only start the motor at low speed (100 - 200 RPM) until correct motor data is verified, and the motor runs without problems.

In section 5.1, 5.2 and 5.3 it is described how required motor data can be measured. In case the motor is not starting, the noted measurements can be used to verify the programmed motor data.

6.3. VVC^PLUS PM Parameters

The frequency converter measures the motor current and calculates, based on the results from the measurement, the required voltage / frequency ratio for the optimal motor control. The applied control strategy is called MTPA (Max Torque Per Amp). For adjustment of the control performance, 4 parameters are available in group 1-14 VVC+ PM.

Par.	Name	Comment
1-14	Damping Gain [%]	Adjusts the dynamic of the motor
1-15	Filter @ low speed [s]	Active below 10% of nominal speed
1-16	Filter @ high speed [s]	Active above 10% of nominal speed
1-17	Voltage filter constant [s]	Increase stability of the motor operation

Damping Gain [%]
The parameter stabilizes the PM motor to run it smooth and stable. The value of damping gain controls the dynamic performance of the PM motor. Low damping gain results in high dynamic and a high value results in a low dynamic performance. If the damping gain is too high or low, the control becomes unstable. The resulting dynamic performance is related to the machine data and load type.

Filter at low speed and Filter at high speed [s]
The filters influence the response time to load steps. Obtain quick control through a short damping time constant. However, if this value is too low, the control gets unstable. Filter at low speed is active below 10% rated speed and filter at high speed above 10% rated speed. If a smooth operation is required, when crossing zero RPM, the filter value must be low.

Voltage filter constant [s]
The constant is used for reducing the influence of high frequency ripples and system resonances in the calculation of the motor supply voltage. Without this filter, the ripples in the motor currents can distort the calculated voltage and negatively affect the stability of the system.

In principle, all 4 parameters behaves in the same way. Higher values slow down the dynamic performance but stabilize the operation. Lower values lead to higher performance, but can lead to instable systems. After entering the motor parameters, the frequency converter calculates default settings for the parameters. These settings are optimized for HVAC applications and an inertia load in the range of $50 > I_{Load}/I_{Motor} > 5$. For typical values at different loads and for optimizing tips, refer to 7.3.

6.4. Minimum current at low speed

The VVC^{PLUS} PM parameters in group 1-1* and *1-66 Min current at low speed* can be used for tuning the motor torque at low speed.

Par.	Name	Comment
1-66	Min. current at low speed [%]	Adjust current / torque at low speed

Adjusting the parameter is not only required for optimizing the application performance (see 7.3) when more torque is required at low speed. Also increase the value when using high switching frequencies (see 7.5) or when the driven motor has a low BackEMF (<70V at 1000 RMS).

It is recommended that the parameter value is at least 30% of the nominal VLT® current. Because parameter 1-66 is related to the motor current, a simple calculation may be required. If the frequency converter and the motor have the same rating, it is sufficient to check that the value is higher than the recommended 30%. A practical way to evaluate if the minimum current is applied is to start the motor at zero speed. If the LCP current read-out value is too low, 1-66 must be increased accordingly.

If the motor current becomes too high after increasing the parameter value, increase the current limit in par. 4-18.

6.5. Flystart

The function for catching a spinning motor is fast in VVC^{PLUS} PM. Therefore, it is activated by default and performed at every start. Only when the motor speed is below 2% of nominal speed, flying start is deactivated. In this case the start function programmed in par. 1-70 is performed (see also 6.6).

Flystart requires a minimum BackEMF from the motor, thus the 2% limit. The 2% limit can be adjusted via *1-59 Flystart Test Pulses* when Parking is selected in par. 1-70. For motors with low BackEMF, increase the value (max. 10%). For motors with high BackEMF, the value can be decreased. If the programmed limit is too low, the frequency converter detects and start the parking function. However, the setting of 2% is suitable for most motors, and does not need adjustment.

6.6. Start Function

For starting a PM motor, the frequency converter must know the exact rotor angle (angle between the stator magnetic axis and rotor magnetic axis). If not, the motor cannot be accelerated. The frequency converter provides two functions for determining this angle which can be selected in *1-70 PM Start mode*. When a start command is given, the frequency converter checks the current motor speed. When the speed is > 2%, the frequency converter automatically applies the flystart (see section 6.5) instead of the start function.

