SIEMENS

Operating three-phase motors with speeds above the rated speed

for SINAMICS G120, G120C and MICROMASTER 440

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Preposition

Aim of the application

Three-phase squirrel-cage induction motors can be connected to the line supply and operated at a constant voltage and frequency – they can also be connected to a drive inverter and operated with a variable voltage and frequency. When an induction motor is fed from a frequency inverter, in addition to variable speeds up to n_{rated}, speeds above the rated speed are also possible.

To achieve higher speeds, the drive inverter output frequency is normally increased. This has the associated disadvantage that the flux and therefore the motor torque are reduced.

As a result of the relatively constant flux – even in the field weakening range - the "87Hz-characteristic" offers an interesting version.

In this particular application, the parameterization (parameter assignment) of the frequency inverter is briefly described – using examples - for speed ranges above the rated speed with "normal" V/f characteristic and with 87Hz characteristic.

Exclusion

This application does not include a description of

- The individual drive inverter
- The STARTER tool
- Dimensioning and selecting motors
- Explosion-protected motors

It is assumed that the reader has basic knowledge about these subjects.

Application description

Motors fed from drive inverters can be operated above their rated frequency in various ways. On one hand using "field weakening" and on the other hand using the "87Hz-characteristic". Both of these versions will now be briefly described in the following text using examples. The examples and description refer exclusively to a motor interpreted for Europe.

1 Basic information

1.1 Three-phase motors fed from drive inverters

Squirrel-cage three-phase motors can be connected to the line supply that has a constant voltage and frequency. They can also be connected to a frequency inverter that has a variable voltage and frequency output. The operating behavior of a motor changes depending on whether it is connected directly to the line supply – or a frequency inverter. When connected directly to the line supply, the motors

operate with sinusoidal voltages and currents with an almost constant speed. Continuous speed control with low associated losses is achieved by connecting a frequency inverter between the line supply and the motor.

The conditions – that change with respect to direct online operation - must be carefully taken into consideration when selecting the motors.

When engineering electric drives, the speed – torque behavior of the motors and the driven load (driven machine) are important. While the speed-torque characteristic is important when an induction motor is fed directly from the line supply, when fed from a frequency inverter, it is especially the limit characteristic of the torque as well as (for speeds above the rated speed), the mechanical speed limit of the motor[1].

1.2 Torque limit characteristic

The speed-torque behavior (characteristics) of the motor and driven load (driven machine) are important when engineering electric drives,.

A typical motor torque characteristic when connected directly to the line supply with the characteristic features starting torque, pull-up torque and stall torque are shown in the following diagram. When fed from a frequency inverter, generally only the steep (high gradient) range - shown as dotted line - is used from the complete speed-torque characteristic (M-n characteristic). Using the frequency and voltage control of the frequency inverter (V/f characteristic), this range can be shifted in parallel towards lower speeds by reducing the frequency. Higher frequencies shift this range, for constant flux, in parallel and for field weakening, with decreasing gradient to the right to higher speeds. The torque that can be continuously achieved is entered as limit characteristic in the diagram. The limit characteristic defines – for a constant flux – the thermally permissible torque in continuous operation.

At the torque limit, the motor temperature rise in continuous operation is not higher than that specified by its thermal class[2]. Operation at "zero" speed is always possible.

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[1] Mechanical stress, grease lifetime: As a result of high speeds above the rated speed when fed from a frequency inverter, oscillation/vibration levels increase, the mechanical smooth running characteristics change and the bearings are subject to higher mechanical loads. As a result, the grease lifetime is reduced together with the bearing lifetime. Especially for frequency inverter operation, the mechanical limit speeds n_{max} at the maximum supply frequency f_{max} should be carefully taken into consideration. In this context, also refer to Catalog D81.1, Catalog section "Motors connected to frequency inverters".

[2] For the "87 Hz characteristic" this means that the motor must have the appropriate thermal reserves for operation (above 50 Hz, the iron losses increase as the field is not weakened).

