Kinetix Faults and Countermeasures

Kinetix systems common machine faults and countermeasures.

Intelligent Devices - Global Portfolio Engineering

SUMMARY OF REVISIONS
REV.1

Introduction

Machine builders and end users are demanding equipment that will deliver the latest capabilities and highest performance. Machines must comply with electrical and machinery standards, and consideration for human and machine safety must be applied. Even with this complete consideration, as with any equipment, there are unexpected faults that can occur. This document will explain several scenarios that result in those common faults and, just as important, their countermeasures. It will provide some high-level guidance and provide references to relevant documentation for further details and implementation of these solutions.

These use cases include different fault modes and countermeasures used to reliably, and safely, control the stopping and disabling of the equipment. It is important to provide countermeasures for unforeseen situations, like power outages and loss of communications. Kinetix® drives have built-in fault handling capabilities that can be used to provide these countermeasures.

None of the *Use Cases* described here is intended to be a complete assessment of a specific application, rather they provide typical considerations when architecting your system to react to different faults including loss of power and loss of communications. This document will focus on the failure modes that are relevant to Kinetix drives using Integrated Motion on Ethernet/IP (CIP Motion), however some of these techniques can also be used on other drives.

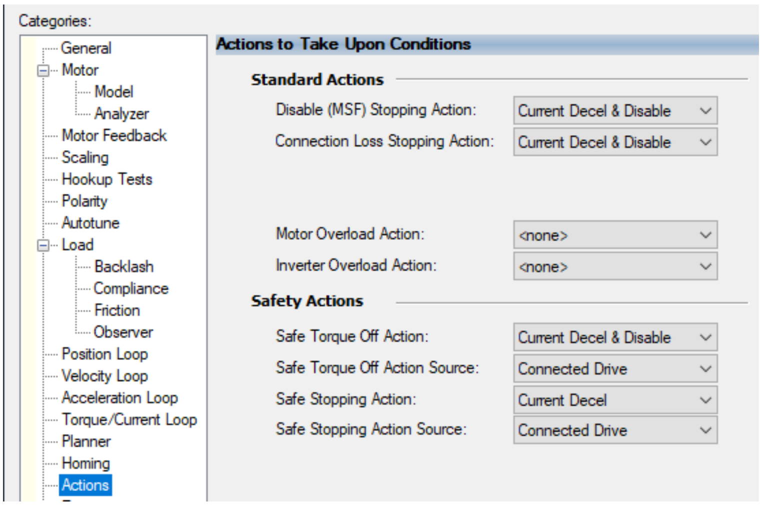
Understanding Stopping Behaviors

This document will explore the stopping behaviors that Kinetix drives (that use CIP Motion) use to stop motors. Predictability is important when exploring the exception (i.e., fault) and stopping behaviors. We can understand how these stopping behaviors affect the application and machine once we know what physical hardware is used and how hard the system is operating. When the system is sized using the mechanical data and the most aggressive cycle profile, appropriate hardware can be selected for the system. Once hardware is chosen, we can start to understand what the different stop type behaviors will be.

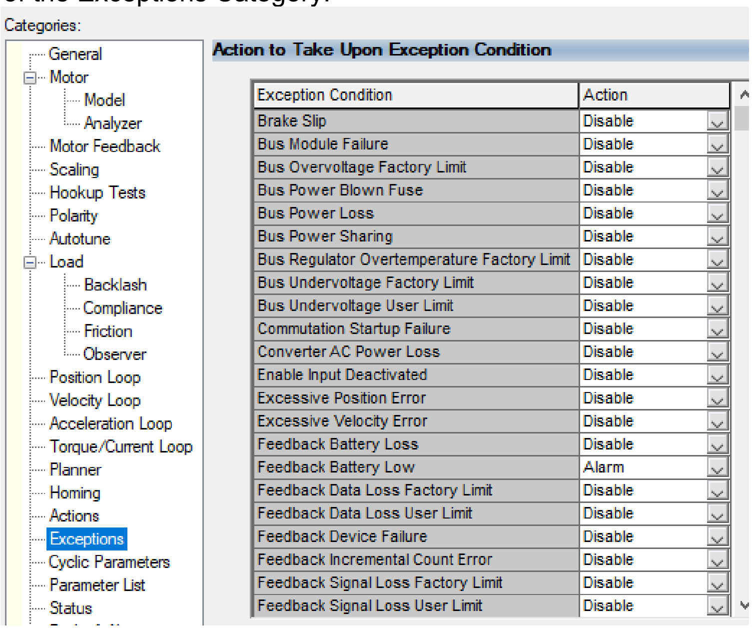
Within Studio 5000 Logix Designer®, the Axis Properties>Exception selections include actions that are configurable. By default, all configurable exception actions are set to the most conservative option which is ‘Disable’. When the exception action is configured for ‘Disable’, the axis will use a pre-defined stopping type that allows the motor to maintain the most control without causing drive failure for the specific exception. Not every configurable exception supports every action. Tables in the Troubleshooting chapter of the Kinetix servo drive User Manuals describe all drive faults and their corresponding *Best Available Stopping Actions*.

Within Studio5000 Logix Designer, the Axis Properties>Actions>Standard and Safety Actions selections are used when an MSF (Motion Servo Off) command is issued, the Drive Enable input is removed, or a safety request is made. Each of these stopping types is configurable.

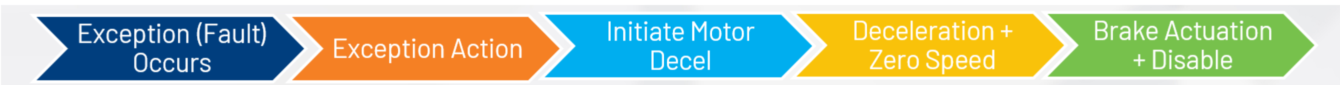
This is an example of the Actions Category:



This is an example of the Exceptions Category:



These predictable fault reactions are important and can impact the design and how you apply the axes on the machine. The use cases described in this document will examine the flow of the exception and the resulting action using the sequencing shown here.

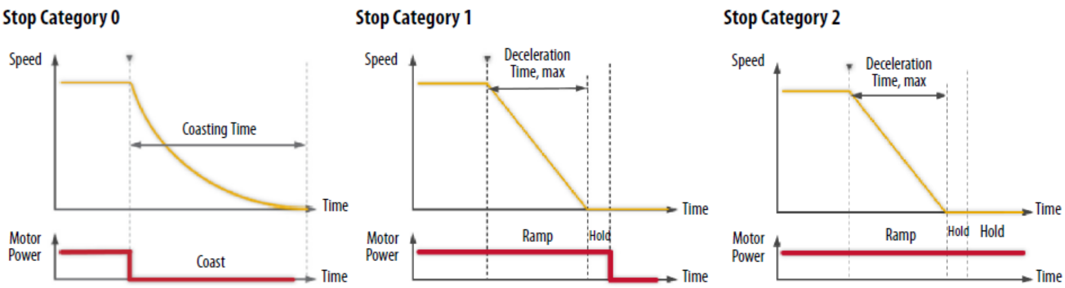


This flow is used because the use cases will use different actions, and sometimes, different sources for the resulting motor stopping operation.

Different stop category types, based on IEC-60204-1 industry standards, are shown below.

Stop Category Type [1]	Stopping Action Type (Kinetix definition)	Description of Operation
Stop Category 0	Disable & Coast	Drive immediately disables the inverter power structure.
Stop Category 1	Current Decel & Disable	Motor is decelerated (trigger condition determines the rate of deceleration) to zero speed and power structure is disabled.
Stop Category 2	Current Decel & Hold	Motor is decelerated (trigger condition determines the rate of deceleration) to zero speed and power structure remains enabled.

(1) The stopping actions that are applicable to a vertical axis align with IEC-60204-1 stop categories.



When designing your machine, you can use Motion Analyzer software to model and size the axes on your machine. An axis consists of a drive and a motor with a feedback device. Within the Motion Analyzer software, you can model the physical characteristics of the load on the axis and its motion profile. Once sizing is complete and the motor and drive are selected, the Motion Analyzer Axis Summary shows the Peak Torque that is required for the axis. Using this Peak Torque, you can estimate the torque that is used when a fault occurs with the axis. This torque estimation is used when the *Current Decel* action type is applied by the drive. It is important that the Current Decel torque is within your machine limits to avoid any machine damage resulting from an aggressive deceleration.

A Current Decel action is applied by the drive when any of the following occurs:

- An MSF command is issued, and the Disable Stopping Action is configured for Current Decel & Disable or Current Decel & Hold
- A safety request is issued, the Safety Action Source is configured for *Connected Drive*, and the safety action is configured for Current Decel or Current Decel & Disable.
- An exception occurs and the action is configured for Disable or Shutdown and the Best Available Stopping Action is Current Decel & Hold or Current Decel & Disable
- An exception occurs, the action is not configurable, and the Best Available Stopping Action is Current Decel & Hold or Current Decel & Disable

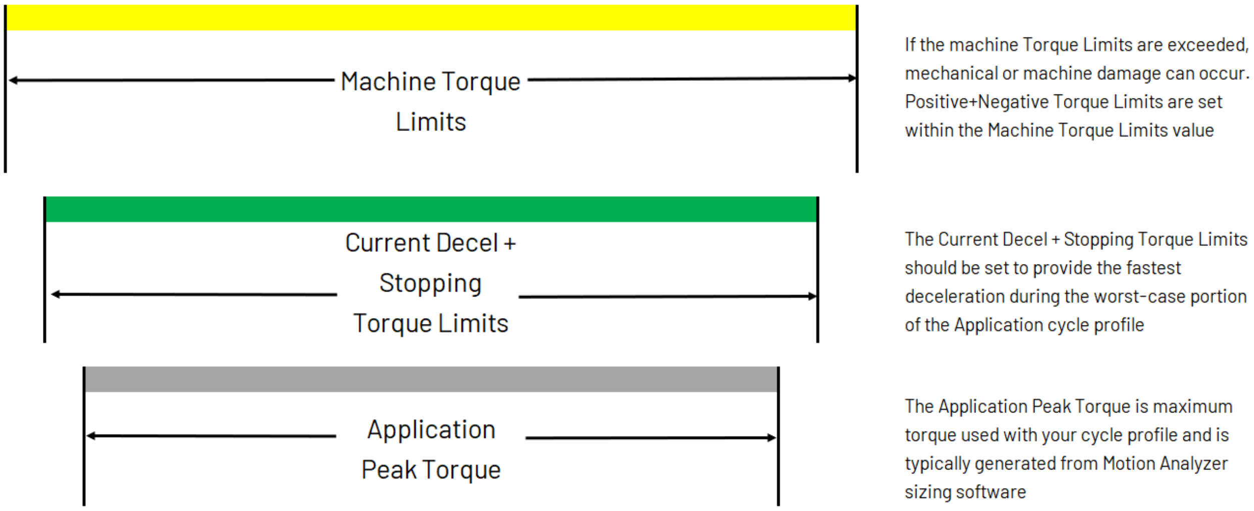
When a *Current Decel* action is triggered, the StoppingTorque and StoppingTimeLimit values are used to define the Current Decel characteristics. These are configured within the Axis Properties>Actions>Parameters. Choosing these values is shown in the Setting The Limits example.

