YASKAWA

Application Note - VFD Considerations & Methods for Starting/Stopping a Rotating Regenerative Load

Purpose

The purpose of this document is to discuss the methods available in Yaskawa VFDs that can be used to address applications where starting into a rotating load cannot be avoided, these methods being:

- Speed Search
- Dwell Frequency
- DC injection

A brief description of the functionality, advantages, and precautions to take for each method are discussed with the hopes of conveying when a particular method may be more suitable than another. For the purposes of keeping this document concise, specifics of function setup will not be covered. Instead, information on parameter settings can be found within the respective drive manuals.

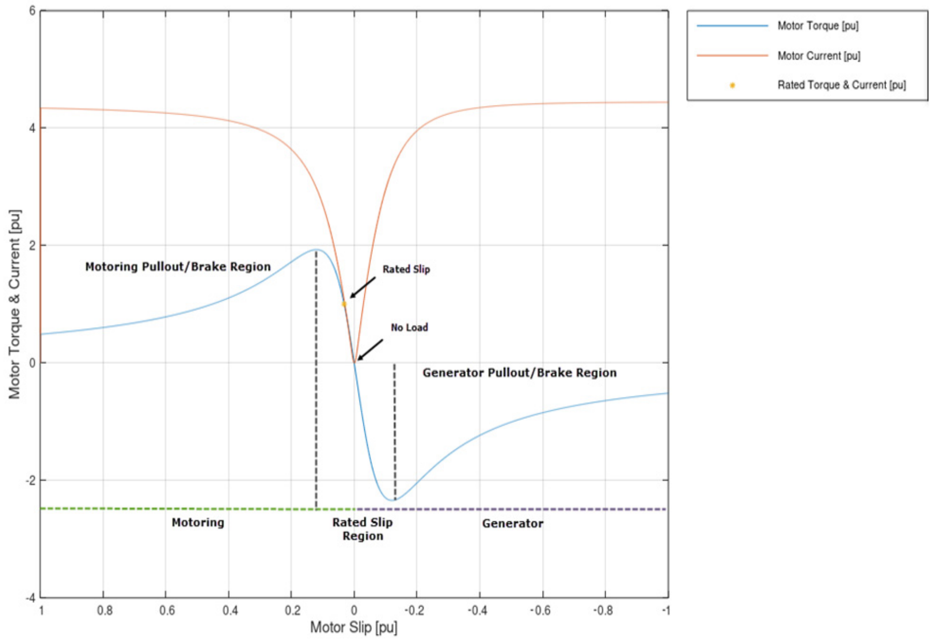
Background

There are many applications utilizing non-synchronous AC motors where the machinery speed is not at zero when beginning operation. Examples include fan applications, where a draft may rotate the fan blades, high inertia free-wheeling applications, and jointly connected systems where a motor may be influenced by other parts of the operation. This rotating condition can be problematic when using a control scheme which expects the load to be at a standstill when attempting to start, often presenting to the system a high current, or an inability to start, until the free-wheel condition subsides.

To understand why these difficulties arise, a basic understanding of an asynchronous motor property known as slip is briefly discussed in the following paragraphs. Essentially, slip governs the motor's torque for a current drawn, and is generally defined as a difference between the motor's running speed and synchronous/commanded speed. Typically, a greater torque can be achieved for a greater slip, though motors are designed to operate at their rated torque at a rated slip (which will differ based on motor design). However, when slip begins to exceed the intended slip rating, motor operation can become unstable, where current versus torque is no longer linear or well defined compared to when slip remains near the rated slip. Depending on the motor properties, a high slip may result in currents over 200% of the motor rating, while the torque could be less than 200%.

Furthermore, depending on the sign of the slip, the motor will be in either a “Motoring” or “Generating” condition. ("Motoring” when the rotor turns slower than the commanded speed, the torque and slip are positive, so the electrical energy from the supply is transferred to the motor; “Generating” when the rotor turns faster than the commanded speed, the torque and slip are negative, and the energy from the motor is transferred to the supply.) So, not only the magnitude of slip, but also the direction of rotation at start is important. It should be noted that although negative slip is tied to a regenerative condition in the motor, if the slip is high enough, the motor efficiency drops to where the majority of energy is no longer transferred back to the supply, but instead dissipated in the motor windings.