1.2 Torque limit characteristic
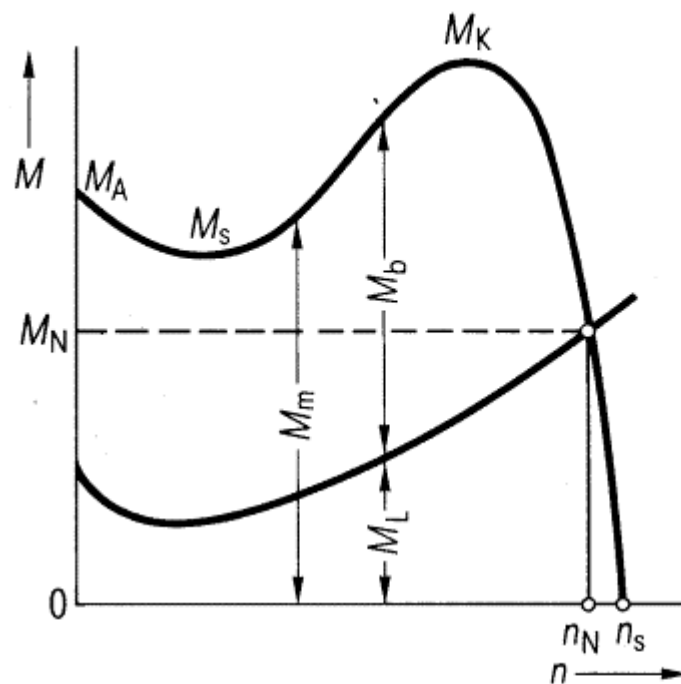
M_N = rated torque
M_m = motor torque   (mean value)
M_L = load torque   (mean value)
M_b = acceleration torque
M_a = locked rotor torque
M_k = break down torque
M_s = pull-up torque
n_N = rated speed
n_s = synchronous speed

2 Task Operating motors at higher frequencies

When operating a motor above the rated frequency (speed), there are two possibilities. One of these possibilities is to operate the motor in the field-weakening range or to operate the motor using the so-called 87 Hz characteristic.

The following always applies: Motors fed from frequency inverters can be operated above their rated frequency.

"Field weakening operation"

When considered from the physical perspective, field weakening of a motor starts if the output voltage of the frequency inverter is no longer increased (can no longer be increased) – however, its frequency is increased.

Generally, "field-weakening operation" is involved when a motor is operated above the rated motor frequency and the supply voltage remains the same.

For this operating mode, the frequency inverter is parameterized for a maximum frequency greater than the rated frequency (e.g. 80Hz / 400V). As the frequency inverter frequency is increased, the output voltage remains constant, the speed increases, however, the torque decreases. The torque decreases because the flux in the motor decreases.

At constant power, the torque decreases inversely proportional to the speed.

"87Hz characteristic"

This operating mode is possible for motors that, at the rated frequency, can be connected-up both in a star as well as a delta circuit configuration. The star circuit configuration with a voltage that is lower by a factor of root (3) is used which means that the speed can therefore be increased by a factor up to root (3) of the motor frequency (87Hz) at an almost constant torque. For this operating mode, e.g. a 230 / 400V motor is connected-up in the Δ circuit configuration (50Hz / 230V) - however, the frequency inverter is parameterized for 87Hz / 400V (for a 400V line supply voltage). For the motor, this means that from the rated motor frequency (50Hz / 230V), the voltage is continuously increased up to almost f_{max} = 87Hz. This means that the motor is not operated in the field-weakening range, but instead operates with a constant flux.

Engineering information:

- When operating a motor above the rated motor frequency (speed), then the frequency inverter and motor must be appropriately selected, dimensioned and parameterized. The motor must be dimensioned for this type of operation. The following should be carefully observed:
  - the mechanical limit speeds
  - the increased thermal load
  - the increased voltage stress on the motor (the motor insulation)
  - the modulation depth of the frequency inverter[3]

- In order to achieve higher speeds, it is generally more practical to select a motor whose rated speed is close to the operating speed.
- Example: In order to reach an operating speed of 1800 rpm, it should be considered as to whether a 4-pole motor with 1500 rpm synchronous motor speed - and a correspondingly higher frequency - or a 2-pole motor with 3000 rpm synchronous motor speed and a correspondingly lower frequency - is the better fit for the particular application.