StoppingAction	Current Decel & Disable	
StoppingTimeLimit	1.0	s
StoppingTorque	243.19067	% Motor Rated

The Current Decel/StoppingTorque limit should be lower than your Machine Torque limits and larger than the Application Peak Torque limit, to help prevent equipment damage but still allow the motor to stop as quickly as possible. This also means that the motor can be stopped at any point of the cycle profile without exceeding any Machine Torque Limits. When your sizing is complete, the axis summary will show the Application's Peak Torque requirements.

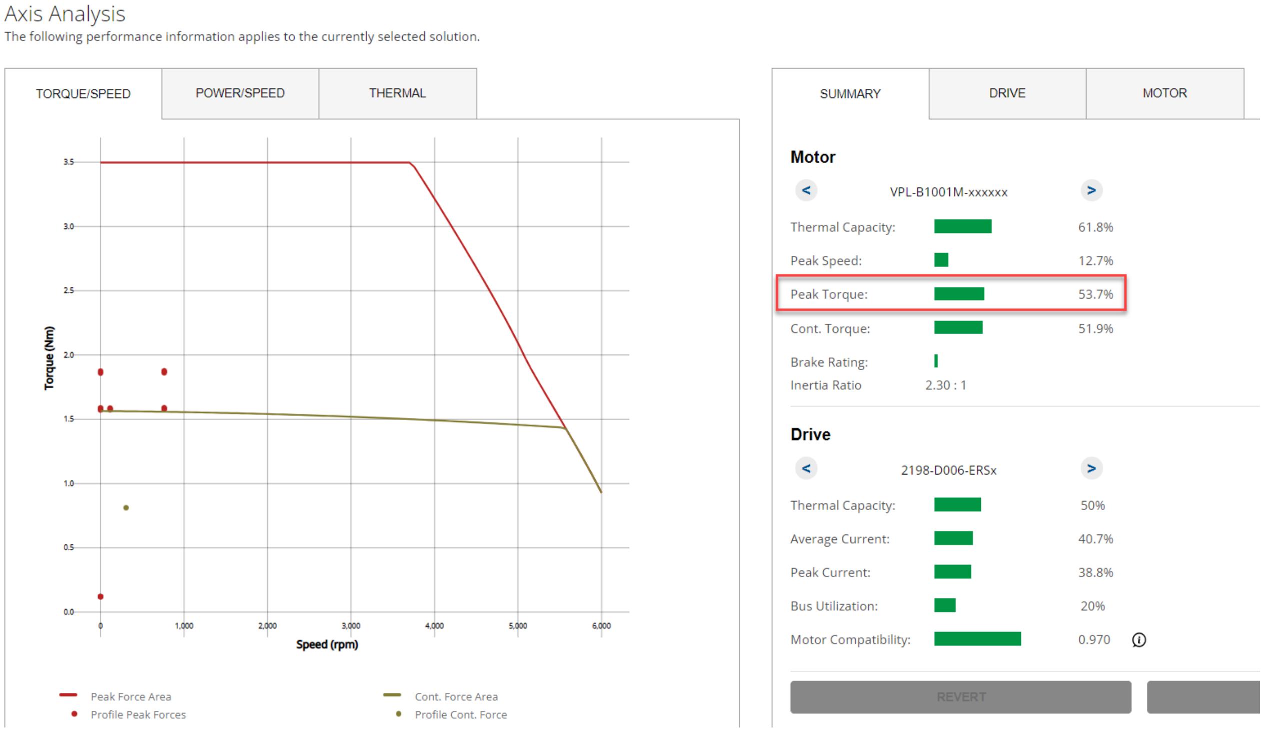
TIP: When using the Velocity Control mode, the option of 'Ramped Decel' is available. Ramped Decel allows the use of the Axis Properties>Planner>Maximum Deceleration value to decelerate the motor in a controlled manner.

The Machine Torque Limits are determined by any limiting mechanics of the machine and must not be exceeded, or damage can occur.



Example: Setting the Torque Limits and Stopping Torque

Let's examine an example of setting the key torque limiting values for a Kinetix axis. The Axis Analysis below generated using Motion Analyzer. The cycle profile shown here was modeled using the worst-case application cycle for this axis. Worst-case here means: 1) the fastest speed the axis will use in the application, 2) the most aggressive acceleration and deceleration cycles, and 3) using the heaviest loads for the cycle profile. The peak torque from this worst-case profile is 53.7% of the available peak torque for the drive and motor combination. The Axis Analysis also has 'dots' that indicate the peak and continuous torques that this profile uses. The peak torque is the Application's peak torque divided by the Peak torque available for the motor and drive combination.



TIP: Looking at the Torque/Speed curve from the Axis Analysis, the Peak Torque value has a maximum of 100%. In this example, 100% represents 3.5N-m, which is the rated peak torque for this motor/drive combination. This axis is drive limited. That means if we used a larger drive with additional output current, the full motor torque (3.78N-m) would be available. For this motor/drive combination, the drive current is limiting the torque capability of the motor. Our application does not require full motor torque, so the smaller drive is used. This is why it is critical to evaluate the drive and motor combination and not just the nameplate data from the motor or drive alone.

Let’s use Studio5000 Logix Designer to examine the limits used for this Axis combination. These limits are automatically chosen when you select your motor/drive hardware. You can find these values in Studio5000 Logix Designer; Axis Properties>Parameter List:

Stopping Torque is shown with the StoppingAction set to use Current Decel & Disable.

StoppingAction	Current Decel & Disable	
StoppingTimeLimit	1.0	s
StoppingTorque	243.19067	% Motor Rated

And we can define the torque limits to be within the machine limits.

TorqueLimitNegative	-243.19067	% Motor Rated
TorqueLimitPositive	243.19067	% Motor Rated

Kinetix Integrated Motion on Ethernet/IP (CIP) motion drives use torque limits derived as a percent of motor rated current. The Logix default settings are chosen from the lesser result of these two cases:

$$Drive\ Peak\ Current\ (A_{RMS}) \div MotorRated\ Current\ (A_{RMS}) * 100\%$$

or

$$Motor\ Peak\ Current\ (A_{RMS}) \div MotorRated\ Current\ (A_{RMS}) * 100\%$$

TorqueLimitNegative/Positive must be set within the machine torque limits so the equipment is not damaged from excessive force. Relating the Logix settings to the torque/speed curve from the Axis Analysis, 243% would be the red peak line of 3.5 N-m. The TorqueLimitNegative/Positive limits should be larger than the StoppingTorque/Current Decel torque. We want to set the Torque Limits based on the mechanical limitations of the machine.

Let’s assume that this machinery cannot exceed 3N-m of torque at the motor shaft; we must set torque limits to reflect this. If we have 3.5N-m available and use the Axis Analysis in Motion Analyzer as the benchmark (which means the Peak Torque maximum value is shown as 100%), we can calculate the limits that should be configured in Studio5000 Logix Designer.

Calculating Machine Torque Limits

The Torque Limits in Studio5000 Logix Designer are calculated as torque referenced at the motor shaft. The Motion Analyzer Peak Torque is reduced to 95% of the allowable 100% range of the machine’s 3 N-m limitation. This keeps us within the allowable peak torque limit.

$$Peak\ Torque_{MA} = [(3 \div 3.5) \times 100] \times 95\% = 81.4\%$$

The 95% is a guideline. You can change this based on your application. This guideline is used because the torque limits set for the axis are not infinitely accurate. They are estimations based on the characteristics of the motor and drive combination. Several environmental factors like ambient temperature, motor temperature, input voltage, and motor winding construction can affect this guideline. It is possible that with your mechanism and axis hardware, that you should make the guideline more conservative.

Now, we must convert $Peak\ Torque_{MA}$ in Motion Analyzer to $Torque\ Limit$ for entry in Studio5000 Logix Designer. That means we are using 81.4% of the 243% available from the motor/drive combination, so that:

$$TorqueLimitPos/Neg_{Logix} = 0.814 \times 243 = 197.8\%$$

That means these TorqueLimitNegative/Positive values can be set for 198% and are within the maximum machine limits.

Calculating Stopping Torque

The StoppingTorque in Studio5000 Logix Designer is calculated as torque referenced at the motor shaft. We use the Peak Torque that is shown in the Axis Analysis to estimate the Stopping Torque. We add a small margin, for example, of 10% to the Peak Torque. This 10% margin can be changed. This value was chosen such that in the event the worst-case dynamics for this axis were exceeded, we are sure that the motor will be stopped as quickly as possible while also observing the Machine Torque Limits.

