

## VSC - Variable Frequency Drives Operating Permanent Magnet- and Brushless DC-Motors



Level 3	1 – Fundamental – No previous experience necessary 2 – Basic – Basic knowledge recommended 3 – Advanced – Reasonable knowledge required 4 – Expert – Good experience recommended
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## Danger! - Dangerous electrical voltage!

- Disconnect the power supply of the device.
- Ensure that devices cannot be accidentally restarted.
- Verify isolation from the supply.
- Cover or enclose any adjacent live components.
- Follow the engineering instructions (AWA/IL) for the device concerned.
- Only suitably qualified personnel in accordance with EN 50110-1/-2 (VDE 0105 Part 100) may work on this device/system.
- Before installation and before touching the device ensure that you are free of electrostatic charge.
- The functional earth (FE, PES) must be connected to the protective earth (PE) or the potential equalization. The system installer is responsible for implementing this connection.
- Connecting cables and signal lines should be installed so that inductive or capacitive interference does not impair the automatic control functions.
- Suitable safety hardware and software measures should be implemented for the I/O interface so that an open circuit on the signal side does not result in undefined states.
- Deviations of the mains voltage from the rated value must not exceed the tolerance limits given in the specification, otherwise this may cause malfunction and/or dangerous operation.
- Emergency stop devices complying with IEC/EN 60204-1 must be effective in all operating modes. Unlatching of the emergency-stop devices must not cause a restart.
- Devices that are designed for mounting in housings or control cabinets must only be operated and controlled after they have been properly installed and with the housing closed.
- Wherever faults may cause injury or material damage, external measures must be implemented to ensure a safe operating state in the event of a fault or malfunction (e.g. by means of separate limit switches, mechanical interlocks etc.).
- Frequency inverters may have hot surfaces during and immediately after operation.
- Removal of the required covers, improper installation or incorrect operation of motor or frequency inverter may destroy the device and may lead to serious injury or damage.
- The applicable national safety regulations and accident prevention recommendations must be applied to all work carried on live frequency inverters.
- The electrical installation must be carried out in accordance with the relevant electrical regulations (e. g. with regard to cable cross sections, fuses, PE).
- Transport, installation, commissioning and maintenance work must be carried out only by qualified personnel (IEC 60364, HD 384 and national occupational safety regulations).
- Installations containing frequency inverters must be provided with additional monitoring and protective devices in accordance with the applicable safety regulations. Modifications to the frequency inverters using the operating software are permitted.
- All covers and doors must be kept closed during operation.
- To reduce the hazards for people or equipment, the user must include in the machine design measures that restrict the consequences of a malfunction or failure of the frequency inverter (increased motor speed or sudden standstill of motor). These measures include: – Other independent devices for monitoring safety related variables (speed, travel, end positions etc.).
  - Electrical or non-electrical system-wide measures (electrical or mechanical interlocks).
  - Never touch live parts or cable connections of the frequency inverter after it has been disconnected from the power supply. Due to the charge in the capacitors, these parts may still be alive after disconnection. Consider appropriate warning signs.

## Disclaimer

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## 1 General

Devices of the series **VSC** are variable frequency drives for the supply of three phase motors. By default they are configured in a way, that induction motors of the respective power class can be supplied without changing the settings. The connection of permanent magnet motors (PM Motors) and Brushless DC Motors (BLDC Motors) is also possible, but requires the selection of the respective Motor Control Mode and an adaptation of some parameters.

Devices of the series VSC control PM motors and BLDC motors in „open loop“ without feedback by a speed sensor. Compared to induction motors they are mainly used because of the smaller frame size and an increased efficiency. The applications are similar to the ones with induction motors, but with increased dynamics. The series VSC is NOT intended to be used in servo applications with PM- and BLDC motors and therefore VSC doesn't have functionalities like positioning .....

In this Application Note the following aspects are covered:

- Selection of the motor control mode
- Adaptation to the connected motor
- Optimization of the application
- Trouble shooting
- Example: PM-Motor settings

Some required parameters are inside level 3. This level has to be activated by prompting the password into P-14 (Password). The password is 201 by default.

See also: AP040052EN "Access to Parameter Level 2 + 3 – Parameter lock – Load Default".

This Application Note presumes that the user is familiar with vector control of induction motors and the setting of the respective parameters, as well as with the optimization of speed control loops.