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[3] MICROMASTER 4 frequency inverters have a modulation depth of between 92% - 95% of V_{line} - depending on the closed-loop control type. This means that above ~ 80Hz/370V, the frequency inverter output voltage no longer increases and the motor is operated in field weakening.

Comparison between V/f characteristic and 87Hz characteristic
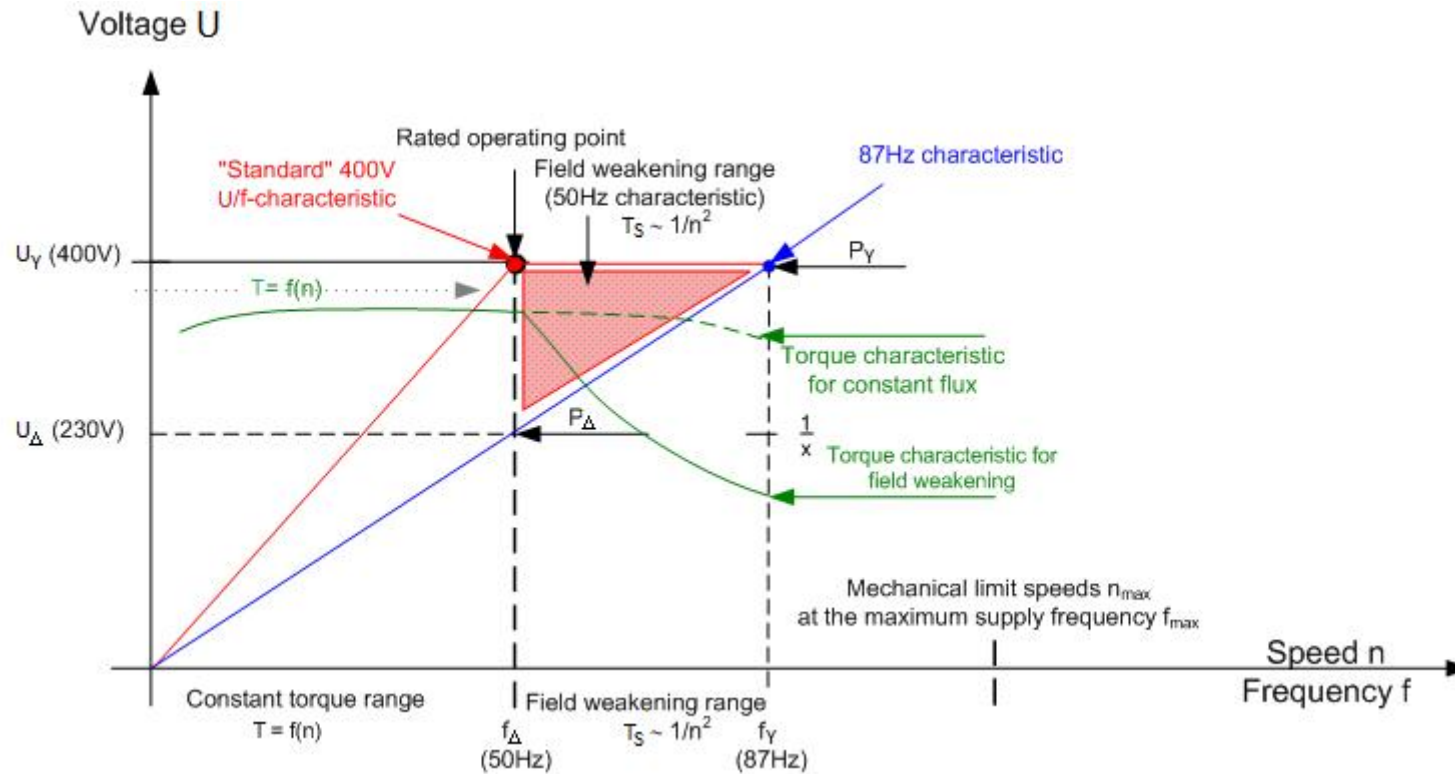
3 Examples

The two variants "field weakening" and "87 Hz characteristic" are now shown using an example of a motor.

Frequency inverter

All 400V MICROMASTER 4 and SINAMICS G120 frequency inverters can be used.