That means we can use Peak Torque = 53.7% and add 10% margin so that:

$$Stopping\ Torque_{MA} = 53.7 \times 110\% = 59.07\%$$

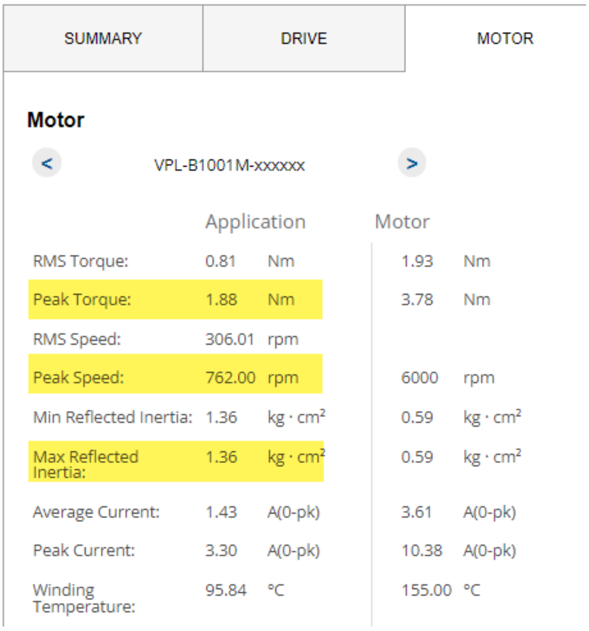
$$Stopping\ Torque_{Logix} = 243 \times 0.5907 = 143.54\%$$

This means the StoppingTorque value can be set for 144% and is within the machine limits.

StoppingTorque is the torque used for the Current Decel stop type.

Calculating Stopping Distance and Time

We can estimate the stopping distance and time using the data in Motion Analyzer Axis Analysis>Motor>Application:



SUMMARY | DRIVE | MOTOR

Motor

< VPL-B1001M-xxxxxx >

	Application		Motor	
RMS Torque:	0.81	Nm	1.93	Nm
Peak Torque:	1.88	Nm	3.78	Nm
RMS Speed:	306.01	rpm		
Peak Speed:	762.00	rpm	6000	rpm
Min Reflected Inertia:	1.36	kg · cm²	0.59	kg · cm²
Max Reflected Inertia:	1.36	kg · cm²	0.59	kg · cm²
Average Current:	1.43	A(0-pk)	3.61	A(0-pk)
Peak Current:	3.30	A(0-pk)	10.38	A(0-pk)
Winding Temperature:	95.84	°C	155.00	°C

This example is only an approximation because there are many variables that will affect the application limits including temperature, voltage, and unforeseen fault conditions.

- Worst-case torque for the application (T_{peak}; Application: Peak Torque)
- Worst-case application speed (V_{max}; Application: Peak Speed: RPM->convert to RPS)
- Max reflected inertia is the load inertia plus motor inertia (J_{max}; Application: Max Reflected Inertia)
- Deceleration Rate ($Decel_{Rate}$)
- Deceleration Time ($Decel_{Time}$)
- Deceleration Distance ($Decel_{Distance}$)

  Deceleration Distance is given in motor rotations, this must be calculated to include any scaling that your axis requires.

TIP: You should change the StoppingTorque and StoppingTime to match your real application limits.

Let's consider an example where you receive your axis hardware and configure it with your machine but did NOT change the torque limits. The Torque/Speed curve shows a peak drive/motor torque of 3.5Nm. If the StoppingTorque was not changed, then 243% = 3.5Nm. This, along with maximum motor speed (6000 RPM), would result in the maximum achievable deceleration rate, time, and the smallest stopping distance with shortest stopping time; but using these settings, as we discussed earlier, may cause damage to your equipment since it was not built to handle that torque.

The Motion Analyzer summary shows that the application requires 1.88Nm (=53.7%= Peak Torque) and a peak speed of 762RPM. That would be the worst-case torque and speed this application uses. The Stopping Torque estimate applies an extra 10% for the same reasons described in the section above (59.07%) which makes the actual StoppingTorque:

$$StoppingTorque_{N-m} = 1.88 \times 1.1 = 2.068\ N - m$$

And the Stopping Distance ($Decel_{Distance}$) and Stopping Time ($Decel_{Time}$)is calculated as:

$$J_{max\quad kg-m^2} = \frac{(J_{max\quad kg-cm^2})}{10{,}000}$$

$$Decel\_Rate = \frac{(T_{peak} \div J_{max\quad kg-m^2})}{2\pi} \frac{rev}{sec^2}$$

$$Decel_{Time} = \frac{V_{max}}{60 \times Decel_{Rate}} sec$$

$$Decel_{Distance} = \frac{1}{2} \times \frac{V_{max}}{60} \times Decel\_Time$$

→

$$J_{\max\quad kg-m^2} = \frac{(1.36)}{10{,}000} = 0.000136$$

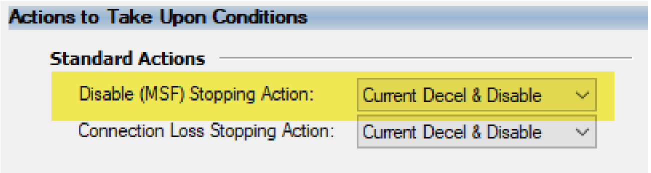
$$Decel_{Rate} = \frac{(2.068 \div 0.000136)}{2\pi} = 2{,}420.09 \frac{rev}{sec^2}$$

$$Decel_{Time} = \frac{762}{60 \times 2420.09} = 0.00525\ sec$$

$$Decel_{Distance} = \frac{1}{2} \times \frac{762}{60} \times 0.00525 = 0.0333\ rev$$

Standard Actions - Motor Disabling

It is important to understand the behavior of the axis when you need to disable it in normal machine operation and not because of a fault condition. This behavior is programmable. The Standard Actions used with the *Disable (MSF) Stopping Action* is what occurs when an MSF command is performed in logic or the Enable input is removed from the drive.



The choices are Current Decel & Hold (Cat. 2 stop), Current Decel & Disable (Cat. 1 stop), and Disable & Coast, Cat. 0 stop).

Zero Speed Condition

It is important to define what is considered a Zero Speed condition for your axis because this condition is used with holding brake timing and the timing for disabling the axis. ZeroSpeed and ZeroSpeedTime values are user configurable. That means you can configure when the Zero Speed condition occurs. It is configured in the Axis Properties>Parameter List. In the example below, 1% of motor rated RPM satisfies the Zero Speed condition. When ZeroSpeed is used with ZeroSpeedTime, the Zero Speed condition is true. When the motor RPM is below the ZeroSpeed value for the duration of ZeroSpeedTime.

ZeroSpeed	1.0	% Motor Rated
ZeroSpeedTime	0.0	s

Understanding Devices Used to Stop the Motor

The most convenient method you can use to stop your motor is with the built-in Axis exception action functionality, since it has been pre-defined to provide a balanced reaction between exception severity and customized stopping of the motor. The exception action functionality also reacts very quickly in the drive and is independent of logic scanning. Taking many different load types into consideration, these stopping methods must be predictable, and the behavior must be consistent for a given exception. When the application encounters a fault type that results in an unwanted action, equipment damage may occur. Consider a load that requires a controlled stop – it may be necessary to use a secondary braking method to stop that load if a drive exception action could cause the drive to disable and coast.

When required, secondary braking mechanisms, which can be mechanical (air brake, rail brake, disk brake, and so on) or electrical, can be used together with the exception actions to help provide a predictable stopping behavior.

Reflecting on mature technology such as the RBM (Resistive Brake Module), these devices were used as a secondary and/or emergency stopping mechanism. This RBM module was placed in-between the motor and drive with a resistor bank that was sized for your motor and 1) stopped the motor in case of a power loss, 2) slowed a moving axis that was faulted, or 3) provided isolation between the drive and motor. Rockwell Automation has the RBM (2090-XBxxx) and our Technology partners have similar devices. For example, Bonitron makes the M3500DB module and also provides the calculations so you can predict the stopping time of your motor. These devices were used with resistors and attempted to decelerate your motor to zero speed. At that point, your axis may need to be held stationary. This is where a motor mounted holding brake or another braking system can be used. While an RBM can be effective in slowing or stopping your motor and motor holding brakes can hold the motor stationary, braking devices like the Stober safety brake can be used to both stop and hold your motor with a single device that removes hardware complexity and is much simpler to implement. This braking device can be used to comply with machine safety standards, or it can be used simply as a stopping and holding device. These devices have a usable lifespan when they operate as a stopping brake (i.e.: actuate a certain number of times before service or replacement is required). This Safety Function Application Technique explains how to use the Stober safety brake with a Kinetix 5700 using the Safe Brake Control function of the drive. Moreover, it explains different stop use cases like an E-stop and normal cycle stop. These different use cases show how to minimize how often it is used to stop the motor, since there is an actuation limit on the brake device.

