

PowerXL™

DG1 Variable Frequency Drives Motor data and V/f curves



Level 2	<ul style="list-style-type: none">1 – Fundamental – No previous experience necessary2 – Basic – Basic knowledge recommended3 – Advanced – Reasonable knowledge required4 – 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

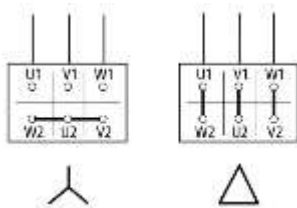
Devices of the series **PowerXL™ DG1** are variable frequency drives for the supply of three phase induction motors. By default they are configured, that motors of the respective power class can be supplied without changing the settings. Many standard cases can be covered.

There are some applications, which require an adaptation by changing parameters. In this Application Note the following aspects are covered:

- Selection of the motor control mode
- Adaptation to the connected motor
- Slip compensation
- Setting the V/f curve

2 Motor data

Condition for a proper operation is the right connection (star / delta) of the motor to the output terminals of the device. The rated voltage of the motor windings is decisive.

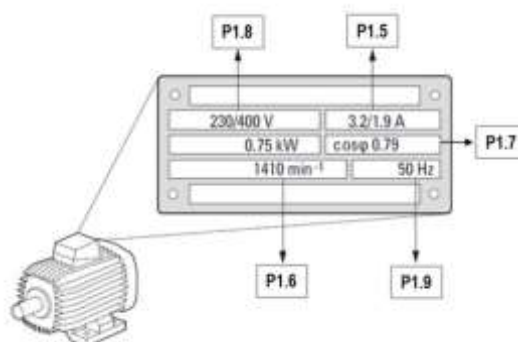


Device	Output Voltage	Motor	Connection
DG1-32...	3 x 230 V	230 / 400 V	Delta
DG1-34...	3 x 400 V	230 / 400 V 400 / 660 V	Star Delta
DG1-34...	3 x 400 V	230 / 400 V	Delta
Special case: 87 Hz-curve (see section 4.2)			

An adaptation to the connected motor can be done with the following parameters:

- P1.6 Motor Nom Speed
- P1.7 Motor PF
- P1.8 Motor Nom Voltage
- P1.9 Motor Nom Frequency

The respective values can be taken from the name plate of the motor or from the data sheet of the motor manufacturer. They are used for the setting of the motor protection and define the V/f curve.



2.1 Motor Nom Current

Parameter P1.5 „Motor Nom Current“ is set to the rated current I_e of the variable frequency drive by default. At the same time it is the set value for the thermal protection of the motor. In case the motor has a nominal current different to the one of the VFD, P1.5 must be set accordingly to ensure motor protection.

It must be pointed out, that this current value is set, which is assigned to the type of connection of the motor. In the example above it is 3,2 A at 230 V (Delta) respectively 1,9 A at 400 V (Star).

Parameter	Name	Range	Default
P1.5	Motor Nom Current	$0,1 \cdot I_e \dots 2 \cdot I_e$	I_e

I_e = Rated current of the variable frequency drive

All measures to protect the connected motor are described in the Application Note AP040176EN “Starting, stopping and operation”.

2.2 Motor Nom Speed

The setting of P1.6 „Motor Nom Speed“ is necessary for three reasons:

- to display the right speed value in all modes of operation
- for calculation of the slip compensation in operation mode “Speed Control” (P8.1 = 1)
- for calculations inside the motor model when operating in vector mode (P8.1 = 5 „Open Loop Speed Control“)

Please use the name plate value for setting P1.6.

Parameter	Name	Range	Default
P1.6	Motor Nom Speed	300 ... 20000 rpm	1750 rpm

2.3 Motor PF

In vector mode (P8.1 = 5 „Open Loop Speed Control“) the power factor ($\cos \varphi$), which is specified on the motor’s name plate, must be set.

Parameter	Name	Range	Default
P1.7	Motor PF	0.3 ... 1	0.85

2.4 Motor Nom Voltage

Motor rated voltage (name plate) taking the connection (star / delta) into account.

In exceptional cases, a different setting of P1-07 is necessary. See section 4.2 “87 Hz curve”

Parameter	Name	Range	Default
P1.8	Motor Nom Voltage	180 ... 690 V	U_e

U_e = Rated voltage of the variable frequency drive, e.g. 230 V or 400 V depending on the device type

2.5 Motor Nom Frequency

Rated frequency of the motor. By default this parameter is set to the mains frequency (50 Hz in Europe, 60 Hz in USA) and doesn't need to be changed in the majority of cases.

