MAXIMIZE GEARMOTOR SPEED RANGE

a technical white paper
from SEW-EURODRIVE

Learn how to push VFDs above 60Hz to widen speed range, improve stability and reduce cost.

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BREAKING THE 60HZ BARRIER

So, what's the big deal about 60Hz? In VFDs designed for use in North America, this operating frequency represents the boundary between an induction motor's constant torque and constant horsepower regions *(see Figure 1)*. Described in terms of the motor's magnetizing flux, the constant torque region represents the motor's constant flux region, while the constant horsepower region corresponds to the motor's field weakened region. Sixty hertz can also be referred to as the motor's field weakening point.

From 0 to 60Hz:

- **Torque is constant.** And it conforms to the torque formula.
  Torque (lb-in) = 63,025 * HP / Speed (RPM)
- **Voltage-to-frequency ratio is constant too.**
  For example 230V / 30Hz equals 460V / 60Hz

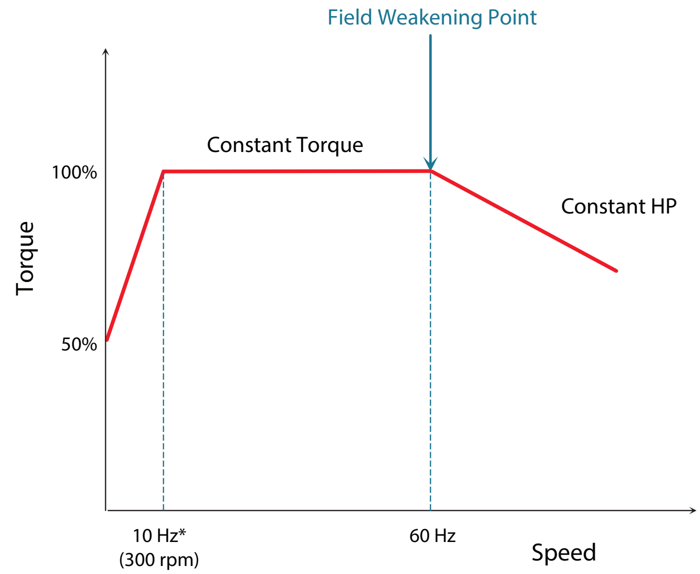
Many engineers assume that the inverter and gearmotor must be designed around this 60Hz threshold. And gearmotor suppliers do make it easy to design around this nominal frequency, since most of the catalog and specification data are given for 60Hz.

However, with a carefully designed drive system and correct ratio, you can push the operating frequency envelope above 60Hz using one of two proven control methods - field weakening or supercharging. Either method offers the following benefits, which vary depending on the application.

Reduced Inertia Mismatch. Driving motors above 60Hz requires a larger gear ratio to accommodate the higher input speed. The ratio increase can be up to 100%, depending on operating frequency.

This ratio increase can come in handy when you need to reduce the reflected load inertia for better system stability. Stability requires the reflected load inertia to be as close to the motor inertia as possible. Because load inertias are reflected to the motor shaft by the square of the gear ratio, increasing speed and ratio greatly reduces the reflected load. Doubling the ratio, for instance, would reduce reflected inertia by a factor of four.

Figure 1 | FIELD WEAKENING



*10 Hz for 4-pole motor

Embrace Field Weakening

If you're convinced that high-frequency VFD operation has benefits in your application, keep in mind there's more to it than simply dialing up the frequency in the drive controller. Operating above 60Hz first and foremost requires a thorough understanding of the load and motor torques.

Whenever you operate a drive system above 60Hz, pay attention to the following effects:

- The voltage-to-frequency relationship is no longer constant. Voltage does not increase, but frequency does.
- Horsepower stays constant.
- Motor torque drops in inverse proportion to the frequency (*see Figure 1).*
- Breakdown torque drops in an inverse square manner to the frequency. In other words, breakdown torque falls faster than motor torque.

From a design standpoint, this last point bears special attention. When operating beyond the field weakening point, it's more likely that the application will be limited by breakdown torque.