> *Rotor detection*
> This function is the best choice for applications where it is ensured that the motor is standing still. These applications are for example pumps, conveyors, or compressors. For determining the rotor angle, the frequency converter sends out a short impulse to the motor. The motor construction influences on the sound created by this impulse. On some motors, it cannot be heard and on others there is a sound. However, the impulse is too low to harm the motor even when the sound is notable.

> *Parking*
> By applying a DC current for a defined time, the rotor is dragged into a well-defined position under a pole in the stator. By doing so, the frequency converter knows the exact rotor angle. The user can adjust Parking current (par. 2-06) and Parking time (par. 2-07). Increase the factory setting of these parameters for applications with high inertia. Speed range where Parking is applied can be adjusted via par. 1-59 (see section 6.5).

Use the Parking function if the motor can turn slightly (approx. 10 RPM to 2% of nominal speed) before starting. Typical applications with this behaviour are fans with light wind milling (stack effect).

Start mode in 1-70	Application
[0] Rotor detection	All applications where the motor is standing still when starting. These are e.g. conveyors, pumps, non rotating fans
[1] Parking	Suitable for applications where the motor is turning with a speed < 2% of nominal speed. These are for example fans with light wind milling. Function can be adjusted in par. 2-06 and 2-07

7. Commissioning Tips

7.1. Installation

In principle, all installation recommendations valid for induction motors must be considered for PM motors as well. For details, refer to the corresponding operating instructions and design guide. In addition, it must be ensured that the motor is not turning while cabling the frequency converter or the motor. As described in 2.3 a PM motor generates voltage which can reach a level sufficient to power the frequency converter on (see 3.8).

7.2. Recommended Programming Steps

Before following the next steps, refer to the operating instructions of the used frequency converter, and make sure that all noted safety precautions are taken! Switch the speed unit from Hz to RPM.

- o   Activate PM motor operation (see section 6.1)
- o   Program the motor data. Sounds easy, but wrong data are the main reason for motors not starting. Study section 6.2 carefully and ensure that all data are in the required format
- o   Start the motor at low speed (100 - 200 RPM). If the motor does not turn, refer to section 7.4
- o   Check if the selected start function fits the application requirements (see section 6.6).
- o   Start the motor at nominal speed. In case the application does not run well check the VVC^PLUS PM settings. Recommendation for typical applications can be found in section 7.3

7.3. Typical application settings

Many applications work smoothly with the standard presets and correctly programmed. The following table provides some recommendations for different applications.

Application	Settings
Low inertia applications I_{Load}/I_{Motor} <5	1-17 to be increased by factor 5 to 10 1-14 and 1-66 should be reduced
Low inertia applications 50>I_{Load}/I_{Motor} >5	Keep calculated values
High inertia applications I_{Load}/I_{Motor} > 50	1-14, 1-15 and 1-16 should be increased
High load at low speed <30% (rated speed)	1-17 and 1-66 should be increased

Recommendation for adjusting parameters in dedicated applications

When the motor starts oscillating at a certain speed, increase *1-14 Damping Gain*. Increase the value in small steps. Depending on the motor, a good value for the parameter can be 10 % or 100 % higher than the parameter preset.

Reducing the ramp time sometimes leads to problems during start-up. Due to the faster ramp, the frequency converter provides more current and gets stuck in the current limit. Before increasing the current limit, consider if increasing *1-17 Voltage filter constant* decreases the higher current. In general, a higher voltage filter constant helps to reduce high currents at low speed.

7.4. Motor is not Starting

The most difficult part when commissioning PM motors is the starting phase. In many cases it is sufficient to enter the motor data. After entering the motor data, the frequency converter adjusts the factory settings of the VVC^PLUS PM parameters. For a short test, accelerate the motor to 100 RPM or 200 RPM.

The following describes some typical issues that can prevent the motor from accelerating. However, before trying to optimize the parameters, check that the motor is not blocked mechanically and that an existing brake is lifted when starting.