In case, motors with rated frequencies different from the mains frequency (e.g. 200 Hz for fast rotating motors) or if the 87 Hz curve is used (see section 4.2), P1.9 has to be set accordingly.

When changing the value of P1.9 the setting of P8.5 "Field Weakening Point" is set to the same value. If the application requires different values for P1.9 and P8.5, Motor Nom Frequency must be set first, before adopting the value for the field weakening point

Parameter	Name	Range	Default
P1.9	Motor Nom Frequency	0.00 ... 400.00 Hz	50 Hz

2.6 Motor Identification

The motor identification MUST be performed in vector mode (P8.1 = 5 or 6) to gain the required parameter values for an optimal performance of the motor.

ATTENTION: The motor data (e.g. the resistance) change with the temperature. Therefore the motor identification run shall be performed with a warm motor.

The kind of motor identification run is determined by the setting of P8.14 „Identification“. The following motor data are identified:

- Motor Stator Resistance R1 (P8.50)
- Motor Rotor Resistance R2 (P8.51)
- Motor Leak Inductance X1 (P8.52)
- Motor Mutual Inductance Xh (P8.53)
- Motor Excitation Current (P8.54)

P8.14 = 0: No Action

No identification of the motor data will be performed. This is the setting during normal operation of the drive.

P8.14 = 1: Identification Only Stator Resistor

During the identification run only the stator resistance is identified. The other values remain unchanged.

P8.14 = 2: Identification with Run

The values for the parameters P8.50 ip to P8.54 are identified. The measurement is done with a running motor. The motor must be unloaded (load decoupled, no gearbox ...).

P8.14 = 3: Identification No Run

The values for the parameters P8.50 ip to P8.54 are identified. During the measurement the motor is standing still.

How to perform a motor identification run:

- Before starting a motor identification run, the motor data (parameters P1.5 up to P1.9) must be set.
- Select the motor control mode P8.1 = "3: Open Loop Speed Control".
- Select in P8.14 „Identification“, which kind of identification shall be performed (P8.14 = 1...3).
- Remove any connection between the drive and a PC during identification run.
- Apply START command
- The identification of the motor data takes place automatically and is active for about 30 s respectively until the START signal will be removed.
- On the keypad „Motor Identification“ is shown.
- The motor data are identified and assigned to the respective parameters.
- In case an identification is not possible, the fault message “Motor ID Fault” (#57) is displayed. One reason could be that the rated power of the connected motor deviates too much from the one of the variable frequency drive. Alternatively the motor data can be set manually on the basis of technical information supplied by the motor manufacturer.
- After a motor identification run, the START signal must be reapplied to start the motor. The motor doesn't start automatically, even when the START signal is still applied to the respective terminal.
- Parameter P8.14 “Identification” is reset to “0: No action” automatically as soon as the identification run is finished.

Parameter	Name	Range	Default
P8.14	Identification	0: No Action 1: Identification Only Stator Resistor 2: Identification with Run 3: Identification No Run	0: No Action
P8.50	Stator Resistor	0.001 ... 65535 Ω	0.033 Ω
P8.51	Rotor Resistor	0.001 ... 65535 Ω	0.034 Ω
P8.52	Leak Inductance	0.01 ... 655.35 mH	0.12 mH
P8.53	Mutual Inductance	0.1 ... 6553.5 mH	3.4 mH
P8.54	Excitation Current	0.1 ... 7.4 A	0.1 A

3 Motor Control Mode

Parameter P8.1 „Motor Control Mode“ determines the way, how the motor is controlled (e.g. frequency or vector control). The information given inside the Application Note refer to the settings P8.1 = 0, 1 or 5.

By default the variable frequency drive is configured for Frequency Control (P8.1 = 0), which is mainly used in simple applications. With speed control (P8.1 = 1 or 5) an improved speed accuracy and a better torque performance can be achieved. In this case the motor data must be set and with Open Loop Speed Control (P8.1 = 5) a motor identification run (P8.14, see section 2.6) is necessary.

Parameter	Name	Range	Default
P8.1	Motor Control Mode	0: Frequency Control 1: Speed Control 5: Open Loop Speed Control 6: Open Loop Torque Control	0

3.1 Frequency Control (V/f)

P8.1 = 0

The output frequency of the variable frequency drive is proportional to the reference, which is for example applied to an analog input. The ratio between the output voltage and the frequency is kept constant. This leads to a speed change when the load is changing, like with a single speed motor connected DOL to the mains.