Common Exception Actions Use Cases

There are several use cases that we will explore related to various fault scenarios and the resulting exception actions. Each of the topics described in the will cover two scenarios:

1) When machine and human safety are the primary consideration

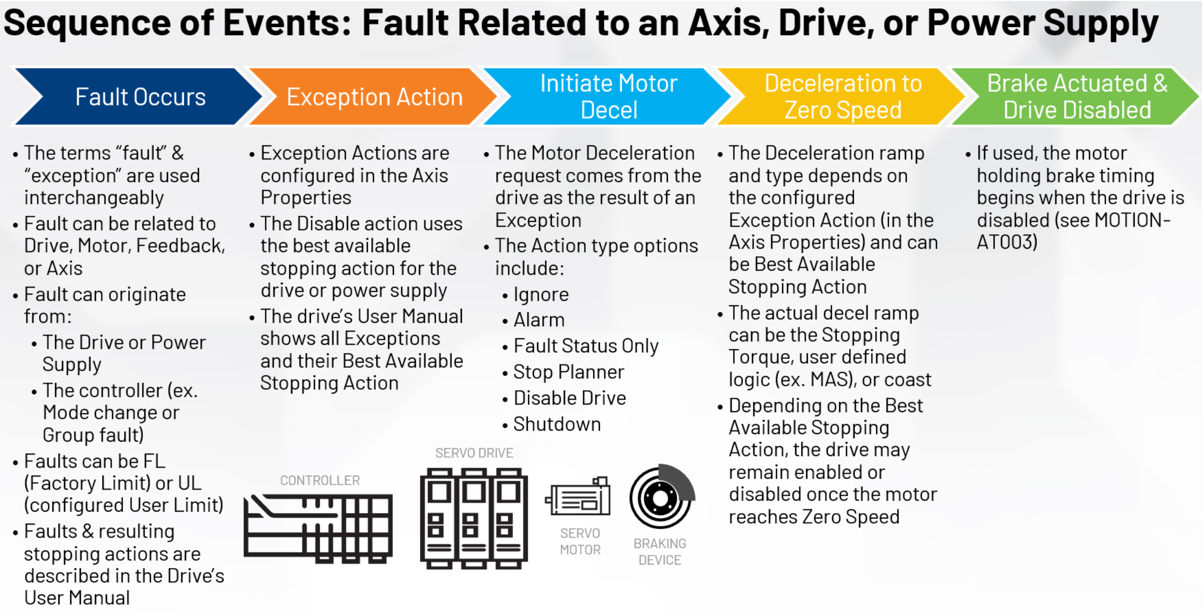
2) When machine and human safety is not the primary consideration

One reason for the delineation regarding safety requirements is that different components are used to achieve the desired outcome. For example, in some cases a GuardLogix® safety controller must be used to achieve different safety levels, while in others, a standard controller would be sufficient. Some drives use drive safety instructions; if that is required, different hardware may be required. For example, a Kinetix 5700 -ERS3 drive can use standard STO (Safe Torque Off) and SS1-T (Safe Stop 1-Timed). The -ERS4 or drive safety, has capabilities like speed and position monitoring, in addition to the -ERS3 features. Depending on the application, the flexibility of the -ERS4 may be required.

The use cases described in this document contain graphics that flow from left to right and that show the sequence of events that occur for a given scenario. The use case section then describes the characteristics of each part of the sequence.

Use Case: Typical Axis Exception Actions

The graphic shows how a typical axis, drive, or power supply exception sequence is evaluated, the countermeasures that can be used, and the important characteristics of each part of the sequence.

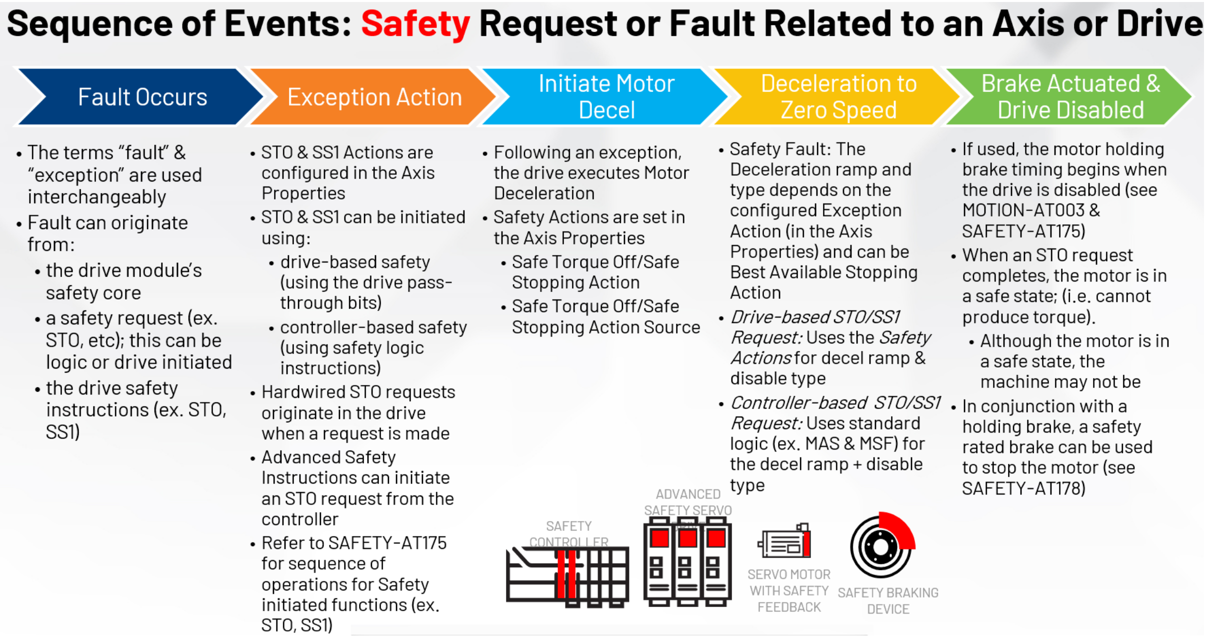


You can see from the graphic that different stop types (from the *Initiate Motor Decel* column) can be used, and the actions increase in severity. Moreover, you can see that the *Disable Drive* action will rely on the drive to dictate the Action. Tables in the Troubleshooting chapter of the Kinetix drive User Manuals describe all drive faults and their corresponding Best Available Stopping Actions. Keep in mind that Actions resulting in a Stop Planner, Disable, or Shutdown apply to an individual axis and are suitable for non-coordinated axes. For coordinated axes, where possible, it is typical that the: *Alarm* or *FaultStatusOnly* action is used together with logic programming to execute a controlled stop (MAS) and disable (MSF) the motors (**TIP**: other instructions can be used to perform the controlled stop and disable but this sequence, in some form, is common). In this manner, a leader axis can be commanded to stop motion while the synchronized follower axes will be brought to a controlled stop. This maintains the mechanical relationship between axes and can help prevent equipment damage. Once the motors are stopped, they can be disabled.

In some cases, when a power supply is used (the Kinetix® 5700, for example), a major fault with the power supply can cause its contactor enable relay to open. When this occurs, three-phase power is removed from the Kinetix 5700 drive system. All the drive modules that use that power supply will also fault. The drive’s User Manual contains all the Exception Actions that apply for a given power supply fault. These behaviors need to be examined to see how your application will be affected.

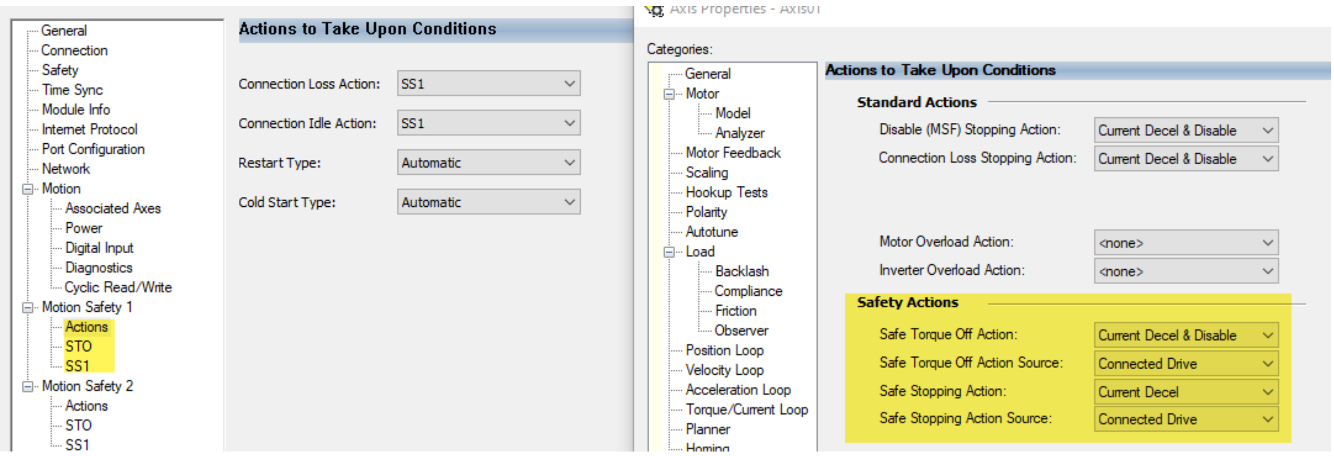
Use Case: Safety Request or Safety Fault Exception Actions

This case evaluates a safety request or safety exception and its resulting action. The safety request considers machine and/or human safety. That type of request, for example, can be an STO request (Safe Torque Off), an SS1 request (Safe Stop 1; controlled stop & disable) and a safety exception with its resulting actions. An example of a safety exception is the loss of feedback from a device that is used for safe monitoring. When using Kinetix drives, a request that results in an STO (Safe Torque Off) state renders the motor incapable of producing torque until the request is removed and a safety reset is performed. It is typical in this configuration that a GuardLogix safety controller or discrete safety components (a safety relay with time delay, Bul. 440R, for example) are used.



