PowerXL™

DA1 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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Contents

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.

Danger! - Dangerous electrical voltage!

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General

Devices of the series **PowerXL™ DA1** 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 DA1 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 DA1 is NOT intended to be used in servo applications with PM- and BLDC motors and therefore DA1 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 part of menus inside level 3. These menus have to be activated by prompting the "Password Level3" (P6-30) into P1-14 (Password). By default, "Password Level3" is 201.

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.

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 P4-01.

In case a PM motor is used in applications with torque control (P4-01 = 4), it has to be noted that the settings are done in speed control mode (P4-01 = 3) first. After the completion of the settings and optimization the changeover to the torque control mode will be done.

Note: The difference between PM motors and BLDC motors is mainly the wave form of the induced voltage (Back EMF). The control modes of DA1 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 (P4-01 = 3) sometimes an improvement can be achieved by selecting the control mode for BLDC motors (P4-01 = 5).

Motor Control Mode (P4-01)

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 P4-01 = 3, 4 or 5.

Information for the control of induction motors (P4-01 = 0, 1 and 2): see Application Note AP040018EN.

PNU	Parameter	Name	Range	Default
255.0	P4-01	Motor Control Mode	0: Speed Control with Torque Limit (vector) 1: Torque Control with Speed Limit (vector) 2: Speed Control (enhanced V/f) 3: PM Motor Speed Control 4: PM Motor Torque Control 5: Brushless DC Motor Speed Control 6: SyncRel Motor Speed Control	2

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.

Motor Nom Voltage (P1-07)

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 √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

$$\text{P1-07} = \frac{50 \text{ V}}{1000 \text{ rpm}} \cdot 3000 \text{ rpm} = 150 \text{ V}$$

PNU	Parameter	Name	Range	Default
211.0	P1-07	Motor Nom Voltage	0 / 20 V … U_e	U_e

U_e = 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?
    o Check of the magnetizing current with P0-14 (see „Tips and tricks during optimization")
    o Run motor at rated speed and switch off. Take an oscilloscope and measure the induced voltage directly after switch off.

Motor Nom Current (P1-08)

Rated current of the motor. By default, parameter P1-08 „Motor Nom Current" is set to the rated current I_e of the variable frequency drive. P1-08 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, P1-08 has to be set accordingly to provide a thermal motor protection.

PNU	Parameter	Name	Range	Default
210.0	P1-08	Motor Nom Current	$0.25 \cdot I_e \ldots I_e$	I_e

I_e = Rated current of the device

Motor Nom Frequency (P1-09)

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.

$$P1\text{-}09 \text{ [Hz]} = n \text{ [rpm]} \cdot \frac{p}{2 \cdot 60 \text{ s/min}}$$

PNU	Parameter	Name	Range	Default
216.0	P1-09	Motor Nom Frequency	25 … 500 Hz	50 Hz resp. 60 Hz

Motor Nom Speed (P1-10)

Motor rated speed in rpm. This is the speed at the frequency set with P1-09.

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

Switching Frequency (P2-24)

Switching frequency of the power section. With PM motors and BLDC motors a minimum switching frequency of 16 kHz (default setting) 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 DA1 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	P2-24	Switching Frequency	0 = 4 kHz 1 = 8 kHz 2 = 12 kHz 3 = 16 kHz 4 = 24 kHz 5 = 32 kHz	3 = 16 kHz

Motor Identification (P4-02)

A motor identification run MUST be performed when using a device of the DA1 series together with a PM motor or a BLDC motor (P4-01 = 3, 4 or 5). 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 (P7-01)
  Motor Stator Inductance (P7-03)
  Leak Inductance Rel (P7-05)

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.
- DA1 must not be enabled (no START signal); STO-Signal (Safe Torque OFF) at terminals 13 and 14 has to be present.
- Select parameter P4-02
- Press OK
- 0 is displayed
- Change value to 1
- Acknowledge with OK → The identification starts automatically, display: Auto-t resp. Auto-tuning (OLED-display)
- After the identification the value of P4-02 will automatically be reset to zero. Display: STOP
- The device has determined the required parameters.

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 P1-07, P1-08 and P1-09 have to be set before starting the motor identification.

PNU	Parameter	Name	Range	Default
340.0	P4-02	Motor Identification	0 = OFF 1 = ON	0

ParameterAdaptation (P7-08)

In particular cases it may happen, that the parameters, which are determined during a motor identification run, have to be changed during operation. Background are temperature dependent values of motor data. In most cases the deviations are of minor importance.

The variable frequency drives of the series DA1 have the possibility, to track the parameters of the identification run during operation automatically. This is not done by a new identification run, but based on a calculation inside the motor model.

In case a tracking of the motor data is necessary, it has to be activated by "ParameterAdaptation" (P7-08).

- P7-08 = 0: The motor parameters are determined during an identification run and remain unchanged afterwards.
- P7-08 = 1: The motor parameters are determined during an identification run. These values are used at start. During operation DA1 calculates the actual values automatically and uses them. Background: changes of motor data e.g. of the resistance because of temperature changes.