Wrong motor data
Wrong motor data cannot be compensated by adjusting other parameters of the frequency converter. Ensure that the correct data are available and that they are programmed correctly and in the right order (see section 6.2). The effect of long motor cables can be compensated by measuring the stator resistance including the cable (see section 5.2).

Frequency converter cannot synchronise with the motor
Essential for PM motor operation is that the frequency converter can determine the current rotor angle. Depending on the motor speed when a start signal is given, the frequency converter offers different mechanisms for this purpose. Above >2% of nominal speed, flystart (see section 6.5) is applied automatically. Below <2% the user can choose the start functions as described in section 6.6. Ensure that a suitable start function is chosen, and that it is working as desired.

Motor gets stuck in the current limit
The main reason why a motor does not accelerate is that the motor current becomes too high and it runs into current limit. To check if this is the reason why the motor is not accelerating, the motor current must be monitored. When the motor stops accelerating and the current is at a constant high level, the problem is identified. Solutions:

Optimizing VVC+ PM parameters
Increasing the VVC+ PM voltage constant in *1-17 Voltage filter constant*, is helping to decrease the starting current. Also decreasing or increasing *1-66 Min. current at low speed* – see section 6.4) can improve the behaviour. A recommendation of typical VVC^PLUS PM parameter settings is given in section 7.3.

Hitting torque/current limits
Solve the issue fast by increasing the torque limit of the motor (parameter 4-16) and the current limit of the frequency converter (parameter 4-18). But even when this works, reduce the starting current by optimizing the VVC^PLUS PM parameters and the starting current as described in the previous paragraph.

7.5. Acoustic Motor Noise

As well as IM, PM motors also produce acoustic noise in operation. The scale is from very silent to very loud. The motor construction influences heavily on the sound. Especially the relation of magnets mounted in the rotor and in the stator influence the sound. In case the sound is too loud, increase the switching frequency of the frequency converter in parameter 14-01.

Unfortunately the losses in the frequency converter increase when the switching frequency is increased. For necessary derating information, refer to the frequency converter operating instructions or design guide. Often it is not necessary to increase the switching frequency to the maximum value. Frequencies around 8 kHz usually eliminate the problem. In case the frequency converter becomes too warm due to high switching frequencies, the inverter reduces the frequency to a lower level automatically.

When a switching frequency higher than 5 kHz is needed, increase parameter 1-66.

8. Overview VVC+ PM Relevant Parameters

The following list provides an overview of the parameters that are most relevant for VVC^PLUS PM. The parameters are listed in the order in which they are typically programmed during commissioning.

Par.	Name	Comment
Activation PM Motor operation (for details refer to 6.1)		
1-10	Motor construction	Set to "PM Motor"
Motor data (for details refer to 6.2)		
1-24	Motor current	Refer to nameplate / data sheet
1-26	Nominal torque	Refer to nameplate / data sheet
1-25	Nominal speed	Refer to nameplate / data sheet
1-39	Motor poles	Refer to nameplate / data sheet
1-30	Resistance Rs	Phase/star value required
1-37	Inductance Ld	Phase/star value required
1-40	BackEMF	Phase/phase RMS value at 1000 RPM required
VVC+ PM (for details refer to 6.3)		
1-14	Damping Gain [%]	Adjusts the dynamic of the motor
1-15	Filter @ low speed	Active below 10% of nominal speed
1-16	Filter @ high speed	Active above 10% of nominal speed
1-17	Voltage constant	Increase stability of the motor operation
Start function (for details refer to 6.6)		
1-70	PM Start mode	Use method for motor start (see also 2.3)
1-59	Flystart pulse frequency	Limit for activating flystart when par. 1-70 = "Parking"
2-06	Parking current	Active < 2% $n_{Nominal}$ when par. 1-70 = "Parking"
2-07	Parking time	Active < 2% $n_{Nominal}$ when par. 1-70 = "Parking"
Start performance (for details refer to 6.6)		
1-66	Min.current @low speed	Should be adjusted when problems during start arise (see also 6.4)
4-16	Motor torque limit	Can be increased when problems during start arise
4-18	Current limit	Can be increased when problems during start arise
Miscellaneous		
14-01	Switching frequency	Can reduce motor noise but increase losses in drive (see also 7.5)