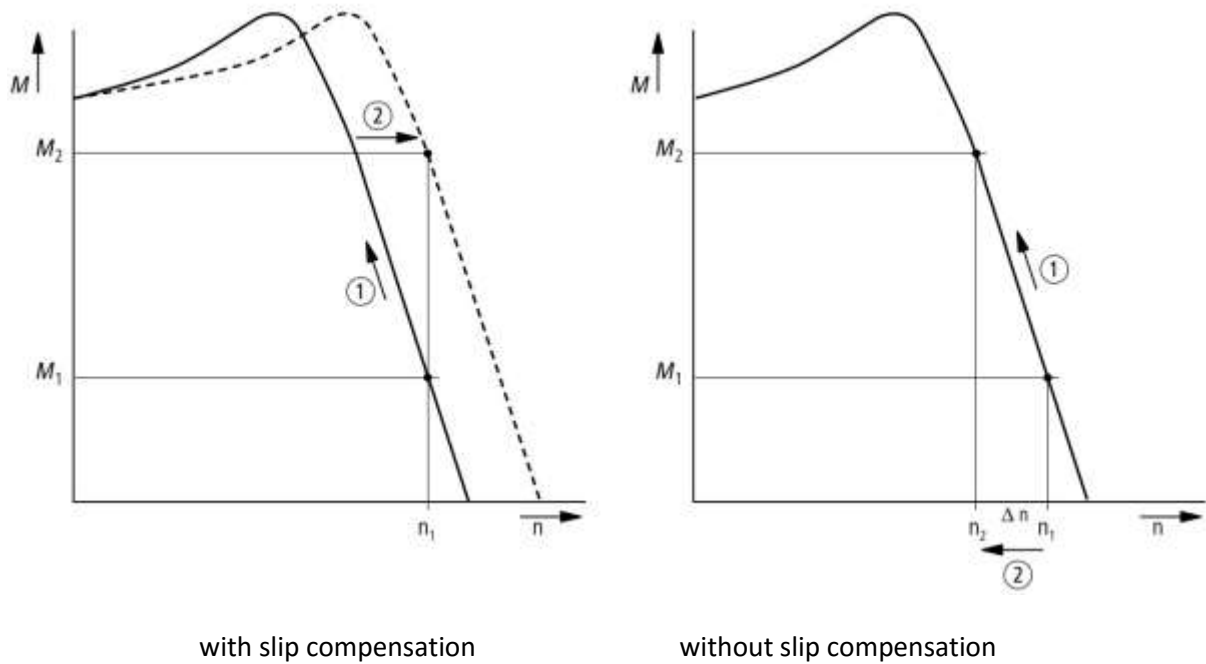
This control mode is preferred, when multiple motors are connected in parallel at the output of one single variable frequency drive respectively in simple applications, where no special requirements concerning speed accuracy at variable load exist.

3.2 Speed Control

P8.1 = 1

In principle the Speed Control works like the Frequency Control described in section 3.1. At Speed Control the slip compensation is activated in addition, which takes care, that the motor speed is kept approximately constant even in case of load changes. In this motor control mode the motor data must be set (P1.5 up to P1.9)

The slip is the difference between a synchronous speed because of a rotating field and the actual speed of the motor. The name plate in section 2 shows a rated speed of 1410 rpm. It is a 4 pole motor with a synchronous speed of 1500 rpm. Between no load and rated load there is a slip of 90 rpm. Running the motor with a variable frequency drive, one wants to prevent the speed variance by compensating the slip.



With slip compensation: at load increase ① voltage and frequency are increased accordingly ②. The speed n_1 remains constant. At load decrease voltage and frequency are reduced.

Without slip compensation: with load ① the speed drops from n_1 to n_2 ②, when unloading the speed increases again.