## 2 Selection of the Motor Control Mode

PM motors and BLDC motors require a different control algorithm compared to induction motors, for which the default settings are intended. A selection is done via parameter P-60.

NOTE: The difference between PM motors and BLDC motors is mainly the wave form of the induced voltage (Back EMF). The control modes of VSC are optimized for that. On the market there is no clear differentiation between the two types of motors and sometimes one can find BLDC motors which are named as PM motors or PM motors with a similar induced voltage as a BLDC motor. In case of a bumpy run in the control mode for PM motors (P-60 = 2) sometimes an improvement can be achieved by selecting the control mode for BLDC motors (P-60 = 3).

### 2.1 Motor Control Mode (P-60)

This parameter adapts the device to the type of the connected motor and determines the way of control. The information given in this Application Note are valid for PM motors and BLDC motors only and refer to the settings P-60 = 2 and 3.

Information for the control of induction motors (P-60 = 0 and 1): see Application Note AP040049EN.

PNU	Parameter	Name	Range	Default
255.0	P-60	Motor Control Mode	0: Speed Control with Torque Limit (vector) 1: Speed Control (V/f) 2: PM Motor Speed Control 3: Brushless DC Motor Speed Control 4: SyncRel Motor Speed Control	1

### 3 Setting Motor Data

Before switching on the motor, the motor data according the name plate or the data sheet have to be prompted and a motor identification run has to be performed.

#### 3.1 Motor Nom Voltage (P-07)

This parameter has to be set to the value of the induced voltage (back EMF) at rated speed. This voltage is the voltage between two phases. In case the manufacturer states the value between phase and neutral, it has to be multiplied by  $\sqrt{3}$ .

Inside the documentation of the motor manufacturers one can find the required information in different formats.

- as a voltage value ( sometimes called “rated voltage”)
- as a voltage constant (induced voltage at a certain speed, mostly 1000 rpm). In this case the voltage at the required speed has to be calculated.

Example:

- voltage constant = 50 V / 1000 rpm
- required speed = 3000 rpm

$$P-07 = \frac{50 \text{ V}}{1000 \text{ rpm}} \cdot 3000 \text{ rpm} = 150 \text{ V}$$

PNU	Parameter	Name	Range	Default
211.0	P-07	Motor Nom Voltage	0 / 20 V ... U <sub>e</sub>	U <sub>e</sub>

U<sub>e</sub> = rated voltage of the device, e.g. 230 V or 400 V, depending on the device type

Note: the voltage given by the motor manufacturers can have different meanings:

- The voltage induced at rated speed (Back-EMF). In this case this value has to be prompted.
- The voltage which is present at rated speed and rated torque. This value is higher than the induced voltage. It can possibly lead to a situation where the motor takes more current respectively runs bumpy. What are the possibilities to determine the right value?
  - Run motor at rated speed and switch off. Take an oscilloscope and measure the induced voltage directly after switch off.

#### 3.2 Motor Nom Current (P-08)

Rated current of the motor. By default, parameter P-08 „Motor Nom Current“ is set to the rated current I<sub>e</sub> of the variable frequency drive. P-08 is also used to set the thermal protection for the motor. In case the rated current of the motor is different to the one of the variable frequency drive, P-08 has to be set accordingly to provide a thermal motor protection.

PNU	Parameter	Name	Range	Default
210.0	P-08	Motor Nom Current	0.25 · I <sub>e</sub> ... I <sub>e</sub>	I <sub>e</sub>

I<sub>e</sub> = rated current of VSC

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### 3.3 I-CurrentLimit (P-63)

The nominal current of the motor (P-08) can be exceeded for a certain time to provide additional torque during acceleration. In default it is 150 % of the rated current for 60 s within 10 minutes or the equivalent.

The maximum value can be set with P-63. This setting has no influence on the motor protection and determines only the max. possible current.

This function is of help in cases, where high inertias are accelerated. From experience this can sometimes lead to trips because of overcurrent, in cases where the max. current and the hardware trip threshold of the device are too close.