Data of the motor used as an example

In the example, a standard Siemens motor (1LA7060-4AB …) is used with the following data (this data has been taken from the D81.1 motor catalog).

Δ: 230V; 50 Hz; 0.73A; 0.12kW; 1350 rpm
Y: 400V; 50 Hz; 0.42A; 0.12kW; 1350 rpm

Rated motor torque T_N = 0.85 Nm

Motor stall torque T_S = 2 Nm
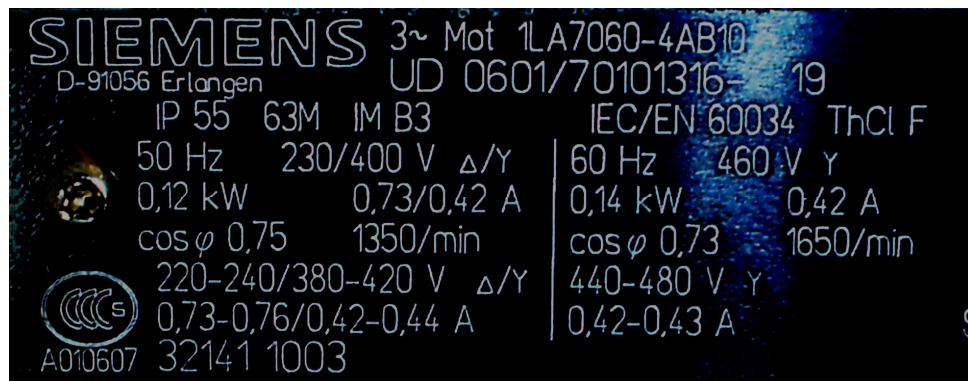
Figure 3-1 Rating plate of the motor being used

Operating speed and operating frequency

In the example the motor shall run with an operating speed of 2250 rpm. The necessary output frequency of the drive is calculated as follows:

$$f_{operation} = \frac{n_{operation} + s}{60} * p = \frac{2250 + 150}{60} * 2 = 80 Hz$$

with
s   = $n_{synchron}$ − n = 1500–1350 = 150 rpm

$n_{synchron}$ = f_N/p *60   = 50/2 * 60   = 1500 rpm

$f_{operation}$ =   Required operating frequency
$n_{operation}$ =   Required operating speed
s   =   Slip
p   =   Number of pole pairs from motor data
$n_{synchron}$ =   Synchronous speed
f_N =   Nominal frequency (rating plate)

Commissioning tools

In the example, the commissioning tool STARTER V4.3.3 can be used for commissioning. An operator panel can also be used to commission the drive.

3.1 Operation in the field-weakening range

With this operating mode, the frequency is increased above the rated frequency – with the voltage kept constant – and the frequency changes. This means that the output voltage of the frequency inverter remains at the value parameterized for f_{rated}. Here, in this particular example, 50Hz / 400V, whereby, the frequency f^* is simultaneously increased (e.g. to 80Hz). .

In the field weakening range the motor stall torque M_K decreases significantly ($T_K \sim 1/f^2$). This means that the operating torque $T_{operation}$ must be reduced more from the limit frequency f_G onwards – otherwise the necessary clearance (margin) between the stall torque M_K and the operating torque $T_{operation}$ would be too low. In practice, the stall torque should lie at least 30% ~ 40% above the torque required under steady-state conditions.

Motor connection

For this operating mode, the motor is connected up in the **Y** circuit configuration
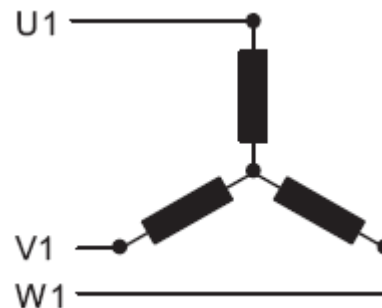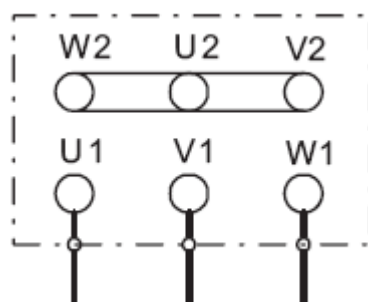
Operation in the field-weakening range is independent of how the motor is connected-up.