PNU	Parameter	Name	Range	Default
625.1	P7-08	ParameterAdaptation	0 = Motor parameter determined once and remain unchanged 1 = Tracking of motor parameters	0

Optimization of the motor performance at start and low speeds

Normally PM motors and BLDC motors can be used in a speed range of 20:1. The series DA1 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.

Torque Boost (P7-14) and Torque Boost Range (P7-15)

A current defined by P7-14 (in percent of "Motor Nom Current" (P1-08)) will be injected into the motor. P7-15 defines the frequency (in percent of the "Motor Nom Frequency" (P1-09)) until which this function is active. Objective is to improve the starting torque and the performance in the lower speed range.

PNU	Parameter	Name	Range	Default
32.0	P7-14	Torque Boost	0.0 … 100.0 % P1-08	0.0 %
33.0	P7-15	Torque Boost Range	0.0 … 100.0 % P1-09	0.0 %

Setting of P7-14:
- Run motor at the lowest speed, which is required for this application.
- Increase value of P7-14, until the required torque is available as well as a smooth run of the motor.
- With too low values of P7-14 it can happen that the drive trips during start, especially under load.
- With too high values it is possible, that the motor heats up and the drive trips because of thermal overload (It.trp).
- A typical value for P7-14, where usually a reliable operation can be achieved, is 10 %.

Setting of P7-15:
- Set limit, until which the torque boost should be effective.
- A typical value for P7-15 is 10 %, which can be increased, if necessary.

PM-MotorSignalIn (P7-16) and PM-MotorSignalInLevel (P-17)

When this function is active (P7-16 = 1, 2, 3) a signal of higher frequency will be injected into the motor. This improves the identification of the rotor position and in many cases it enables an increased speed range (> 20:1) of the motor.

By default, this function is deactivated (P7-16 = 0). The setting of P7-16 determines in which situation the injection is active, while P7-17 determines the amplitude. The setting of P7-17 is application dependent. It has to be set in a way, that the function is effective as well as the drive does not trip because of a fault.

Hint: The higher frequent signal causes a noise inside the motor.

PNU	Parameter	Name	Range	Default
230.0	P7-16	PM-MotorSignalIn	0 = disabled 1 = active during magnetizing period 2 = active at low speed 3 = active during magnetizing period and at low speed	0
231.0	P7-17	PM-MotorSignalInLevel	0 … 100	10

Sequence of the settings

- Set the right value of P1-07. During the setting the other optimization functions have to be disabled:
  - o P7-12 = default
  - o P7-14 = 0.0 %
  - o P7-15 = 0.0 %
  - o P7-16 = 0
- Set P7-14 and P7-15 as described above („Torque Boost (P7-14) and Torque Boost Range (P7-15)").
  - If necessary, adopt P7-12 („Adaptation of the magnetizing time and the torque limits")
- In case an operation in the low speed range is necessary, adopt P7-16 and P7-17. Keep the value of P7-17 as low as possible to prevent unintended trips.

Adaptation to the inertia of the load

LoadInertiaFactor (P7-10)

Parameter P7-10 enables the possibility, that the internal calculation is able to take the ratio of the inertias of motor and load into account. In order to get a quick response, the internal algorithm uses a feed forward signal which is dependent on the value of P7-10. The right ratio helps to adopt torque and dynamics to the application. If the inertias are not known, it is recommended to keep the default setting (10).

The value to be prompted is calculates as follows

$$\text{P7-10} = \frac{J_{Tot}}{J_{Mot}} \cdot 10$$

J_{Tot} Total inertia (Motor, load, clutch …)
J_{Mot} Inertia of the motor

The inertia of the motor is an information inside the data sheet. The inertia of the load is either known by the machine designer or it has to be determined by measurements.

Optimization of the speed regulator

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.

Values recommended for PM motors and BLDC motors:

- P4-03 „MSC Kp" (Proportional gain of the speed regulator):   50 [%]
- P4-04 „MSC T_I" (Integral time constant):   100 [ms]

Changes of P4-03 and P4-04 should be done step by step, while observing their impact to the system behavior.

MSC_{Kp} Proportional gain of the speed regulator (P4-03)

The proportional gain is used, to pass the difference between the required and the actual speed to the output of the device proportionally. Therefore the reaction of the drive depends on the value of P4-03. Increasing the value leads to a stronger reaction and consequently to a reduction of the response time.

In case the value of P4-03 is too low, it leads to a slow reaction, too high values can cause instability of the system.

MSC_{TI} Integral time constant of the speed regulator (P4-04)

The integral gain is a cumulated one, which takes into account the difference between reference and actual value as well as the duration, to avoid permanent control deviations. The time constant is set with P4-04 in s. The smaller this time (integration time), the more direct is the impact of a deviation the drives output, which can lead to instability in case the value is too low. Small changes of the time constant can cause significant changes at the drive's output.