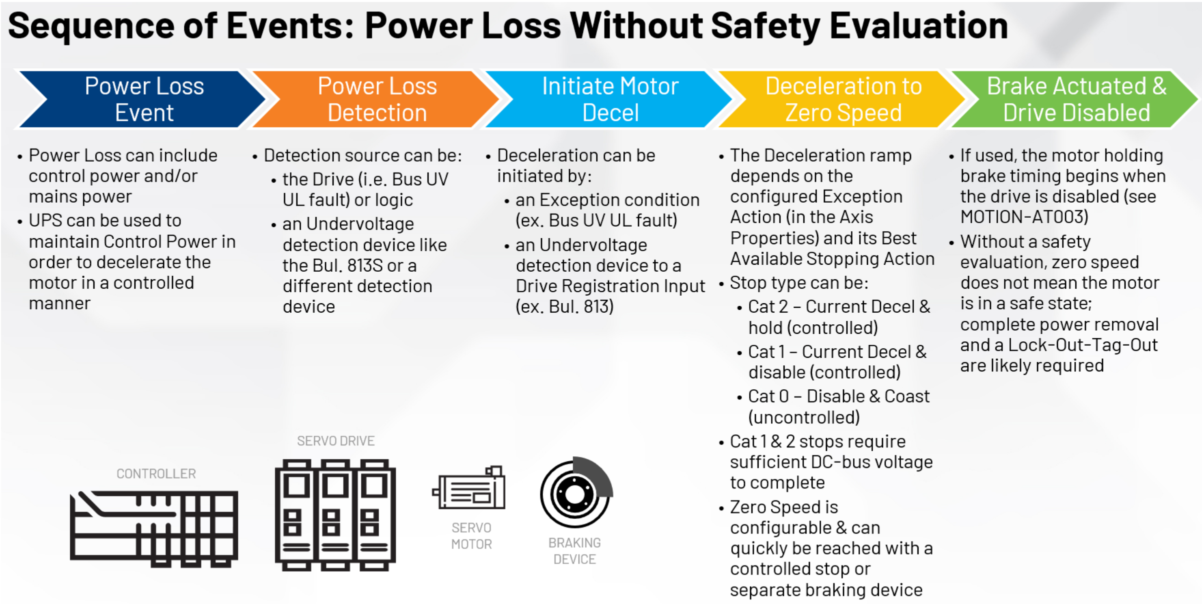
It can be useful to understand the entire sequence that occurs when a safety request is initiated. This request can be initiated by the Drive Module tags (Drive Based/Connected Drive) or using drive safety instructions (Controller based/Running Controller). SAFETY-AT175 shows all the behaviors and timing used for initiating an STO and SS1. SAFETY-AT175 also shows the holding brake timing (when a braking device is used) that is required to actuate a device to either stop or hold the motor (or mechanism) when it is stationary.

This image shows the drive module Add-On profile (left) and the Actions (right) for different safety features.



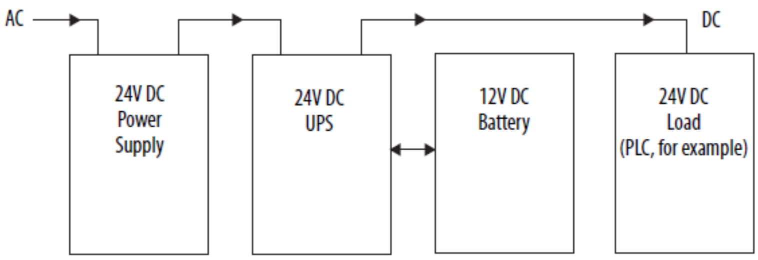
Use Case: Total Power Loss Without Safety Evaluation

A common use case is handling an unexpected AC power loss. This is not a typical machine power removal, such as when the machine is powered down for service, or when the machine is typically in a stopped and disabled state and power is removed - this is a loss of power that is not planned.



When a Power Loss event occurs, the first option to consider is to use a UPS (Uninterruptible Power Supply) module to maintain power to the system. There are several types of UPS modules to consider. An AC Line powered UPS, like the Bul. 1609, is output size limited but can be useful for low voltage applications (Bul. 1609 have ratings of 230V@1KVA). You can use this UPS to bring your motor to a known stopped and disabled state without relying on residual drive DC power alone. An alternative to the traditional AC powered UPS is the 24V DC Bul. 1606-XLS UPS solution. This is used to buffer or maintain control power when total power is removed. To determine the size required for this UPS type, you must obtain the combined current requirements for the drive, brakes, and depending on how the UPS is used, drive logic power. When using the 1606-XLS UPS module, a 24V DC supply is already present. The UPS module provides a means to receive 24V DC from this power supply and maintain power through a power loss condition using a 12V DC battery. The battery (with a capacity of up to 40 Ah) is used during power loss and generates a 24V DC output (through the UPS module).

Block Diagram Showing a Typical 1606 UPS Module as a UPS Function

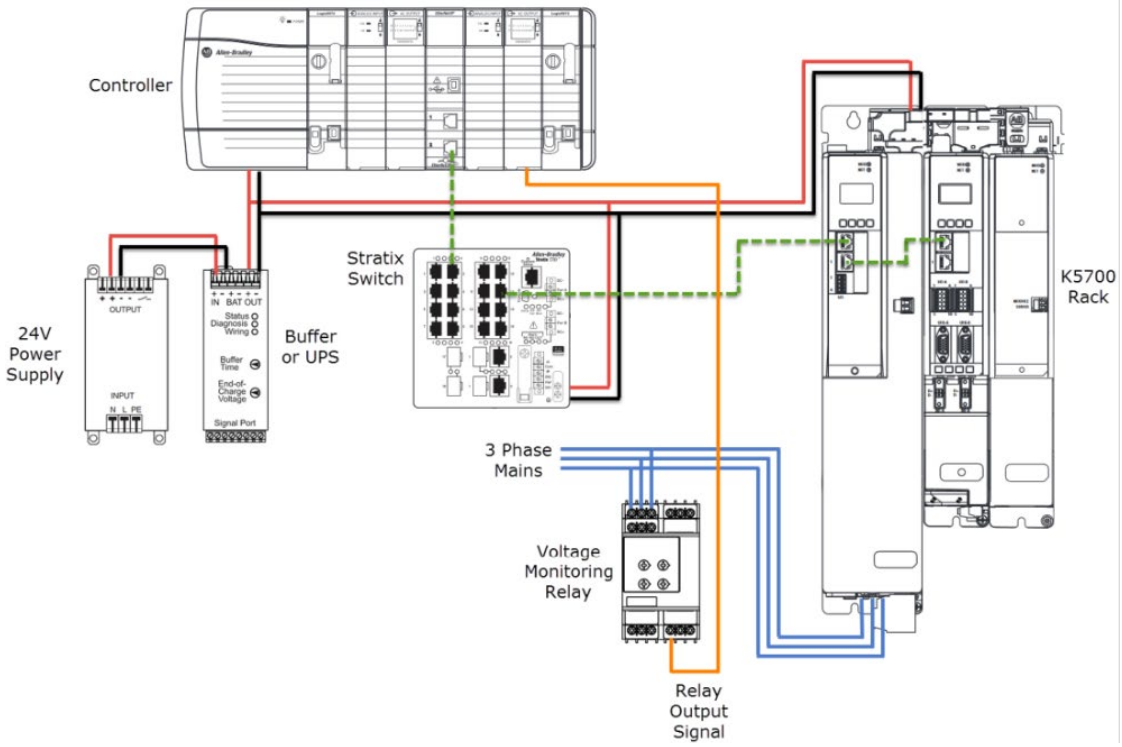


The main reason for using the UPS module is to maintain the control power to the drives, the controller and holding brakes, while still being able to use residual DC-bus energy to attempt to stop the motors in a controlled manner. Once this stop is completed and the motors are not able to produce torque, the UPS can become idle or even have its power removed if its only function is to reliably stop and disable the motors.

When a UPS is not used and a power loss occurs, the resulting fault that occurs may not be predictable, as it will depend on the machine's last operating state. Furthermore, when a power loss occurs, there may not be enough time to reliably use the available DC-bus energy to decelerate the motors. In some simple testing, it was observed that either the Converter AC Phase Loss, Bus Power Loss, or Bus Undervoltage User Limit fault (when the limit is set) would occur depending on the machine's operating state when the power loss takes place (For example, was the machine idle or running a full cycle at speed). In addition, it is essentially impossible to predict when the control power loss will occur, which can result in an unpredictable stopping action.

The next consideration is the power loss detection method. If you use the built-in drive exception/actions, the *Bus Undervoltage User Limit* fault, for example, can be triggered if the User Limit is set to detect a small loss in DC-bus energy. This limit is configured in the drive's Add-on Profile under the Power category. Detailed information on the Undervoltage User Limit configuration, and its use, can be found here. Depending on the total capacitance of your Kinetix drive system (for example, if it's a multi-bus system like the Kinetix 5700 or single bus system like the Kinetix 5300) and using the worst-case cycle profile you can determine how much time is available to reliably stop the motors. When the required motor power (Motoring Peak Power from the Axis Analysis in Motion Analyzer) is less than the system delivered power, your motor can decelerate under residual DC-bus power when AC line power is lost. If the required motor power exceeds the system delivered power, additional capacitance is required. If power loss introduces problematic risk, capacitor modules can be used for additional bus ride-through time to stop a motor.

An alternate and effective method for quickly detecting power loss is to use discrete components like the Bul. 813S Voltage Monitoring relay.



This relay device is powered by 24V DC and energizes a relay output that reacts to an undervoltage condition (% of input voltage) within a programmable time (min 100ms). The relay output can be wired to any available drive Registration Input (or a fast-reacting input) and a logic-based *Registration Event Task* can be used to execute controlled stops on all the motors. The stop can consist of a Motion Axis Stop (MAS) and/or a Motion Servo Off (MSF), which provides an effective method to stop the motors in a controlled manner before residual DC-bus power is no longer available.

Once you determine the detection method, you can evaluate how you want to trigger the motor deceleration by either using the:

- Configured exception action from the Axis Properties, for example, a Bus Undervoltage condition.
- Relay output of the voltage monitoring device.

Now the deceleration method is chosen. If the exception action method is used to decelerate the motor, the stop action will occur. Keep in mind that for coordinated (or multi-axis) stopping, the Action should be set for *Alarm* or *Fault Status Only* so that user programming logic can be used to detect the fault and stop (MAS) then disable (MSF) the motors. If the voltage monitoring device is used, the Registration Event task is used to execute logic that will stop and disable the motors.