Figure 1: Normalized Power/Torque vs. Slip curve of a typical induction Motor[1]



1. Figure 1 is a generic motor curve to illustrate how torque and current may change as slip increases. If slip increases, operating speed falls into breakdown region, where motor torque production reduces, drawing high current.

Based on the above, one can rationalize that the rotating start issues are related to a high slip operating condition. A primary reason to use a VFD is to have the ability to control the frequency and voltage it outputs to the motor. Depending on the severity and direction of the rotation, certain functions within a VFD can be employed to properly start/attain control of the motor.

In Yaskawa VFDs, for example, functions of Speed Search, Dwell Frequency, and DC Injection can be used to start into an already rotating machine, whether it be matching speed of rotation to allow for immediate operation, or first slowing down the machinery to near zero speed prior running at the desired output. Of these methods, speed search is the most commonly used. However, if for instance a fan is rotating backwards due to a supply/return air draft, then as the motor returns to the forward direction by first decelerating against the draft, a regenerative load condition appears. In this case, a regenerative package would be necessary if speed search is used. It is therefore important to consider what is expected of the application at start to properly apply the functions a VFD may have.

Speed Search

Description

Of the three functions in this document, speed search provides an all-encompassing, yet functionally complex, solution to rotating start applications. Speed Search, as the term implies, aims to detect the speed of the rotating machine at the start of a VFD run command, synchronizing with the motor, and then increasing/decreasing the output command from the detected speed towards the originally desired command speed. For example, if the command frequency is 50Hz, however the motor rotates at 20Hz, Speed Search aims to detect the 20Hz to first obtain motor control, and then accelerate to the 50Hz command.

Speed search is often employed in applications where after VFD control is relinquished, the motor coasts, and continues to coast for a considerable time before another run cycle is issued. This coasting condition is common in high inertia applications such as centrifuges, or fans/blowers, which could take several minutes to stop after a shut down. Rather than waiting for the coast to end, speed search can be used to begin control at the coast speed during the time of run. Speed search can be also be used if it is not certain whether the application is rotating, such as the potential for a draft presence in a supply/return fan system.

Two categories of speed search exist in Yaskawa VFDs: a) Speed Detection and b) Current Detection. For Current Detection, two methods are available, their availability depending on drive series; Current Detection 1 and Current Detection 2. For more information on speed search types, please refer to document AN.AFD.38. Following are brief descriptions on the basic principles used in Speed Detection and Current Detection.

a) Speed Detection:

When power is removed from induction motor, there is a period in which current flow still remains present within the motor windings, and so motor flux and residual voltage is still present, albeit decaying. If the frequency of this residual voltage can be detected, then a motor speed can be estimated. However, as this decay can occur rather quickly, speed search detection will DC inject voltage into the motor if the initially detected back-emf falls below ~5% of the motor rated voltage. The response of the motor from the DC injection is then used to determine speed and direction.

b) Current Detection:

An induction motor, even when in a no load condition, draws current, often referred to as the no load or magnetizing current which is essential for developing a magnetic field in the motor for torque production when there is a load demand. Motor manufacturers will often list this current on their nameplates, which while not necessarily being the same as the true magnetizing current (due to effects of efficiency losses in windings and the like), can often be used as an indication of the magnetizing current. In Figure 1 above, it is shown that if the motor speed and synchronous, or commanded, speed match one another, no torque is produced, and therefore no power. If then the VFD output matches the motor speed synchronously, there should be minimal torque production, and therefore only a "no load" current should be present. Current detection type Speed Search aims to detect this no load current, sweeping the output frequency and voltage based on the programmed V/Hz pattern of the VFD, this no load current indicating that speeds are closely matching between VFD and motor.