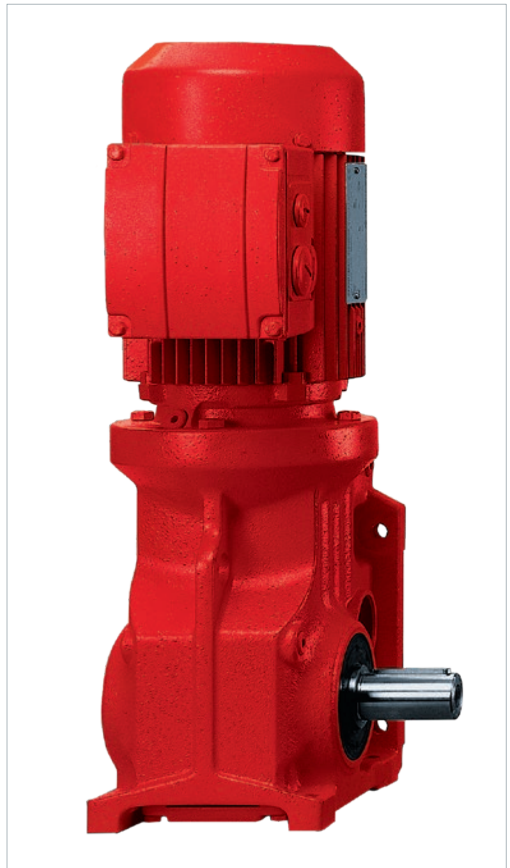
In most applications, the loss of breakdown torque won't pose a problem if you adhere to certain limits on operating frequencies. With a smaller motor—typically those under 10 HP—the limit may be as high as 85Hz. However, larger motors, which have a sharper drop in breakdown torque, should be limited to 75-80Hz. Regardless of motor size, it's also wise to design with a cushion between breakdown torque and load torque. We recommend that breakdown torque be at least 25% higher than the load torque.

Extended Speed Range. Operating above 60Hz can widen the speed range available from a given gearmotor. Speed range will obviously increase on the top end when you bump up the VFD operating frequency above 60Hz. However, what may be less obvious is that the speed range will also increase on the bottom end.

Normally, an induction motor running at low speed experiences cooling difficulties when its shaft-mounted fan turns too slowly to dissipate heat. A separately-wired blower can keep it cooler, but a blower increases the motor's initial and ongoing operating costs. An alternate cooling method involves reducing the amount of torque the motor produces, which in turn lowers the amount of current it draws. Below 300 RPM (10Hz for 4-pole motor), the torque reduction needed to keep an induction motor sufficiently cool begins to decline linearly to 50% *(see Figure 1).*

However, driving motors above 60Hz can eliminate the low-speed cooling issue without the need for expensive blowers or torque limitations. Because field-weakened motors go hand-in-hand with higher gear ratio, gearmotors that deliver the required torque above 60Hz will inherently have torque to spare below 60Hz. Consequently, the motor can run slower and cooler below 60Hz while still meeting torque requirements. Put differently, gearmotors sized for operation above 60Hz will gain a thermal buffer - allowing the motor to operate cooler below 60Hz and to operate below 10Hz without a blower, which extends the speed range considerably. Constant torque applications easily benefit from this approach. But, so do many variable torque applications.

Smaller Motors. Yet another benefit of raising the VFD frequency above 60Hz is that you can sometimes use a smaller motor in a variable torque or supercharged application. The smaller motor occurs because supercharged motors actually have twice the power at 120Hz than at 60Hz, which is often surprising to many engineers. For example, a motor with a 60Hz nameplate of 1 HP actually becomes 2 HP at 120Hz. When the application allows the use of a smaller motor, you save money on not only the purchase price of the motor but also its ongoing operating costs.