3.3 Open Loop Speed Control

P8.1 = 5

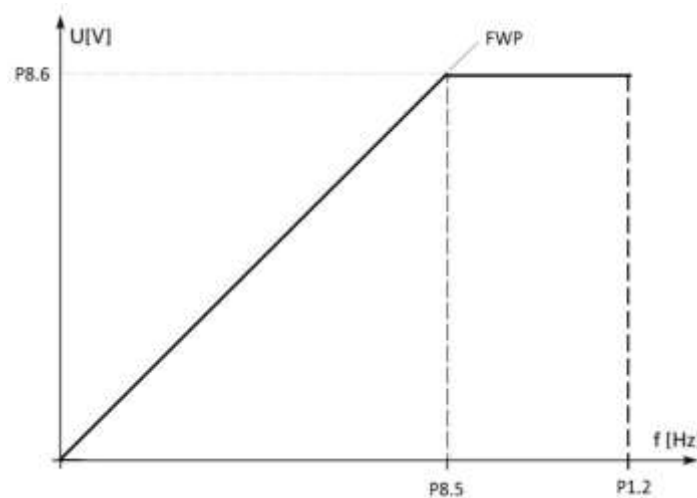
Open loop means, that a feedback of the motor speed to the variable frequency drive, e.g. by using an encoder, is not required. The speed information used in the control algorithm is the result of a calculation by the motor model. To ensure an optimal performance, the motor data (parameters P1.5 up to P1.9) must be set and a motor identification run must be performed (see section 2.6). Speed accuracy and torque performance are improved compared to the motor control mode "Speed Control" described in section 3.2.

Note: When multiple motors are connected in parallel to one single variable frequency drive, this motor control mode may not be used!

4 V/f curve

The V/f curve determines the magnetization of the motor and therefore the torque behavior significantly. In addition the energy efficiency of the complete system can be impacted.

As described in section 3, multiple motor control modes exist. Common to all of them is, that the field weakening point (FWP) and the maximum frequency must be defined. In case of open loop speed control (P8.1 = 5), the variable frequency drive calculates the necessary settings on the basis of this information and the determined motor data. In case of frequency control (P8.1 = 0) or speed control with slip compensation (P8.1 = 1) it is possible to modify the V/f curve to improve the torque behavior (see section 4.1).



- P1.2 „Max Frequency“
maximum frequency for the application. This frequency may be above the „Motor Nom Frequency“ (P1.9).
- P8.5 „Field Weakening Point“
This parameter defines the frequency, at which the maximum output voltage, defined with P8.6, is reached.
- P8.6 „Voltage at FWP“
Maximum voltage of the variable frequency drive in percent of the Motor Nom Voltage (P1.8). This voltage is reached at the field weakening point (FWP) defined with P8.5.

Note: At a change of parameter P1.9 „Motor Nom Frequency“ P8.5 is automatically set to the same frequency value. In applications, where the frequency at FWP is different to the Motor Nom Frequency, P1.9 must be set first, before setting P8.5. The same is true for the voltage. Here P1.8 “Motor Nom Voltage” must be set before P8.6 “Voltage at FWP”.

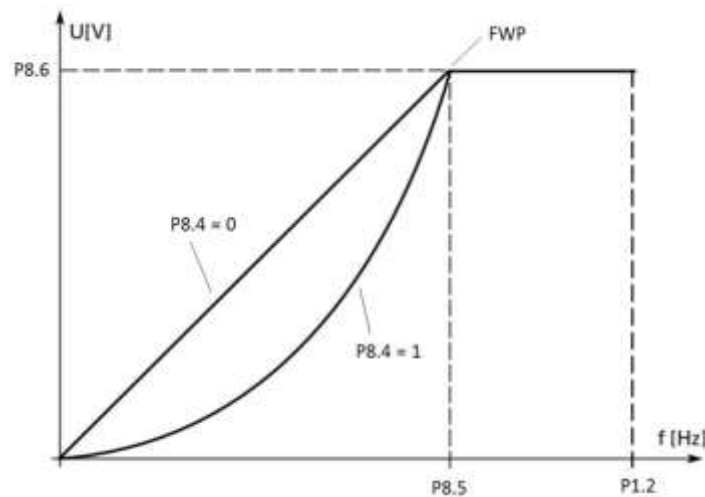
Parameter	Name	Range	Default
P1.2	Max Frequency	P1.1 ... 400 Hz	50.0 Hz
P8.5	Field Weakening Point	8.0 Hz ... P1.2	P1.9
P8.6	Voltage at FWP	10 ... 200 % • P1.8	P1.8

4.1 Optimizing the V/f curve at Frequency Control and Speed Control

The V/f curve shown in section 4 is idealized (P8.4 = 0 “Linear”) and sufficient for many applications. There are two cases, where the shape of the V/f curve should be adopted:

- where a higher starting torque is required, respectively where the motor has to run at lower speed stationary
- in pump and fan applications, where the motor losses shall be reduced by field weakening under part load conditions.

The different shapes of the V/f curve can be selected with P8.4 “V/Hz Ratio”.