Advantages:

- Reduces downtime of coasting applications by immediately synchronizing with motor speed without the need to first stop
- Capability to detect motor in forward/reverse direction (depending on speed search method used)

Precautions:

- Motor Regenerates after Speed Search when attempting to decelerate

  Although speed search is the preferred method in most situations due to its ability to control the motor from a coasting speed, there are conditions where once speed is detected, the motor may regenerate into the VFD, resulting in an overvoltage fault. This may be due to the initial detection finding a speed where the net slip is negative, and so results in a negative torque. In these cases it may simply require adjusting speed search specific parameters. There are other times however, not specific to speed search, where regeneration results during the deceleration of a machine. In terms of speed search, when the target command speed is less than the detected speed, or the detected speed is in the reverse direction, the output frequency of the VFD must decelerate towards the command. In high inertia applications, where significant torque is necessary to alter speed, a deceleration action can regenerate the system. Supply/return fan systems for example, are a common application where a regeneration condition can appear due to the inertia of the fans in combination with a continual draft, potentially accentuating the negative torque requirement during deceleration. In such conditions, it may be necessary to increase the deceleration time in parameter C1-02 to reduce the regenerative torque magnitude, or install a dynamic braking package to absorb the regenerative energy.

- External components between VFD and motor affecting speed search accuracy

  Speed search relies on proper detection of residual voltage in the motor, or current, in order to properly determine motor running speed. Adding components with high L and C components which can alter the effective load as seen by the VFD, may reduce the success of speed detection. As an example with the Speed Estimation method, a DC component is injected into the motor, and so if a transformer (or other device which can block DC) is installed between the VFD and motor, speed detection may not see a feedback.

Unlike Speed search, the remaining two functions of Dwell and DC Injection work to halt, or slow the machine down prior to operation rather than immediately synchronizing with the coasting motor. However, as it was mentioned above, there may be times where controlling a deceleration from one speed to another may incur a regenerative torque. Without having a regenerative/braking package, Dwell and DC Injection provide for good alternatives to a controlled deceleration. Or, can be used if needing to stop a coasting machine in general.

Dwell Frequency

Description

Dwell operation refers to holding an output frequency command at a predefined, often low frequency for a set period of time. While it may not be obvious that dwell can be used for the purposes of slowing a rotating machine based on this description, referring back to the background section of this document in Figure 1, in high slip conditions (a difference between motor speed and command speed), torque production is still achievable, albeit lower in magnitude when compared to operation within motor rated slip region. Depending on this sign of slip as well, motor torque production will either result in a motoring (supply transfers energy to motor) or generating condition (motor transfers energy to supply).

When decelerating, depending on the inertia of the application along with any extraneous factors which may accentuate a continual force on the application, a motor operation in the negative slip region becomes likely, where regenerative energy gets produced, and is transferred to the VFD, incurring the possibility of overvoltage conditions. However, unlike operation within rated slip where there is efficient power transfer, high slip operation is inefficient, meaning the majority of any regeneration is dissipated in the motor. This makes dwell an appropriate alternative for halting/slowing a machine where deceleration in general, or deceleration after a speed search may result in overvoltage. Therefore, by taking advantage of this inefficient motor operation at high slip, a motor can be slowed with the torque that is produced while avoiding regeneration into the VFD.

High slip motor operation does require some precaution however, as when comparing torque/current between rated slip and high slip, higher slip produces significantly higher currents. Therefore, care must be taken to limit the current drawn during dwell operation to avoid overload conditions of oL1/oL2. Additionally, depending on the severity of rotation and torque required to halt the machine (due to inertia, drafts, etc.), more torque/time may be necessary in certain applications than in others. There is also the uncertainty of how much torque can be achieved at high slip, because whereas torque production is defined at a motor rated slip, high slip torque production depends on inherent motor properties that may not be listed as an operation point by motor manufacturers. In combination with the application too, achieving necessary torque to halt the machine may not be possible if more torque is needed than what high slip operation can achieve.

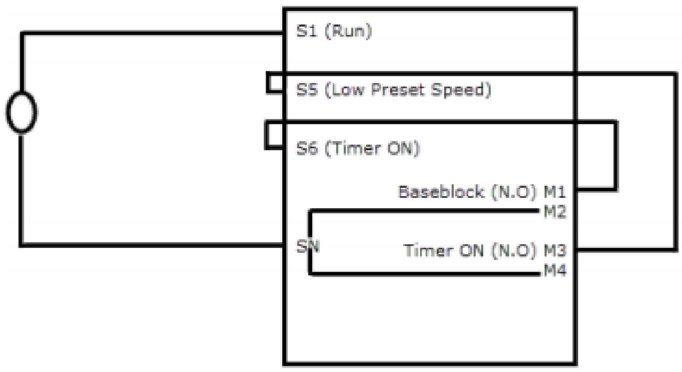
Basic Setup:

Setting Dwell Frequency and Duration

A specific group of parameters "b6" allow for automatically performing a dwell at every start command without the need of any external controls, however dwell can also be implemented through other means if desired. I.e using a PLC or Yaskawa DriveWorks EZ (DWEZ) (for drives compatible with Driveworks EZ) to provide the VFD a frequency reference could set a frequency command to 1.5Hz for 20 seconds. This may be preferred if needing to prolong the dwell duration, as the parameters within the VFD specific to dwell is limited to 10 seconds, which depending on the time needed to halt the machine, may not be enough. It is also possible to extend the dwell duration utilizing timer related functions and digital inputs/outputs such as in the below scheme:

H1-05 = 3	(Multi-Step) Speed 1 for Terminal S5
d1-02 = 1.5	Low Frequency (1.5 Hz)
H1-06 = 18	(Timer Function Input) for terminal S6
H2-01 = 8	(During Baseblock, Normally Open) for Digital Output M1/M2
H2-02 = 12	(Timer Function Output) for Digital Output M3/M4
b4-01=0	(Timer On-Delay Time)
b4-02= Dwell Duration	(Timer Off-Delay Time)

Figure 2: Sample scheme for applying Dwell functionality via digital inputs/outputs



Limiting Current Draw:

Depending on the control method being used, limiting current can be achieved by setting torque limits during the duration of dwell, or by adjusting the V/Hz ratio at the desired dwell speed.

<u>(OLV, Advanced OLV, CLV, EZ Vector):</u> In control methods where torque limit settings are available torque limits can be set to within 100% of the VFD rating in order to keep current within VFD rating, either through the use of DWEZ, analog input set to a torque limit to coincide with the desired dwell time, or if the application throughout its entire operation will be limited to 100% of the motor rating, simply setting the static torque limit settings in L7-01 - L7-04 to $\leq$ 100.

<u>(V/Hz Control):</u> In V/Hz control, by reducing the voltage at the desired dwell frequency, current can be limited. This is done through the E1 V/Hz parameter settings in Yaskawa VFDs, which define the voltage to be applied to the motor at various speeds. Note however that reducing the current will also reduce the high slip torque capability of the motor. So, the key is to determine how low the current needs to be to still provide enough torque to adequately slow the machine.

Sample Scheme using DWEZ to Limit Current During Dwell

Halt a reverse or forward rotating machine by applying a forward run command with a preset timer to force a low starting output frequency. Depending on the speed of the machine, this speed difference will result in high slip braking, slowing down the machine speed to match this low speed. During the process, current draw can be high, which can be limited by using a torque limit if available in the control method being used (such as OLV), or reducing minimum voltage if in V/Hz control. If the current remains high for an excessive time during this process, this method will pause, and attempt auto-restart, slowing down the machine in steps. If current remains low during dwell for a set time, then continue to normal operation.

Process:

1) Begin operation at 1.5Hz with a current limit set to 100% (if in a control method where torque limits can be set), or if in V/Hz control, manually adjust minimum voltage level in E1-10 until current drawn is within desirable levels. In addition, set a current detection threshold equal to 100% to be triggered after 100% current has been exceeded for a set time, enabling auto-restart attempts.

2) As the actual fan speed differs from the commanded 1.5Hz, the fan will draw high current while slowing down. If current remains over 100%, base block VFD output, and pause for L2-03 time. After L2-03 time expires, apply a 1.5Hz command once again.

3) If the max restart attempt is exceeded, then fault and end operation. If current remains below 100% for a set time during the dwell 1.5Hz command, continue operation to commanded speed.

Advantages:

- Stop/slow a low-high speed rotating machine without the use of a regenerative package
- Can be used as an alternative to speed search if needing to stop a machine or if external devices such as transformers are used which may impede speed search accuracy.

Precautions:

- Can be used as an alternative to speed search if needing to stop a machine or if external devices such as transformers are used which may impede speed search accuracy:

  As dwell relies on motor high slip operation, current draw for the same applied voltage levels when compared to rated slip will be significantly higher. As such, precautions must be taken to limit this current; otherwise the VFD will fault on overload oL1/oL2 conditions. As discussed earlier, current can be limited by either utilizing torque limit features of Yaskawa VFDs (if available in the control method being used), or by reducing the output voltage applied at the desired dwell frequency by adjustments of the V/Hz output settings.