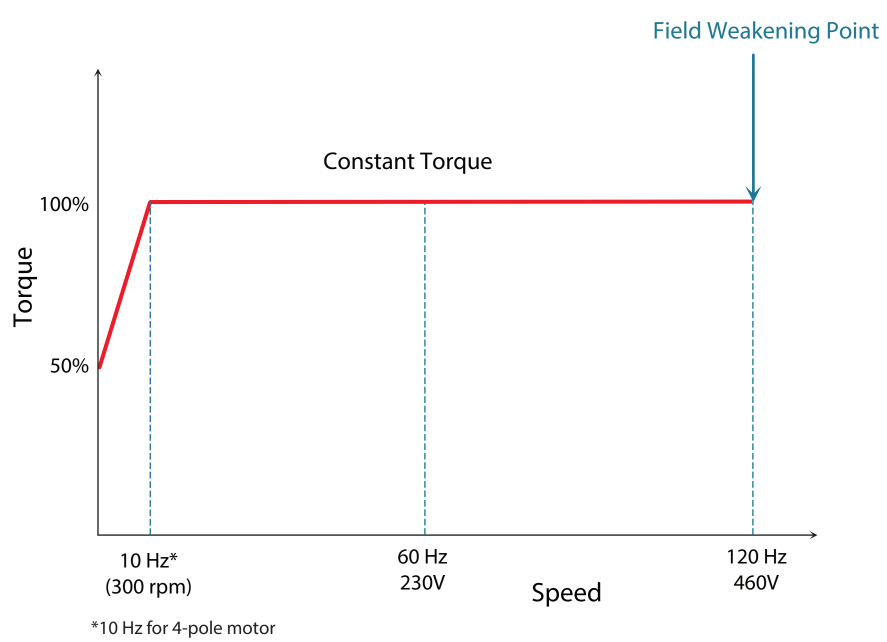


K67DRN90L4
Helical-Bevel Gearmotor from SEW-EURODRIVE

MOVING BEYOND 60HZ

Despite the benefits of driving motors above 60Hz, most engineers have never even considered turning up the frequency of their drives. Yet, this unconventional control strategy will improve performance in a wide variety of applications. Among them are constant torque applications such as conveyors and hoists, as well as variable torque applications such as batch mixers or pumps. Regardless of the application, pushing above 60Hz does require a bit of extra work upfront, but the work will be well worth the effort if you solve your speed, cooling, inertia or cost problems.

Figure 2 | SUPERCHARGED



Supercharge the Drive

You can take gearmotor performance to a new level through a technique we call *supercharging*. It entails wiring the motor for 230V and driving it via a 460V inverter with a higher HP rating. For example, a 1 HP, 230V motor is used with a 2 HP, 460V inverter. So, the motor receives 230V at 60Hz, and 460V at 120Hz *(See Figure 2)*. Supercharging works by:

- Shifting the field weakening point upwards. Supercharging extends the motor's constant voltage-to-frequency relationship and constant torque behavior up to 120Hz, rather than stopping at 60Hz.
- Forestalling the drop in breakdown torque. The loss of breakdown torque that would normally begin at 60Hz won't take place until 120Hz. In essence, supercharging eliminates the worry about not having sufficient breakdown torque.

Supercharged gearmotors do have a noteworthy limitation related to increased thermal losses in the gearbox, due to a higher input speed. These losses warrant a careful evaluation of the gearbox's thermal capacity. However, these churning losses will be offset to some degree by the increased cooling from the motor's fan, which spins faster in a supercharged system.

In practice, the gearbox losses can sometimes prevent supercharged systems from reaching the full 120Hz. A conservative rule-of-thumb for evaluating supercharging is that applications below 25,000 lb-in or applications with gearbox ratios higher than 25:1 should have adequate thermal capacity. Outside of those guidelines, high temperature seals (FKM) and synthetic oil can be used to increase the thermal capacity. When in doubt about thermal capacity, check with the gearmotor manufacture.

RUNNING THE NUMBERS

Application | Conveyor with Constant Torque

Here's a typical conveyor application with a constant load. The application requires a speed range of 12:1.

Load = 7.5 HP, RPM = 11.5 to 140

METHOD 1: 60HZ MAXIMUM

Without field weakening, the maximum frequency is set to 60Hz. And from Figure 1, the lowest speed the motor can safely operate without a blower is 300 RPM. So, to determine the corresponding frequency of a 4-pole motor, use the Hz formula:

- Hz = RPM * # of poles / 120
- Hz = 300 * 4 / 120 = 10

The acceptable speed range for the gearmotor is 10–60Hz, which is only 6:1 and not sufficient for the required application. Therefore, an auxiliary blower fan is required to operate below 10Hz.

METHOD 2: FIELD WEAKENING

Looking at the manufacturer's breakdown torque for 7.5 HP, it is acceptable to assign the highest speed to 85Hz.

STEP 1: Determine Load Torque

Always use the highest speed in the torque formula for a constant torque application. Therefore,

- T_{Load} = 63025 * HP / $RPM_{Highest}$
- T_{Load} = 63025 * 7.5 / 140 = 3375 lb-in

STEP 2: Determine RPM at 60Hz

Since the highest speed is set at 85Hz, calculate the 60Hz speed.

- [85 / 140] = [60 / X]
- X = 99

So, select a 7.5 HP, 99 RPM from a 60Hz catalog.

STEP 3: Determine Available Torque at 10-60Hz

The available torque @ 10-60Hz is higher than the load torque, which is necessary to provide the thermal buffer. Using the torque formula and the 60Hz speed,

- T_{Avail} = 63025 * HP / RPM_{60Hz}
- T_{Avail} = 63025 * 7.5 / 99 = 4770 lb-in

STEP 4: Determine Low Speed

Determine the motor's lowest permissible speed. Since the point falls on the slope below 0 and 300 RPM, use SEW's Low Speed Formula.