PNU	Parameter	Name	Range	Default
2400.0	P4-03	MSC_{Kp}	0.1 … 400 %	50.0 %
2401.0	P4-04	MSC_{Ti}	0.001 … 2.000 s	0.050 s

Procedure to optimize the speed regulator

- Set P4-04 to its highest value (2.000 s)
- Set P4-03 to a value, where the motor reacts in an optimal way without instability.
- After this, set P4-04 to a value that permanent control deviations are eliminated.

Adaptation of the magnetizing time and the torque limits

t-Excitation-V/f (P7-12)

The magnetizing time, which can be set with P7-12, causes a delay between enable and the ramp up of the frequency. This is used to position the rotor and to produce magnetizing current inside the motor windings. The magnetizing current is 50 % of the value set with P1-08 (Motor Nom Current).

This function causes a delay at start. A too short time can lead to a reduction of performance up to trips during start. If required, the value of P7-12 has to be increased.

In cases where the magnetizing time hast to be reduced it has to be ensured, that this does not cause problems during the start of the motor.

PNU	Parameter	Name	Range	Default
25.0	P7-12	t-Excitation-V/f	0… 5000 ms	$f(I_e)$

$f (I_e)$ = depending on the rated current of the device

M-Max Motoring (P4-07) and M-Max Generative (P4-09)

PM motors and BLDC motors have a high peak torque. Normally the factory settings for P4-07 (motor operation) and P4-09 (generator operation) don't have to be changed. Nevertheless there is a possibility to change the values, if necessary.

PNU	Parameter	Name	Range	Default
30.1	P4-07	M-Max Motoring	0 … 200 %	150 %
31.1	P4-09	M-Max Generative	0 … 200 %	100 %

Tips and tricks during Optimization

Many different types of PM motors and BLDC motors exist and also many related information of much different quality. It may be very time consuming to find the right settings and to eliminate possible problems. This section offers a help to check, if the parameters are set correctly.

Checking the magnetizing current with P0-14

After prompting the motor data and performing a motor identification run, the drive can be started. Observe the value of P0-14 during operation in the range of 50…70 % rated speed.

PM motors and BLDC motors don't need magnetizing current and therefore the value of P0-14 should be 0 A, whereat a value of 0.1 A is also acceptable. If this is not the case, it is most likely that the value for P1-07 "Motor Nom Voltage" (Back EMF) is not set correctly. Please adopt the value and try again!

Faults and possible root causes

General fault messages and their root causes are described in the user manual for the drives series DA1. The faults listed below are especially related to the use of PM motors and BLDC motors.

Symptom	Possible root cause and remedy
P4-01 for the selection of the motor control mode cannot be set.	• Level 3 of the parameter menu is not accessible. Prompt password for level 3 into P1-14 (determined by P6-30. Default = 201).
Delay between enable of the drive and start of the motor	• There is a delay time defined by P7-12 to produce magnetizing current and to position the rotor. Optimization see section "Adaptation of the magnetizing time and the torque limits"
Poor torque behavior at low speed	• See „Optimization of the motor performance at start and low speeds"
Too much current leads to heating of the motor	• Check, if „Motor Nom Voltage" (P1-07) is set correctly • Check, if „Motor Nom Current" (P1-08) is set correctly • If the motor runs at low speeds for a longer period of time: Check parameters for torque boost (P7-14 / P7-15)
Motor stalls	• Check motor connection • Check values of the motor parameters (P1-07 … P1-10) • Check result of the motor identification run and repeat if necessary • Load too high → reduce it • Acceleration (P1-03) and deceleration ramp time (P1-04) too short → extend ramp • Use next higher rating of drive / motor
Speed oscillations	• Check, if the switching frequency (P2-24) is at least 16 kHz • Check values of the motor parameters (P1-07 … P1-10) • Check result of the motor identification run and repeat if necessary • Check settings of the speed regulator (P4-03 / P4-04) and reduce gains when necessary
Poor dynamics of the motor, long response times	• Check values of the motor parameters (P1-07 … P1-10) • Check result of the motor identification run and repeat if necessary • Check settings of the speed regulator (P4-03 / P4-04) and increase gains when necessary

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]	$KE_{LL150°C}$ [V /1000rpm]		$R_{UV20°C}$ [Ω]	$R_{UV150°C}$ [Ω]	L_N [mH]	$Kt_{0\ 150°C}$ [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:

- P1-07 = $KE \cdot n_N$ = 64,2 V / 1000 rpm · 3600 r/min = 231 V*
- P1-08 = 7.5 A
- P1-09 = 240 Hz
- P1-10 = 3600 r/min

Further important settings

- Enable menu level 2 (Prompt value defined by P6-30 into P1-14. Default: 201)
- The switching frequency (P2-24) has to be at least 16 kHz (= Default)
- Select motor control mode with P4-01 (in this example: 3 → PM motor with speed regulation)
- Perform motor identification run with P4-02
- Optimize motor performance at start and low speeds. In this example following settings were found to be the optimal ones: P7-14 = 25 %, P7-15 = 10 %. The values are application dependent!
- Optimize speed regulator, if necessary
- Optimize magnetizing time with P7-12, if necessary