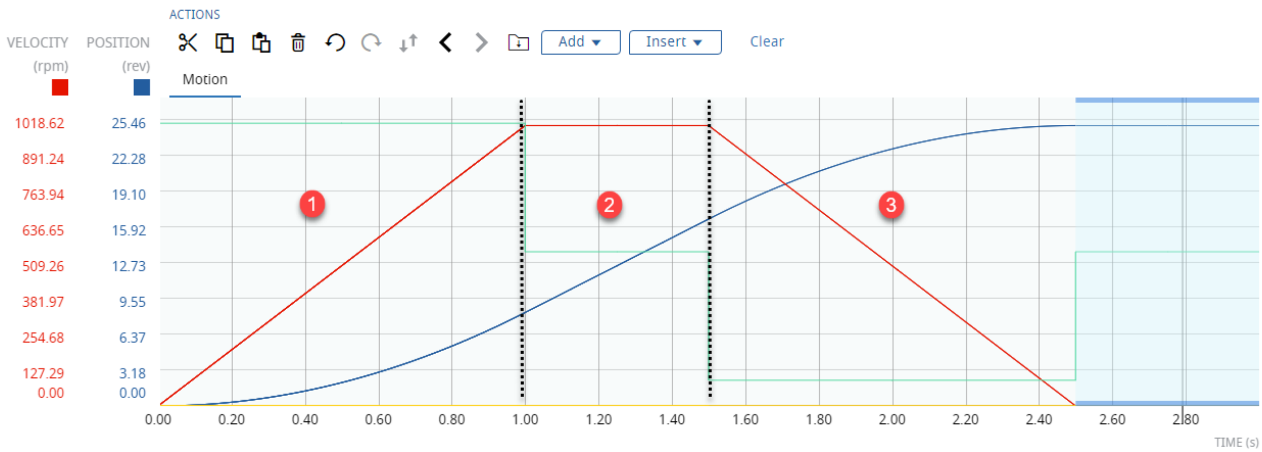
Both methods are suitable for multi-axis systems and work well if a coordinated axis stop is required. Once the motors are stopped and disabled, the holding brakes (if used) can be applied.

Example: Model the Available DC-Bus Energy

When the incoming AC power is lost, you must be sure that the drive system has sufficient DC-bus voltage to complete the stopping process during the worst-case segment of a motion cycle profile.

The more capacitance that the system has, the more capacity the system has to stop the motor in a controlled manner while the motor is performing its worst-case profile segment. For this example, we will evaluate the acceleration segment, since this is when the DC-bus will be supplying the most power to the motor (worst-case) which could result in an undervoltage condition. Let's examine this scenario in more detail.

We'll begin by reviewing a trapezoidal profile and how the different segments affect the DC-bus voltage. This is important because the DC-bus is what the axis uses to drive the motors and generate motion.

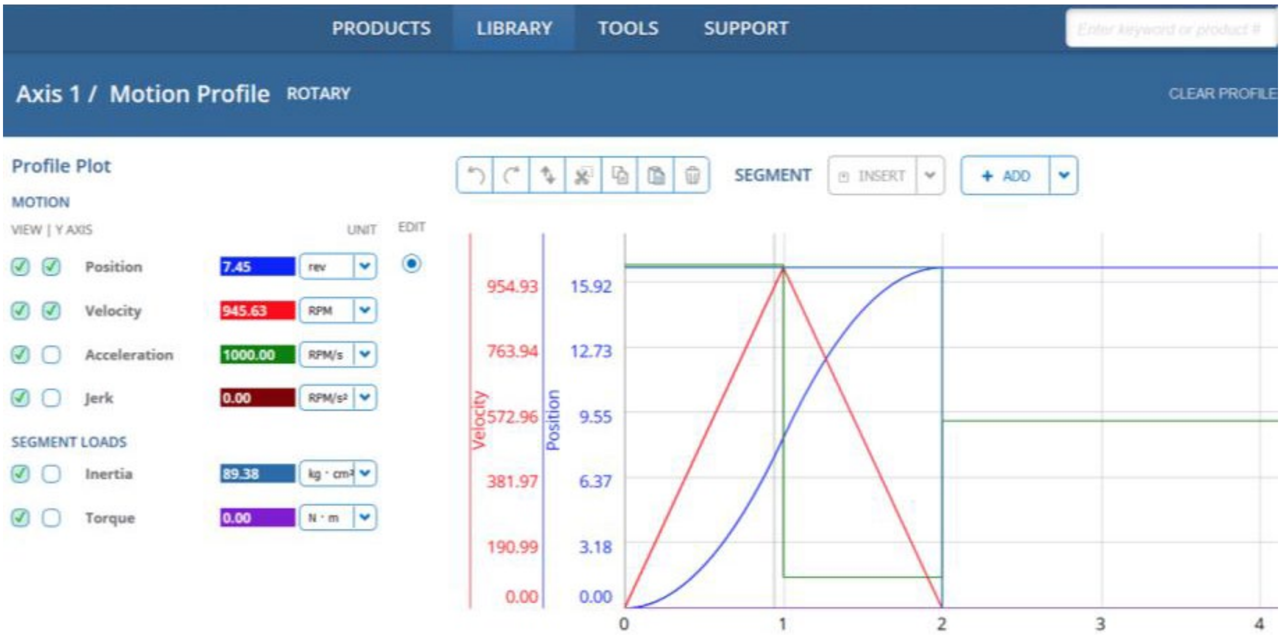


During the acceleration segment (1), the motor receives power from the DC-bus to produce acceleration torque (motoring). The DC-bus voltage may reduce slightly during the acceleration segment, and the converter works to keep the DC-bus level constant. While the motor is at constant speed (2), the DC-bus is relatively stable because it does not require as much power from the DC-bus to maintain constant speed. When the motor is decelerating (3), the DC-bus may rise because the mechanical energy in the motor and load is transformed to electrical energy and returned to the DC-bus (regenerating).

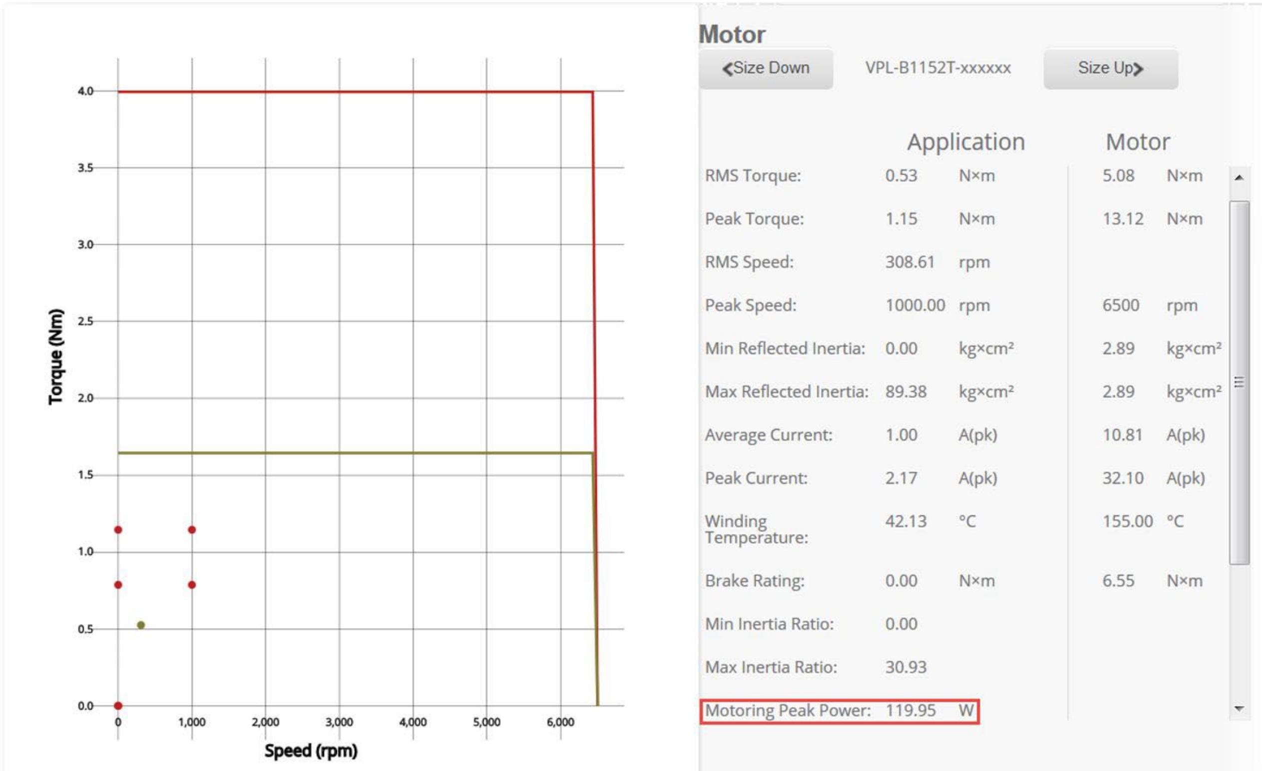
During a power loss condition, this is what needs to occur as part of the stopping process:

- The axis recognizes the Power Loss (Axis Fault or 813S output detection)
- The axis reacts to stop the motor as quickly as possible (using the exception action Current Decel/Stopping Torque or a user programmed stop with MAS and MSF)

The example below removes the constant speed segment and shows the worst-case cycle profile modeled in Motion Analyzer. The cycle profile accelerates and decelerates in 2 seconds (equally, with 1 second per segment).

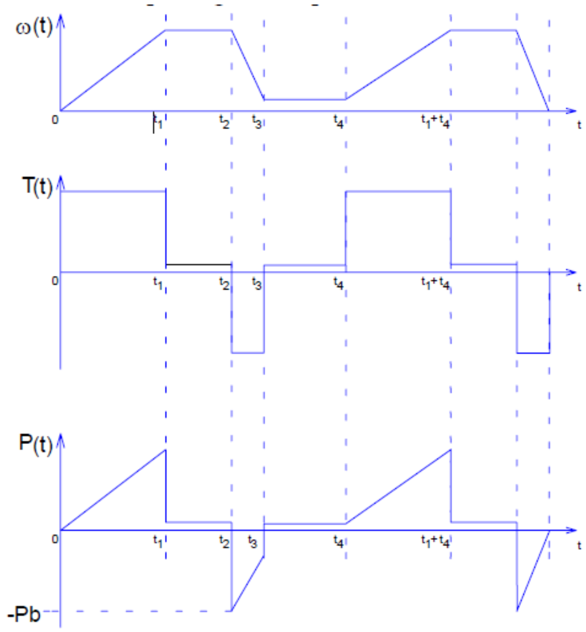


The Axis Summary shows the *Motoring Peak Power* value. This can be used to provide the application worst-case requirement for energy use (in our example, the acceleration segment).