3.1 Operation in the field-weakening range

Torque characteristic at field weakening

Schematic representation of the torque characteristic of a motor, fed from a frequency inverter for field weakening

Stall limit at the maximum drive
inverter output voltage
$T_S = \sim 1/n^2$

Rated operating point

P_N

T_N

$T = f(n)$

$P = f(n)$

Characteristics of the power requirement
over the complete frequency bandwidth

Reduced stall torque for the
field-weakening range T_{KRed}

Maximum possible torque for field-
weakening operation when fed from a
drive inverter

≥ 30% difference

Operating point in the
field-weakening range $T_W = T_{operation}$

Speed n
Frequency f

Constant torque range

Field weakening range

Mechanical limit speeds n_{max}
at the maximum supply frequency f_{max}

f_{min}

n_N
(f = 50Hz)

n_1

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3.1 Operation in the field-weakening range

Calculating the motor torque for field-weakening operation

$$T_{operation} = \frac{f}{f_{operation}} * T_N = \frac{50Hz}{80Hz} * 0,85Nm = 0,53Nm$$

$T_{operation}$ = Operating torque
f = Rating plate frequency
$f_{operation}$ = Operating frequency
T_N = Nominal torque from rating plate

Calculating the reduced stall torque

Reduced stall torque in the field-weakening range is calculated as follows:

$$T_{S\,Red.} = \left(\frac{f}{f_{operation}}\right)^2 * T_S = \left(\frac{50Hz}{80Hz}\right)^2 * 2Nm = 0,78Nm$$

$T_{SRed.}$ = Reduced stall torque
f = Rating plate frequency
$f_{operation}$ = Operating frequency
T_S = Stall torque from motor data

Stall limit

In order to guarantee reliable operation in the field-weakening range, the difference between the lower stall torque and the (maximum possible) operating torque ($T_{operation\,max}$) must be more than 30%!

This is calculated as follows:

$$Stall\ limit = \frac{T_{S\,Red.}}{T_{operation}} \times 100\% = \frac{0.78Nm}{0.53Nm} \times 100\% = 147\%$$

$T_{SRed.}$ = Reduced stall torque
$T_{operation}$ = Operating torque

The stall limit for our motor in the example is 147% of the operating point. This means, that for the motor in the example, there is a margin of 47% (T_{Sred} – $T_{Soperation}$ = 147% - 100%). Under the prerequisite that the motor is not subject to a load higher than 0.53Nm in continuous operation at the operating point, then it may be operated up to 80Hz in field weakening.

Parameterization via operator panel or STARTER expert list

For field-weakening range select the rating plate data for star circuit configuration as follows:

P0304 = Rated motor voltage: 400 V
P0305 = Rated motor current: 0,42 A
P0307 = Rated motor power: 0,12 kW
P0308 = Motor cosPhi: 0,75
P0310 = Motor frequency: 50 Hz
P0311 = Rated motor speed: 1350 rpm
P1082[4] = Max. frequency: 80 Hz
P1082[5] = Max. speed: 2400 rpm
P2000[4] = Reference frequency: 80 Hz
P2000[5] = Reference speed: 2400 rpm

Parameterization via the STARTER configuration wizard

Under „Motor data" adjust the following parameters:

P0304 = Rated motor voltage: 400 V
P0305 = Rated motor current: 0,42 A
P0307 = Rated motor power: 0,12 kW
P0308 = Motor cosPhi: 0,75
P0310 = Motor frequency: 50 Hz
P0311 = Rated motor speed: 1350 U/min

Under „Important parameters"" adjust the following parameters:

P1082[4] = Max. motor frequency: 80 Hz
P1082[5] = Max. motor speed: 2400 U/min

(P2000 Reference frequency/speed is automatically set to P1082.)

3.2 Operation with constant flux / "87Hz-characteristic"

Information regarding the motor

In this mode the frequency inverter's output is parameterized to 87Hz / 400V and the motor is operated in Δ circuit configuration (230V / 50Hz). So the motor is exposed to factor $\sqrt{3}$ of its Δ circuit configuration data.