- RPM = [600 * T_{Load} / T_{Avail}] – 300
- RPM = [600 * 3375 / 4770] – 300 = 124

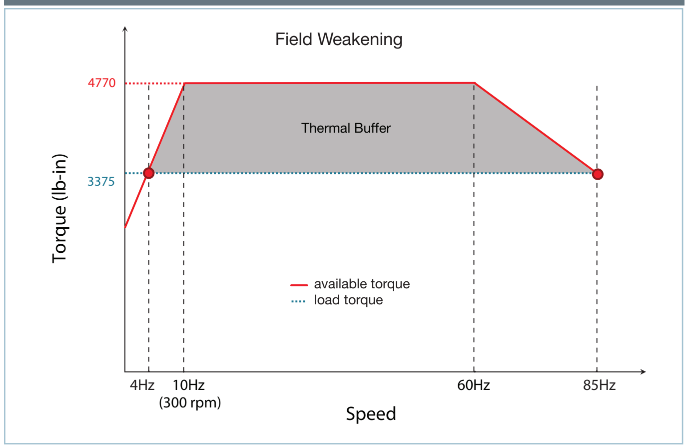
From the Hz formula,

- Hz = RPM * 4 / 120 : Hz = 124 * 4 / 120 = 4

Thus, the permissible speed range is 4–85Hz (21:1), which is more than adequate. Repeating the calculations in steps 2-4 for other frequencies above 60Hz yields the results below. The bottom three rows are acceptable options, since their speed range is at least 12:1. But, the solution with the maximum thermal buffer and thus the largest speed range is 4-85 Hz. *See Figure 3.*

Low Hz	High Hz	Speed Range	60Hz RPM	Gear Ratio
8.4	65	7.7 : 1	129	13.5
7	70	10 : 1	120	14.5
6	75	12.5 : 1	112	15.5
5	80	16 : 1	105	16.5
4	85	21 : 1	98	18

FIGURE 3



RUNNING THE NUMBERS

METHOD 3: SUPERCHARGING

When supercharging, there is no reduction in torque above 60Hz. Instead, there is constant torque from 10-120 Hz. However, depending on the VFD, size of gear reducer, or other reasons, it may not be desirable to go all the way to 120Hz.

STEP 1: Determine Hz Range

Select the speed range depending on maximum Hz. In this example, 100Hz is the desired maximum. 10-100Hz is constant torque, but it is only 10:1. To achieve 12:1 range, calculate the low Hz.

- 100 / 12 = 8Hz

Therefore, 8-100Hz is needed. But, a thermal buffer must exist to avoid using a ventilator fan at 8Hz. Perform the next steps to determine if 8Hz is permissible.

STEP 2: Determine RPM at 60Hz

Since the highest speed (140 RPM) is assigned to 100Hz, calculate the 60Hz speed.

- [100 / 140] = [60 / X]
- X = 84. Therefore,
- Gear ratio = [1750 / 84] = 21

STEP 3: Determine HP at 60Hz

From 10-100 Hz, the torque is constant, but the HP varies proportionally. Rearrange the torque formula to calculate the required HP at 60Hz.

- $HP_{60} = [\, T_{Load} \times RPM_{60} \,] / 63025$
- $HP_{60} = [3375 \times 84] / 63025 = 4.5$ HP

Use a nominal 5 HP motor. Since it is larger than 4.5, it provides a buffer which may be sufficient to allow operation as low as 8Hz. Notice it is also smaller than the 7.5 HP motor used in Method 2.

STEP 4: Determine Available Torque at 60Hz

Use the torque formula to calculate the torque available from the 5 HP motor.

- $T_{Avail} = 63025 * HP / RPM_{60}$
- $T_{Avail} = 63025 * 5 / 84 = 3750$ lb-in

STEP 5: Determine Lowest Speed

Determine the motor's lowest permissible speed. Since the point falls on the slope below 0 and 300 RPM, use SEW's Low Speed Formula.

- $RPM = [600 * T_{Load} / T_{Avail}] - 300$
- $RPM = [600 * 3375 / 3750] - 300 = 240$

From the Hz formula,

- $Hz = 240 * 4 / 120 = 8$

Therefore, 8-100Hz speed range is permissible with 5 HP. See *Figure 4*.

STEP 6: Determine VFD Size

The required power of the VFD depends on load and increases to 100Hz.

- $HP_{100} = [3375 \times 140] / 63025 = 7.5$ HP

CONCLUSION

Field-weakening provides a thermal buffer that allows the motor to operate at a lower speed without a blower. However, the highest frequency is limited due to reduction in breakdown torque.

Supercharging allows frequencies up to 120Hz without affecting the breakdown torque. It also yields a higher ratio (i.e. a lower reflected load inertia) and a smaller motor, as summarized below.

Method	Motor HP	VFD HP	Aux Fan	Gear Ratio
60Hz Maximum	7.5	7.5	Yes	12.5
Field Weakening	7.5	7.5	No	15.5 to 18
Supercharging	5	7.5	No	21

FIGURE 4