Energy used for accelerating the motor.

The figure below shows the characteristics of a trapezoidal profile. Notice that during acceleration, speed (ω) is linear, Torque (T) is constant, and power (P) is also linear.



Since we have a linearly increasing power and constant acceleration for a given time (0-1000 RPM in 1s), we can calculate the energy required for the acceleration segment using the area of a triangle formula such that:

$$E_{accel} = \frac{1}{2} * time * Motoring\ Peak\ Power$$

For our example:

$$E_{accel} = \frac{1}{2} * 1s * 119.95W = 59.975Ws$$

Energy provided by the system.

Now, let’s examine the system’s available energy. The DC-bus system is composed of capacitors, which store energy. The first step is to find the total DC-bus capacitance of all the connected modules in the drive system.

Power Supplies Drives Capacitor Modules

$$C_{DCBus} = C_{P1} + C_{P2} + \cdots + C_{D1} + C_{D2} + \cdots + C_{C1} + C_{C2} + \cdots$$

Calculate the total energy stored in the DC-bus at a given moment:

$$E_{DC\ Bus} = \frac{1}{2} * C_{DC\ Bus} * {U_{DC}}^2$$

Where ${U_{DC}}^2$ is the DC-bus voltage squared and $C_{DC\ Bus}$ is the total capacitance.

Let’s assume we are using the Kinetix 5700 drive with 400-480V AC input. For this example, we will not consider other energy dissipation devices such as a shunt resistor. When the main power is removed, the drive eventually exhibits a FL Bus Undervoltage fault. In this example, the Factory Limit (FL) for the DC-bus undervoltage fault is 275V DC. That means, if we want to systematically stop the motors, we need to detect the power loss and command the motors to stop before the DC-bus reaches 275V DC or the drive will fault and stop the motor according to the configured exception action. To determine if it is feasible to stop the motor before the fault occurs, we need to calculate the usable electrical energy as follows:

$$E_d = \frac{1}{2} * C_{DC\ Bus} * U_{DC\ Nom}{}^2 - \frac{1}{2} * C_{DC\ Bus} * U_{DC\ UV}{}^2$$

Where $(U_{DC\ Nom}{}^2)$ is the nominal DC-bus voltage squared and $(U_{DC\ UV}{}^2)$ is the DC-bus undervoltage limit (275V DC).

The nominal DC-bus voltage depends on the AC mains voltage:

$$U_{DC\ nom} = U_{AC\ nom} * \sqrt{2}$$

With these equations, we can calculate the energy available given the data in the table below (source:2198-UM002):

Power Supply	2198-P070	Capacitance: 780uF
Drive	2198-D006-ERS3	Capacitance: 165uF
AC voltage	480V 3 phase	

$$C_{DC\ Bus} = 780\mu F + 165\mu F = 945\mu F$$

$$E_d = \frac{1}{2} * 945\mu F * \left(480V * \sqrt{2}\right)^2 - \frac{1}{2} * 945\mu F * (275)^2$$

$$= 217.72J - 35.732J = 182Ws$$

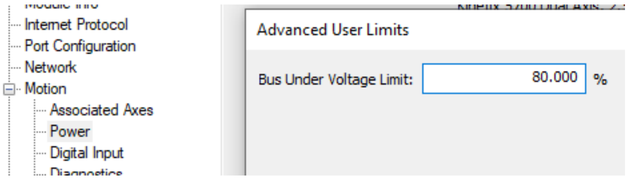
If we apply a 20% safety factor for DC-bus losses, the usable system energy is *145.6Ws.*

Conclusion.

The energy used for the acceleration portion of our profile is about 60Ws. The usable energy in the bus before we encounter a DC-bus undervoltage condition is about 146Ws. This means we should have enough energy to complete the entire profile to bring the motor to a stop before the drive faults.

In some cases, it may be necessary to quickly detect the power loss condition and immediately issue a stop command before the fault being declared. To detect the power loss condition before the drive faults, consider using the User Limit Bus Undervoltage (UL) as an alarm by setting it to *FaultStatusOnly*. Once you determine the minimum DC-bus voltage level observed when running your application, you can set the user limit voltage just below that minimum. This should provide you with the most time, without external detection, to detect the power loss condition and perform a controlled stop.

The Bus Under Voltage setting is in the drive Add-On Profile>Motion>Power:

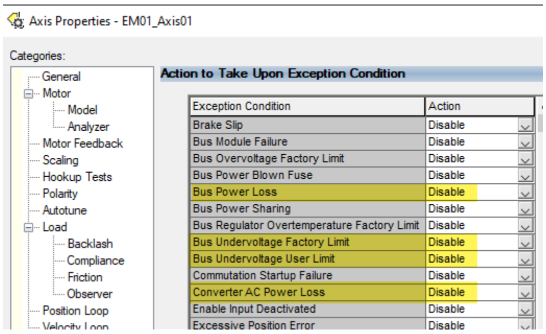


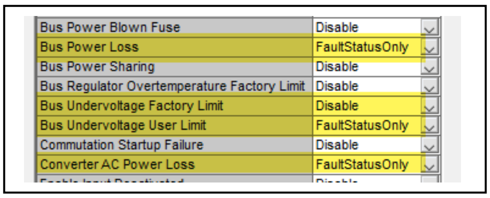
Actual application variables likely differ from estimated values, so modeling using these calculations is solely an exercise intended to determine feasibility. These power loss scenarios must be tested and verified using trends with real-world equipment.

If the motor required more energy than the drive can deliver during the accelerating (motoring) segment, more capacitance can be added to the drive system. Capacitance acts as a buffer to maintain the DC-bus.

The exception actions for this example would need to be set for *FaultStatusOnly* so that the user’s program can execute a deceleration rate-limited MAS (Motion Axis Stop) followed by an MSF (Motion Servo Off) to stop the motor in a controlled manner.

Alternatively, we can use the Disable action; StoppingTorque and Time to allow the drive to stop the motor in a controlled manner using the exception action setting. These are some common Power Loss Exception Actions:





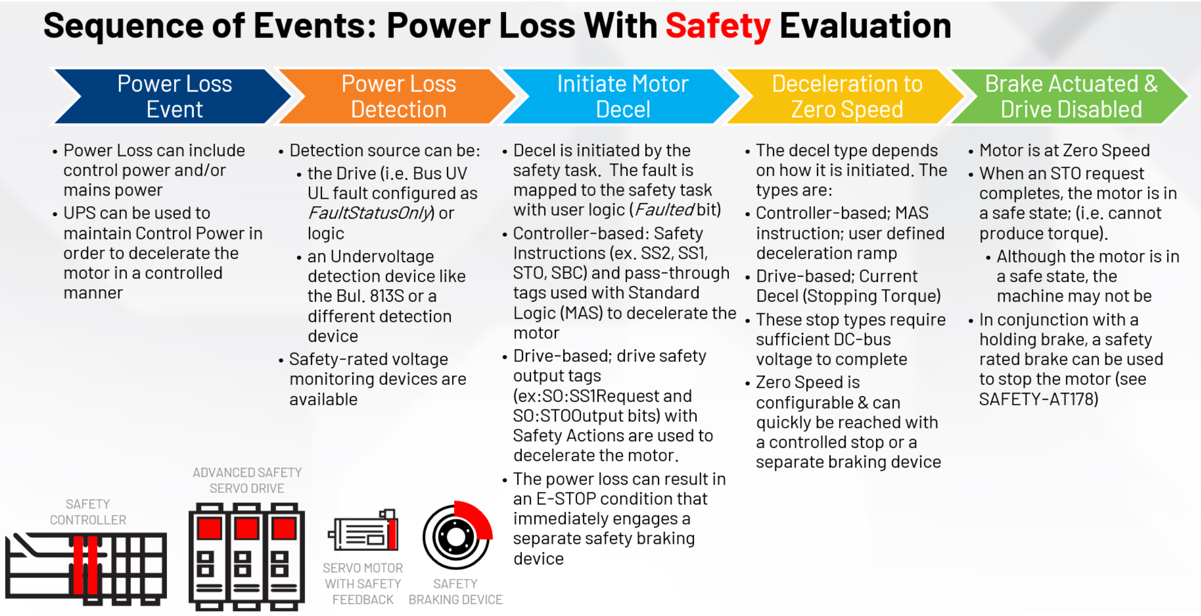
This table is an example from the drive's User Manual and shows the available Fault Actions and the Best Available Stopping Actions for this drive:

Exception Fault Code	Exception Text	Inverter Modules 2198-*xxxx*	Permanent Magnet Motor	Induction Motor	Fault Action: Ignore	Fault Action: Alarm	Fault Action: Minor Fault	Fault Action: Major Fault	Best Available Stopping Action (applies to major faults)
FLT S22 – AC POWER LOSS	Converter AC Power Loss Fault	-ERS3 (series A)	X	X	X	X	X	X	Decel/Disable
		-ERS4 -ERS3 (series B or later)							Ramped Decel(1)/Disable
FLT S27 – BUS REG OVERTEMP FL (2)	Bus Regulator Overtemperature Factory Limit Fault	-ERSx	X	X	–	–	–	X	Disable/Coast
FLT S32 – BUS CAPACITOR MODULE FAILURE	Bus Capacitor Module Failure	-ERS3 (series A)	X	X	X	X	X	X	Decel/Hold
		-ERS4 -ERS3 (series B or later)							Ramped Decel(1)/Hold
FLT S33 – BUS UNDERVOLT FL	Bus Undervoltage Factory Limit Fault	-ERS3 (series A)	X	X	–	–	–	X	Disable/Coast
		-ERS4 -ERS3 (series B or later)	X	X	–	–	–	X	Disable/Coast (3)
FLT S34 – BUS UNDERVOLT UL	Bus Undervoltage User Limit Fault	-ERS3 (series A)	X	X	X	X	X	X	Decel/Hold
		-ERS4 -ERS3 (series B or later)							Ramped Decel(1)/Hold

For a versatile common DC-bus architecture, you can use the Kinetix 5700 regenerative bus supply (2198-RPxxx). Regenerative bus supplies use a PWM-controlled IGBT converter for full regeneration of power to the AC line. The regenerative bus supply returns energy back to the distribution system instead of dissipating energy with shunt resistor (braking) technology. That allows incoming power to be used by the common DC-bus system or when the DC-bus is above a threshold, that energy is returned to the distribution system. Regeneration creates a unique condition when incoming power is lost. Considerations for regenerative systems are not covered in this document, however you can refer to the Kinetix 5700 User Manual (2198-UM002) for more information on the regenerative bus supply.