For this operating mode, the frequency is increased above the rated frequency with increasing voltage. This means that the frequency inverter output voltage increases from f_{rated} (50Hz) to the value parameterized for f_{max} (87 Hz); as a consequence, both the magnetic flux as well as the available torque remain approximately constant.

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[4] MM4, G120 CU2x0x
[5] G120 CU2x0x-2, G120C

3.2 Operation with constant flux / "87Hz-characteristic"

However, the torque has to be reduced due to the iron losses that increase with the frequency. However, in spite of this, when using this technique, a significant increase in power is achieved compared to the rated power.

As the frame size increases, this power increase becomes lower and therefore no longer "pays off".

- For operation with the "87Hz characteristic" please note the following:
    - The motor must be connected in the delta circuit configuration.
    - The motor must have the appropriate voltage strength (appropriate motor insulation) – not all motors are suitable for 87Hz operation.
    - The mechanical motor limit values must be taken into account (this is especially true for 2-pole motors).
    - A higher noise level when compared to 50Hz must be taken into account.
- Generally, the "87Hz characteristic" only makes sense for motors with a "lower power rating" (up to approximately 45 kW).
- Above the rated motor frequency, the iron losses increase over-proportionally. This is the reason that above this frequency, the thermal motor torque must be reduced.

Information regarding the frequency inverter

For the "87Hz characteristic", the motor must be connected-up in the Δ circuit configuration and the frequency inverter software cannot make a distinction between a star circuit configuration and delta circuit configuration (the frequency inverter software sees the motor as a back box"). This is the reason that the motor model parameters must be appropriately parameterized.

- The frequency inverter must be dimensioned for the higher current demand of the motor (delta circuit configuration); this means that under certain circum-stances, the frequency inverter must be selected one power stage larger.
- The "87Hz characteristic" is independent of the control type and can therefore be used both for V/f control (open-loop control) as well as for vector control.

Motor connection

For this operating mode, the motor is connected-up in the Δ circuit configuration

Data, 230V; 50 Hz; 0.73A; 0.12kW; 1350 rpm
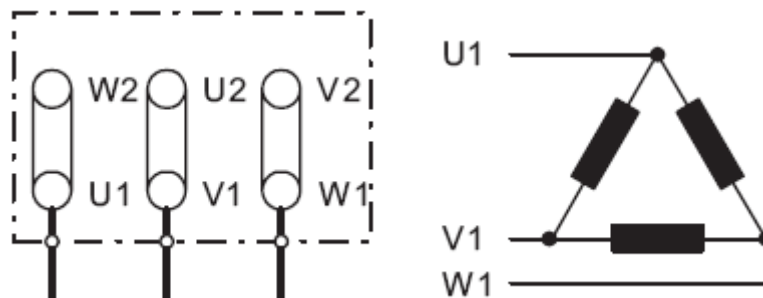
Additional data on the 87Hz characteristic are provided in the Operating Instructions of the particular frequency inverter.

3.2 Operation with constant flux / "87Hz-characteristic"

Torque characteristic at 87Hz operation

Schematic representation of the torque characteristic of a motor fed from a frequency inverter for the 87Hz characteristic