PNU	Parameter	Name	Range	Default
281.0	P-63	I-CurrentLimit	0.1 175 %	150 %

### 3.4 Motor Nom Frequency (P-09)

Frequency which is necessary for the required speed of the motor. Mostly it can be found as “rated frequency” on the motor name plate or in a data sheet. In case the frequency is not known, it can be calculated out of speed and number of poles p.

$$P-09 \text{ [Hz]} = n \text{ [rpm]} \cdot \frac{p}{2 \cdot 60 \text{ s/min}}$$

PNU	Parameter	Name	Range	Default
216.0	P-09	Motor Nom Frequency	25 ... 500 Hz	50 Hz resp. 60 Hz

NOTE: A change of P-09 affects the following parameter settings:

Parameter	will be set set to
P-01 (f-max)	value of P-09 (Motor Nom Frequency)
P-02 (f-min)	0
P-10 (Motor Nom Speed)	0
P-20 (f-Fix1)	default
P-21 (f-Fix1)	default
P-22 (f-Fix1)	default
P-23 (f-Fix1)	default

### 3.5 Motor Nom Speed (P-10)

Motor rated speed in rpm. This is the speed at the frequency set with P-09.

PNU	Parameter	Name	Range	Default
217.0	P1-10	Motor Nom Speed	0 / 200 ... 30000 rpm	0 rpm

NOTE: A change of P-09 “Motor Nom Frequency” will set P-10 to 0!

### 3.6 Switching Frequency (P-17)

Switching frequency of the power section. With PM motors and BLDC motors a minimum switching frequency of 16 kHz is recommended. Setting the switching frequency is always a compromise between a smooth run of the motor at higher values and resulting additional losses at the same time. At values above 16 kHz it has to be noted, that VSC possibly has to be derated and in some cases a device with the next higher rating has to be used.

PNU	Parameter	Name	Range	Default
390.0	P-17	Switching Frequency	0 = 4 kHz 1 = 8 kHz 2 = 12 kHz 3 = 16 kHz 4 = 24 kHz 5 = 32 kHz	depends on device type

### 3.7 Motor Identification (P-61)

A motor identification run MUST be performed when using a device of the VSC series together with a PM motor or a BLDC motor (P-60 = 2 or 3). It sets the parameters automatically, which are necessary for an optimal performance. After the motor identification run the drive is ready to be used. Further optimization, see below.

The motor identification run determines the values of the following parameters

- Motor Stator Resistance (P-64)
- Motor Stator Inductance d-axis (P-65)
- Motor Stator Inductance q-axis (P-66)

The respective values can also be prompted manually, in case they are available from the motor manufacturer. It is recommended to rely on the motor identification run, because it gives very accurate values and ensures optimal performance.

A motor identification run is performed during stand still. The internal motor model uses the results for an optimal control of the connected motor.

Procedure:

- Real Time Edit Mode of a DrivesConnect Software, which is possibly connected to the drive, has to be deactivated. Better: Unplug the connection at the RJ45 jack when performing a motor identification run.
- VSC must not be enabled (no START signal)
- Select parameter P-62
- Press **OK**
- **!** is displayed
- Change value to **!**
- Acknowledge with **OK** → The identification starts automatically, display: **Auto-t** resp. **Auto-tuning** (OLED-display)
- After the identification the value will automatically be reset to zero. Display: **STOP**
- The device has determined the required parameters.

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HINT: The motor identification run has ALWAYS to be performed at the device itself. It is NOT possible to activate it through the parameter software DrivesConnect. The motor parameters P-07, P-08 and P-09 have to be set before starting the motor identification.

PNU	Parameter	Name	Range	Default
340.0	P-61	Motor Identification	0 = OFF 1 = ON	0

## 4 Optimization

### 4.1 Motor performance at low speed

Normally PM motors and BLDC motors can be used in a speed range of 20:1. The series VSC has a boost function, which increases the torque in the lower range resulting in an improved start behavior and true running in the lower speed range.

In case „Motor Control Mode“ P-60 = 2 (PM motors) or P-60 = 3 (BLDC motors), a current, which is injected into the motor, can be set with P-11. The amount of current is calculated as follows:

$$I_{\text{Boost}} = 4 \cdot P-11 \cdot P-08$$

PNU	Parameter	Name	Range	Default
27.0	P-11	V-Boost	FS1: 0 ... 25 % Ue FS2: 0 ... 20 % Ue FS3: 0 ... 15 % Ue FS4: 0 ... 10 % Ue	FS1: 3 % Ue FS2: 2,5 % Ue FS3: 2 % Ue FS4: 1,5 % Ue

FS = Frame Size

### 4.2 Optimization of the speed controller

The control of PM motors and BLDC motors is based on vector algorithms and the speed loop can be optimized. The factory settings are intended for induction motors. PM motors and BLDC motors allow higher gains and therefore shorter response times and improved behavior.