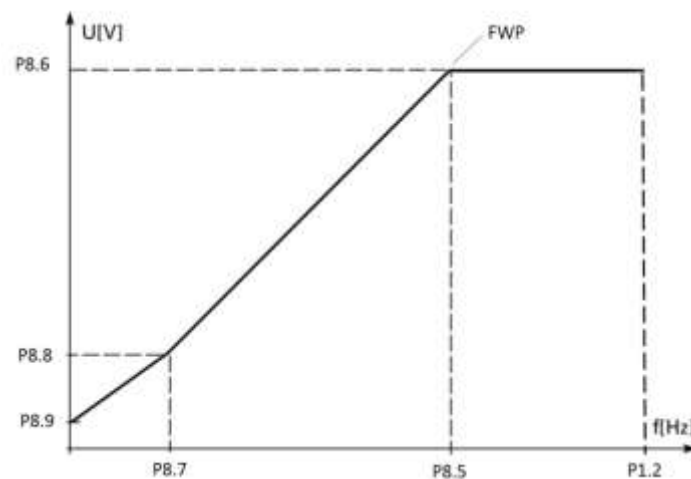
- P8.4 = 0 „Linear“
Voltage and frequency change linearly from zero up to the field weakening point (FWP)
- P8.4 = 1 „Squared“
Voltage and frequency change squared from zero up to the field weakening point (FWP). See also section 4.1.2.
- P8.4 = 2 „Programmable“
The shape of the curve can be configured, see also section 4.1.1-
- P8.4 = 3 „Linear + Flux Optimization“
The shape of the V/f curve is adopted to the load conditions automatically, see also section 4.1.2.

Parameter	Name	Range	Default
P8.4	V/Hz Ratio	0: Linear 1: Squared 2: Programmable 3: Linear + Flux Optimization	0: Linear

4.1.1 Improving the torque behavior

When operating with lower speeds, the voltage drop inside the motor becomes particularly noticeable, which leads to a reduced speed, unbalanced run and in extreme cases to a standstill of the motor with current flow at the same time. This effect can be reduced by increasing the output voltage in the lower speed range. P8.3 “V/Hz Optimization” determines, in which way this will be achieved:

- P8.3 = 1 „Enabled“
 - The voltage is increased automatically. The value depends on the motor rating and the values are based on experience. Setting:
 - Set motor data in parameter group 1 (P1.5 up to P1.9)
 - P8.3 = 1: Enabled
- P8.3 = 0 „Disabled“
 - The shape of the V/f curve can be configured manually. In this case P8.4 „V/Hz Ratio“ has to be set to „2: Programmable“.



- P8.7 „V/Hz Mid Frequency“
- P8.8 „V/Hz Mid Voltage“
- P8.9 „Zero Frequency Voltage“

The V/f curve is divided into two sections. It starts at zero frequency with a voltage defined with P8.9 „Zero Frequency Voltage“, proceeding linearly to a point defined by P8.7 “V/Hz Mid Frequency” for the frequency and by P8.8 “V/Hz Mid Voltage” for the voltage, and from there to the field weakening point (FWP). With this measure it is possible to increase the voltage in the lower range above average to compensate the voltage drop inside the motor and to improve the torque behavior.

Beside other cases this measure is used, when a drive is operated in the lower speed range stationary. It has to be noted, that the cooling of the motor is usually realized by a fan, which is mounted on the motor’s shaft and whose cooling effect is reduced correspondingly. When a certain torque is required in this range, it must be ensured, that the motor will not be overheated. Eventually a separately driven fan must be used.

When setting the parameters, the motor must initially be operated unloaded with linear V/f curve. It is presumed, that the motor data (P1.5 up to P1.9) are set already and that the general settings for the V/f curve (see section 4) are completed.

- P8.4 „V/Hz Ratio“ = 0: Linear
- Run the motor with 2/3 of its rated speed.
- Read the motor current on the keypad or in the configuration software inControl (M4). Because of the unloaded motor the actual current corresponds approximately to the excitation current.
- Remove START signal
- Set P8.54 „Excitation Current“ to the value measured before. It is required for internal calculations.
- P8.4 „V/Hz Ratio“ = 2: Programmable
- During the following settings P1.1 “Min Frequency” must be set to zero, even when the application requires higher values for the minimal frequency during normal operation. When the V/f settings are completed, P1.1 can be set back to the value, which is required by the application.
- Frequency reference = 0, start variable frequency drive
- Increase the value of P8.9 “Zero Frequency Voltage”, until the current is as high as measured before.
- Stop drive
- Set P8.7 and P8.8 to the required values. The setting is application dependent. Additional to the settings here it is possible to set the motor control mode (P8.1) to “1: Speed Control” and/or to enable the “V/Hz Optimization” with P8.3. In general good results can be achieved by using the following rule of thumb:
 - $P8.8 = 1,4 \cdot P8.9$
 - $P8.7 = P8,5 \cdot (P8.8 : P8.6)$