3.2 Operation with constant flux / "87Hz-characteristic"
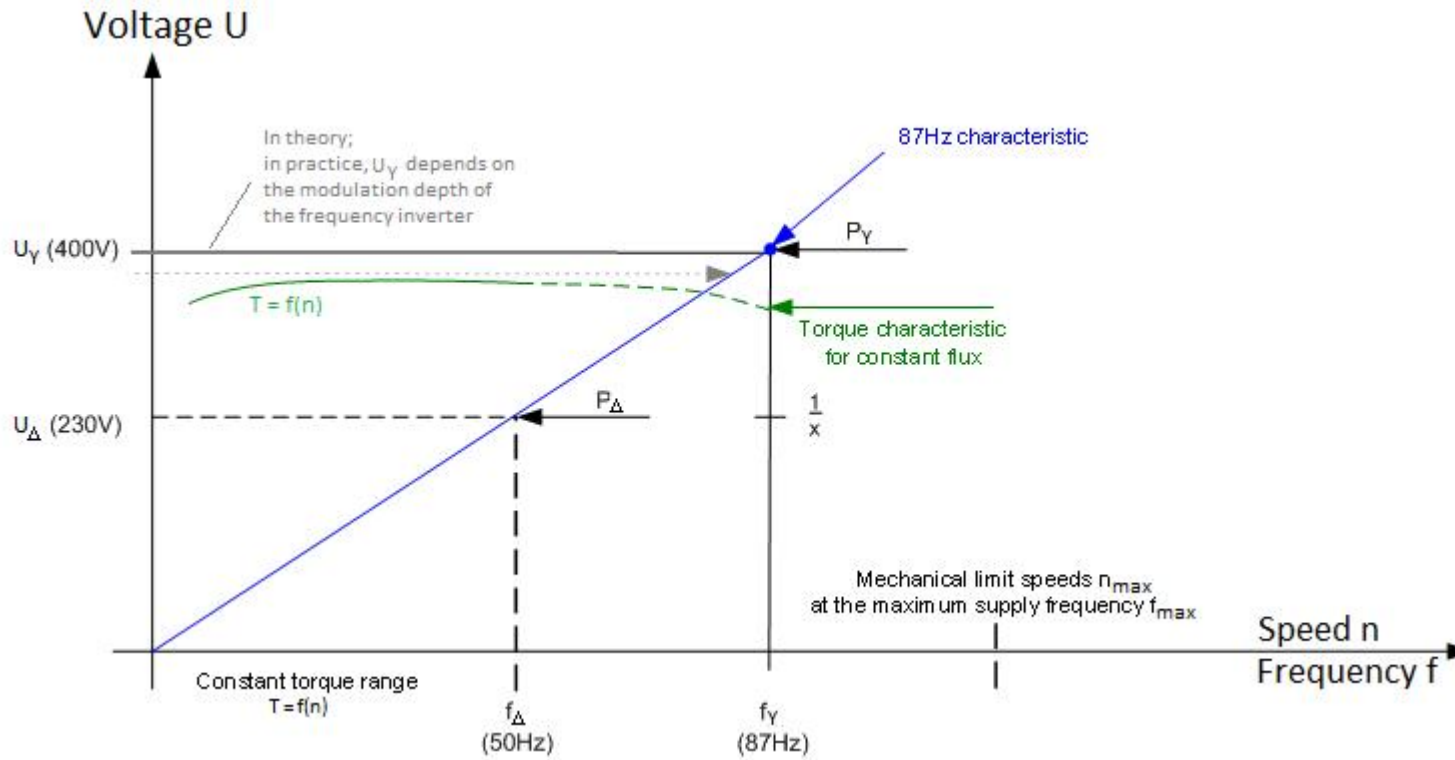
Rated frequency and rated motor speed

From the viewpoint of the frequency inverter, with „87Hz characteristic" a motor get connected whose rated frequency (P0310) and rated speed (P0311) is calculated as follows:

$$ f_{87} = \frac{U_Y}{U_\Delta} * f_N = \frac{400V}{230V} * 50Hz = 87Hz $$

f_{87}	=	Rated motor frequency (P0310)
U_Y	=	Voltage from rating plate (at Y connection)
U_Δ	=	Voltage from rating plate (at Δ connection)
f_N	=	Frequency from rating plate

$$ n_{87} = \frac{f}{p} * 60 - s = \frac{87Hz}{2} * 60 - 150 = 2460 U/min $$

n_{87}	=	Rated motor speed (P0311)
f_{87}	=	Rated motor frequency
p	=	Number of pole pairs (from motor data)
s	=	Slip (siehe Seite 10)

Parameterization via operator panel or STARTER expert list

For operation with „87Hz characteristic" select the rating plate data as follows:

P0304	= Rated motor voltage:	400 V
P0305	= Rated motor current:	0,73 A
P0307	= Rated motor power:	0,21 kW
P0308	= Motor cosPhi:	0,75
P0310	= Motor frequency:	87 Hz
P0311	= Rated motor speed:	2460 U/min
P1082[6]	= Max. frequency:	80 Hz
P1082[7]	= Max. speed:	2400 U/min
P2000[6]	= Reference frequency:	80 Hz
P2000[7]	= Reference speed:	2400 U/min

Parameterization via the STARTER configuration wizard

1. Under „Motor data" adjust the parameters for the sample motor in Y circuit configuration. Deviating from that, for the rated motor current (P0305) and the rated motor power (P0307) use values increased by factor √3.