Parameter P-62 „MSC Gain“ affects the proportional gain of the speed controller as well as the integral one. Changes should be done step by step, while observing their impact to the system behavior.

Increasing the value leads to a stronger reaction and consequently to a reduction of the response time. Too high values of P-62 can lead to an instability of the system.

PNU	Parameter	Name	Range	Default
2408.0	P-62	MSC Gain	0.1 200.0 %	50.0 %

## 5 Faults and possible root causes

General fault messages and their root causes are described in the user manual for the drives series VSC. The faults listed below are especially related to the use of PM motors and BLDC motors.

Symptom	Possible root cause and remedy
P-60 for the selection of the motor control mode cannot be set.	<ul style="list-style-type: none"> <li>Level 3 of the parameter menu is not accessible. Prompt password for level 3 into P-14 (= value of P-37 + 100).</li> </ul>
Poor torque behavior at low speed	<ul style="list-style-type: none"> <li>See „Optimization of the motor performance at start and low speeds“</li> </ul>
Too much current leads to heating of the motor	<ul style="list-style-type: none"> <li>Check, if „Motor Nom Voltage“ (P-07) is set correctly</li> <li>Check, if „Motor Nom Current“ (P-08) is set correctly</li> <li>If the motor runs at low speeds for a longer period of time: Check parameters for torque boost (P-11)</li> </ul>
Motor stalls	<ul style="list-style-type: none"> <li>Check motor connection</li> <li>Check values of the motor parameters (P-07 ... P-10)</li> <li>Check result of the motor identification run and repeat if necessary</li> <li>Load too high → reduce it</li> <li>Acceleration (P-03) and deceleration ramp time (P1-04) too short → extend ramp</li> <li>Use next higher rating of drive / motor</li> </ul>
Speed oscillations	<ul style="list-style-type: none"> <li>Check, if the switching frequency (P-17) is at least 16 kHz</li> <li>Check values of the motor parameters (P-07 ... P-10)</li> <li>Check result of the motor identification run and repeat if necessary</li> <li>Check settings of the speed regulator (P-62) and reduce gains when necessary</li> </ul>
Poor dynamics of the motor, long response times	<ul style="list-style-type: none"> <li>Check values of the motor parameters (P-07 ... P-10)</li> <li>Check result of the motor identification run and repeat if necessary</li> <li>Check settings of the speed regulator (P-62) and increase gains when necessary</li> </ul>

## 6 Example how to set motor parameters

Excerpt from a data sheet of a PM motor manufacturer:

$n_N$ [r/min]	$M_O$ [Nm]	$M_{max}$ [Nm]	$M_N$ [Nm]	$P_N$ [kW]	$I_o$ [A]	$I_N$ [A]	$I_{max}$ [A]	$U_{N,AC}$ [V]	$f_N$ [Hz]
3600	11.0	29.0	7.50	2.80	10.0	7.50	33.0	295	240
$N_{100\%}$ [%]	J [kgcm]	$KE_{LL150^\circ C}$ [V / 1000rpm]		$R_{UV20^\circ C}$ [Ω]	$R_{UV150^\circ C}$ [Ω]	$L_N$ [mH]	$Kt_{0\ 150^\circ C}$ [Nm/A]	$N_{max}^{(2)}$ [r/min]	$m^{(1)}$ [kg]
92	8.10	64.2		1.00	1.35	12.5	1.09	6000	10.7

Settings of motor parameters:

- P-07 =  $KE \cdot n_N = 64,2\text{ V} / 1000\text{ rpm} \cdot 3600\text{ r/min} = 231\text{ V}^*$
- P-08 = 7.5 A
- P-09 = 240 Hz
- P-10 = 3600 r/min

Further important settings

- Enable menu level 3 (Prompt value defined by P-37 + 100 into P-14. Default: 201)
- The switching frequency (P-17) has to be at least 16 kHz
- Select motor control mode with P-60 (in this example: 2 → PM motor with speed regulation)
- Perform motor identification run with P-61
- Optimize motor performance at start and low speeds (P-11).
- Optimize speed controller, if necessary