Parameter	Name	Range	Default
P8.3	V/Hz Optimization	0: Disabled 1: Enabled	0: Disabled
P8.7	V/Hz Mid Frequency	0 Hz ... P8.5	0 Hz
P8.8	V/Hz Mid Voltage	P8.9 ... P8.6	
P8.9	Zero Frequency Voltage	0 % ... 40 % P8.6	0 %
P8.54	Excitation current	Depends on drive rating	

4.1.2 Increasing energy efficiency

Objective is to reduce the losses inside the motor to increase the overall system efficiency. Because of the voltage reduction the field of the motor is weakened, which leads to a reduction of the reactive current, while the active one is increasing at the same time, but not as much as the reactive current decreases. This leads to a decrease of the overall motor current. This principle is only applicable, when the application doesn't require full torque in the complete speed range.

The device series DG1 has two possibilities to achieve this:

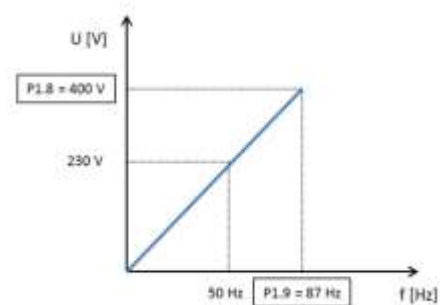
- P8.4 „V/Hz Ratio“ = 1: Squared
with this setting the voltage increases squared with the frequency, until it reaches its maximum at the FWP, see also drawing in section 4.1.1
- P8.4 „V/Hz Ratio“ = 3: Linear + Flux Optimization
In principle the V/Hz curve is linear. When the drive operates under part load conditions for a certain time (approximately 1 minute), the voltage is automatically decreased by some Volts. The procedure is repeated until the current is at its minimum. This leads to less losses inside the motor and to a noise reduction. In case a higher torque is required the drive returns to its linear V/f curve and the process starts again. This kind of energy optimization makes sense, when different torque can be required at the same speed. This principle is only applicable to drives without short term speed changes, but with constant speed for a certain time.

4.2 87 Hz curve

In the majority of cases standard asynchronous motors are used up to their rated frequency. The maximum output frequency of the variable frequency drive is 50 Hz. The power of the motor can be increased by $\sqrt{3}$, by increasing the frequency from 50 Hz to 87 Hz ($50 \text{ Hz} \cdot \sqrt{3}$), keeping the flux (magnetizing current) constant at the same time.

Conditions at a 400 V mains

- The motor is wound for 230/400 V (not 400/690 V)
- The windings are connected in delta.
- The variable frequency drive has a maximum output voltage of 400 V and a maximum frequency of 87 Hz. This results in 50 Hz at 230 V.
- The variable frequency drive is selected for a current which is the rated current of the motor at 230 V.



Parameters

- P1.8 = 400 V
- P1.9 = 87 Hz (with 50 Hz on the name plate)

ATTENTION: When using a 50 Hz motor at 87 Hz, possible imbalances of the rotor can cause mechanical damages. It is recommended to contact the motor manufacturer before using this motor at speeds above rated speed.

Example for selection:

Motor data

- 230 / 400 V
- 3,2 / 1,9 A
- 0,75 kW
- 1410 min⁻¹
- 50 Hz

Selection

- Device rated for 400 V, but for the current which is assigned to 230 V (here: 3,2 A) → DG1-343D3FB-C21C.
- The power of the motor results in $0,75 \text{ kW} \cdot \sqrt{3} = 1,3 \text{ kW}$ (rated torque at $\sqrt{3}$ times rated speed).
- The synchronous speed of the motor is $1500 \text{ rpm} \cdot \sqrt{3} = 2598 \text{ rpm}$
- The expected speed at rated load is $2598 \text{ rpm} - 90 \text{ rpm} = 2508 \text{ rpm}$
Remark: 90 rpm corresponds to the slip speed ($1500 \text{ min}^{-1} - 1410 \text{ min}^{-1}$)