- Not intended for applications requiring significant torque to slow machine:

  The torque production capability of a motor at high slip is limited and often less than at rated slip. If an application requires more torque than what the motor can achieve at high slip, then applying the dwell method may not have the ability to stop the machine.

- Torque capability is dependent on high slip motor properties, not nameplate rating:

  Unlike motor nameplate rating for torque, which often coincides with rated slip, a rating for operation at high slip is rarely, if ever, provided.

- Increased motor temperature if used excessively:

  Due to the increased temperature of the motor windings, do not use dwell to frequently stop the motor. The duty cycle should be around 5% or lower.

DC Injection

Description

The DC Injection function found in Yaskawa VFDs applies a programmable level of DC current into the motor windings. This DC current creates a fixed magnetic field in the motor, resulting in a braking action as the rotor rotates through this field. Compared to the methods of dwell or a controlled deceleration however, the magnitude of torque produced by DC injection is significantly less. Therefore, the scope of DC injection is primarily to be used for applications with minimal free-wheeling, otherwise an extended period of DC injection may be required, resulting in motor heating. Of the three methods in this document, DC Injection is the simplest to set up, however with limited scope to low speed rotation, or rotation requiring minimal torque to stop.

Advantages:

- Stop/slow a low speed rotating machine without the use of a regenerative package
- Can be used as an alternative to speed search if only needing to stop a slowly rotating machine
- Limit current draw with a definable current limit setting

Precautions:

- Limited in scope compared to speed search and dwell, for slowly coasting loads:

  Applications with high inertia loads or higher speeds may require more torque to reduce in speed than what DC Injection can achieve

- Motor heating if DC Injection is applied for an excessive period of time:

  As compared to Dwell and controlled deceleration, DC Injection produces significantly less torque than when controlling the motor or applying dwell. Therefore, in order to stop machines, DC Injection may require a longer on-time, where the energy that is produced is dissipated into motor windings.

- Cannot be used with DC blocking components between VFD and Motor:

  As with speed search, components between the VFD and motor, specifically DC blocking components such as transformers, DC injection cannot be used.

Summary

With the use of VFD functions such as Yaskawa's Speed Search, Dwell, DC Injection, among others, it becomes possible to start an application which is already rotating, whether it be matching speed of rotation to allow for immediate operation, or first slowing down the machinery to near zero speed prior running at the desired output. It is necessary however to consider what is expected of the application at start to properly apply the functions a VFD may have, as one method may fare better than another under certain situations. Below is a table summarizing the usage, advantages, and precautions of the three methods discussed in this document:

Table 1: Summary Table of Methods for Starting into/Stopping an Already Rotating Load

Method	Description	Usage	Advantages	Precautions
Speed Search	Detect & Synchronize VFD output to motor speed and rotation direction at the start of a VFD run command	Synchronize with motor speed, allowing for immediate motor controllability	Reduces downtime of coasting applications by immediately synchronizing with the rotating motor, allowing for non-zero speed start capability Ability to detect motor in forward/reverse direction	Motor Regenerates after Speed Search ends when attempting to decelerate motor speed, may require a regenerative package such as dynamic braking External components between VFD and motor may affect detection accuracy
Dwell Frequency	Utilizes high slip motor torque to brake a rotating motor while avoiding motor regeneration into VFD	Slow down/stop coasting motors	Stop a low to high speed coasting motor without the use of a regenerative package An alternative to speed search when stopping or decelerating a motor to zero speed, such as in reverse spinning fan applications	Current draw can be high, requires current limiting setup via reducing V/Hz or current limiting functions such as torque limit based on control method Braking torque dependent on motor high-slip properties Motor heating if used excessively
DC Injection	Applies DC current to motor windings, creates a fixed magnetic field in the motor, resulting in a braking action as the rotor rotates through the field.	Slow down/stop low speed coasting motors	Stop a low speed rotating machine without the use of a regenerative package An alternative to speed search if only needing to stop a low speed coasting motor Limit current draw with a definable current limit setting	Limited in scope to low speed coasting Motor heating if DC Injection time is excessive Low braking torque capability when compared to dwell Cannot be used with DC blocking components between VFD & Motor, such as a transformer