2. Place a check mark at „87Hz calculation". Motor frequency (P0310) and motor speed (P0311) are automatically re-calculated for 87Hz characteristic.

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[6] MM4, G120 CU2x0x
[7] G120 CU2x0x-2, G120C

3.2 Operation with constant flux / "87Hz-characteristic"

P0304 = Rated motor voltage: 400 V

P0305 = Rated motor current: 0,42 A ⇨ 0,73 A ⎫ Enter values

P0307 = Rated motor power: 0,12 kW ⇨ 0,21 kW ⎭ increased by factor √3

P0308 = Motor cosPhi: 0,75

P0310 = Motor frequency: 50 Hz ⇨ 87 Hz ⎫ Is entered

P0311 = Motor speed: 1350 rpm ⇨ 2336 rpm[8] ⎭ automatically

3.   Under „Important parameters" adjust the following parameters:

P1082[4]   = Max. motor frequency: 80 Hz
P1082[5]   = Max. motor speed: 2400 rpm

(P2000 Reference frequency/speed is automatically set to P1082.)

NOTE	Setting the check mark at „87Hz calculation", P1082 is also set to 87Hz resp. 2610 rpm. To run with 80Hz/2250rpm according to our example, the parameter modification above in „Important parameters" has to be performed.

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[8] The calculated value depends on the drive.

4   Additional information

Number of pole pairs

> The motor's number of pole pairs is calculated automatically and has not to be entered as a parameter.

Reference frequency/speed (P2000)

> When P2000 is changed, the analog output and the serial connection are automatically re-scaled so that the full scale corresponds to this value. An additional parameter, that is re-scaled as a consequence of changing P2000 is, for example, the frequency displayed at the analog output.

Scaling of the frequency/speed setpoints

> For the scaling of the frequency/speed setpoints (analog inpits), parameters P0757 – P0760

Stator resistance

> For MM440 and G120 frequency inverters, parameter P0350 has different meanings!
>
> - **MM440:**
>   P0350 is valid for the value of the stator resistance, phase-to-phase plus the cable resistance → the value that is measured between two phases using an ohmmeter can be directly written into parameter P0350.
>
> - **G120:**
>   P0350 is valid for the phase value of the stator resistance → the value of the equivalent circuit diagram data can be directly written into parameter P0350.

5 SIZER engineering tool

For the particular application, the matching motor/frequency inverter combination can be selected using the SIZER tool.

More detailed information is provided in FAQ ID: 29419768:

"Selecting and dimensioning (application engineering) low-voltage motors for frequency inverter operation; supportive information on utilizing the torque"

http://support.automation.siemens.com/WW/view/en/29419768

6 Related literature

Table 6-1

	Topic	Titel
\1\	Siemens Industry Online Support	http://support.automation.siemens.com
\2\	Download page of this entry	http://support.automation.siemens.com/WW/view/en/25338130
\3\	Manuals	SINAMICS G120 http://support.automation.siemens.com/WW/view/en/22339653
\4\		SINAMICS G120D http://support.automation.siemens.com/WW/view/en/25021636
\5\		SINAMICS G120C http://support.automation.siemens.com/WW/view/en/48213081
\6\		MICROMASTER 4 http://support.automation.siemens.com/WW/view/en/10804923
\7\	Catalogues	Katalogues and brochures http://www.automation.siemens.com/mcms/mc-drives/en/low-voltage-inverter
\8\	FAQ	Operate a motor at 87Hz full power http://support.automation.siemens.com/WW/view/en/21139232
\9\	Download	STARTER http://support.automation.siemens.com/WW/news/en/26233208

7 Contact

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8 History

Table 8-1

Version	Date	Modifications
V1.0	04/2007	First version
V1.1	05/2007	Links revised
V2.0	09/2009	Text revised
V2.1	01/2014	Extended to G120 CU2x0x-2, G120C