Use Case: Total Power Loss with Safety Evaluation

The use case for a total power loss with a safety evaluation is very similar to the previous use case. The differences between the use cases include the method used for initiating a motor deceleration and the resulting sequence. When the system has a safety evaluation, we can use the same detection methods as the previous use case. For example, the exception/action or an external device to indicate that a power loss has occurred.



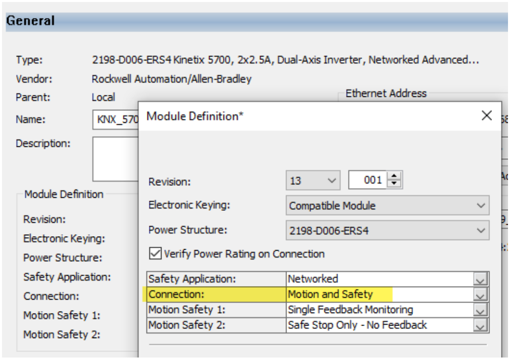
When using the exception/action detection method, the axis fault tag (ex: *AxisX.BusUndervoltageULFault*) is triggered and a user created *Faulted* bit is set using standard logic. This *Faulted* bit is logically mapped (with the safety-mapping tool) from the standard task to the safety task. The faulted bit can then be used in the safety logic to initiate an SS1 or STO request. The same Drive or Controller based stopping method from the Safety Request or Safety Exception Action use case can be used here. When using the Exception Action method, the fault tag must be mapped to the safety task and logically scanned to execute the safety instruction (ex. SS1 or STO). This introduces extra logic execution time and needs to be acceptable for your application.

When the Bul. 813 voltage monitor is used, the relay output from the monitor can be wired directly to a safety input, which is immediately available to the safety program without requiring safety mapping. That safety input can then be used directly with your safety and standard logic to perform any motion stopping and disabling. Eliminating Safety tag mapping may be necessary to minimize the response time when you consider program scan time and the rate of decay of the residual DC-bus voltage. This method can also be used to immediately engage a safety brake device to stop any motion.

Both power loss detection methods are acceptable when used with a multi-axis or coordinated system. In response to a power loss event, you can disable the axes together and when safety logic is used, you can also initiate multiple safety instructions sequentially. Your application and timing will dictate where and how the deceleration and disable are best performed. The Safe Monitoring Solutions using Drives Application Note (SAFETY-AT175) provides guidance on timing differences between controller and drives-based safety functions. When your machine uses a Safety rated braking device, your motor may need to be stopped as quickly as possible. Typically, for a power loss event, the E-stop method will be used to immediately stop and disable the motor. When the motor must be stopped and held, that will count as an actuation cycle for the braking device (Keep in mind that the safety braking device has limited uses when it is used as a stopping brake. See the Safe Brake Control Safety Function Application Technique SAFETY-AT178 for details on the different stopping use cases).

Use Case: Ethernet/IP Connection Loss

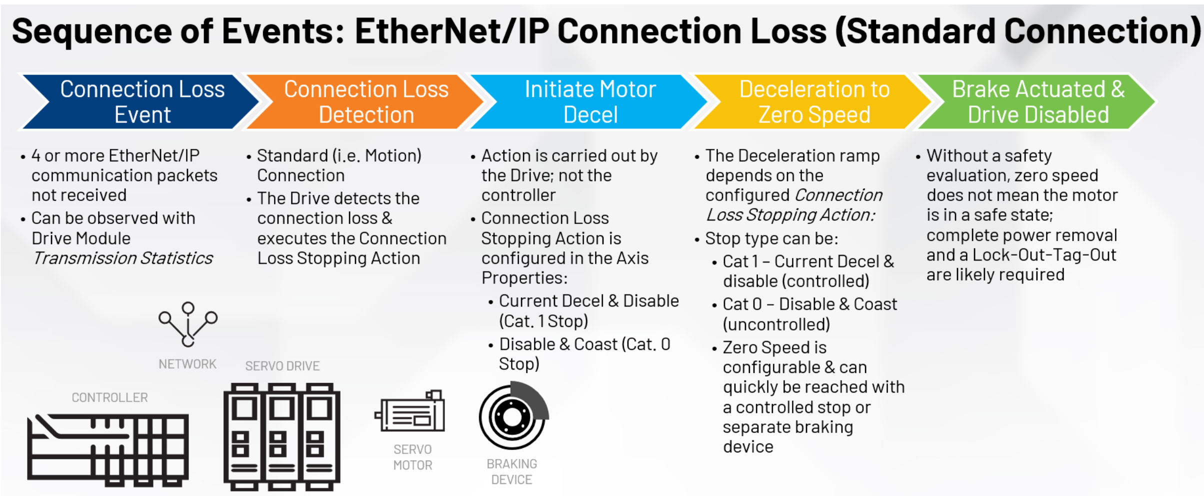
In general, there are two Ethernet connections that a Kinetix drive can use - a standard (motion) connection and a safety connection. These two connections can be made to separate controllers, or they can be used by one controller. The Ethernet connection types are configured in the Drive Add-On Profile. This is shown below.



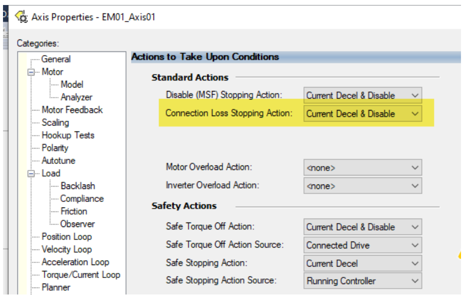
Understanding how the system responds with this use case is critical because Integrated Motion on Ethernet/IP relies on the standard Ethernet/IP Ethernet connection to command motion. When CIP Safety is used, it relies on the Safety Ethernet/IP connection to provide safety information.

CIP Motion Standard Ethernet/IP Connection Loss

When this connection is removed, damaged, or affected by its environment (ex. poor cable design) the controller cannot send the motion command to the drive, so the motor must be stopped and disabled.



The standard Ethernet connection uses the exception action method to stop and disable the motor. The standard connection can use Current Decel/Disable (Cat. 1 stop) or Disable/Coast (Cat. 0 stop). It is configured in the Axis Properties shown here:

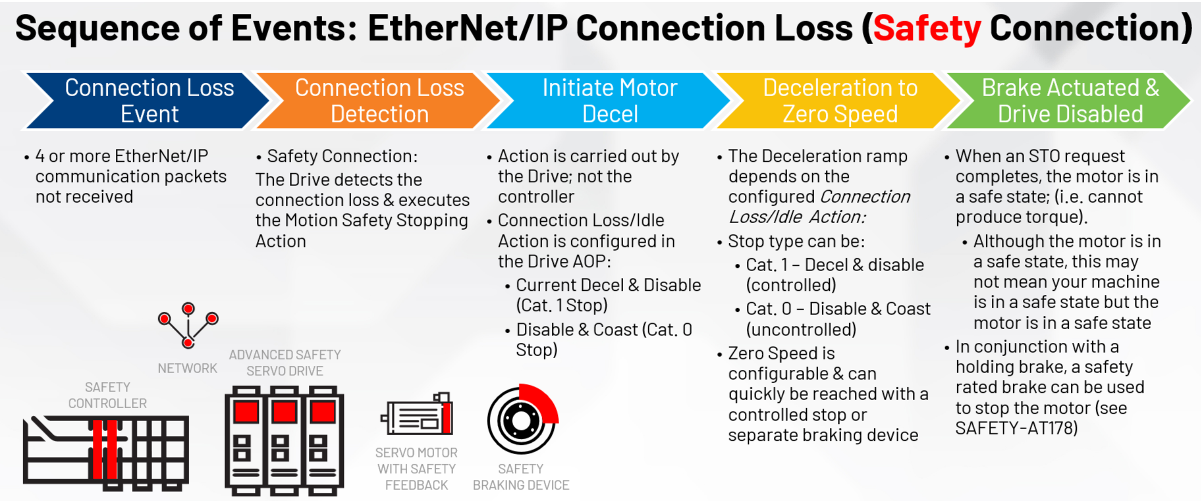


The action is initiated by the drive. Keep in mind that multiple motors cannot be stopped in a coordinated manner if this fault occurs, since the resulting action cannot be configured for *Alarm* or

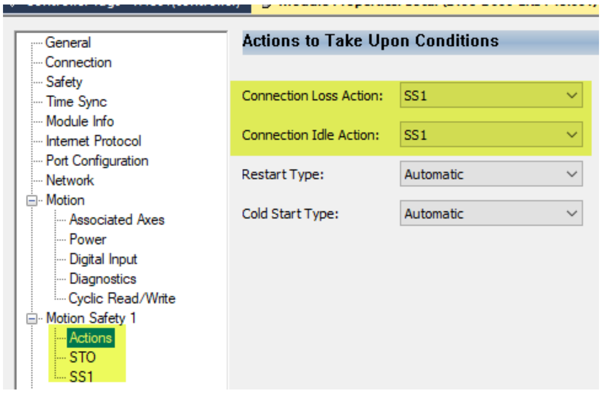
FaultStatusOnly. Once the motor reaches Zero Speed, a holding brake can be used to hold the motor stationary. A safety brake or secondary braking device can be used with this use case.

CIP Safety Ethernet/IP Connection Loss

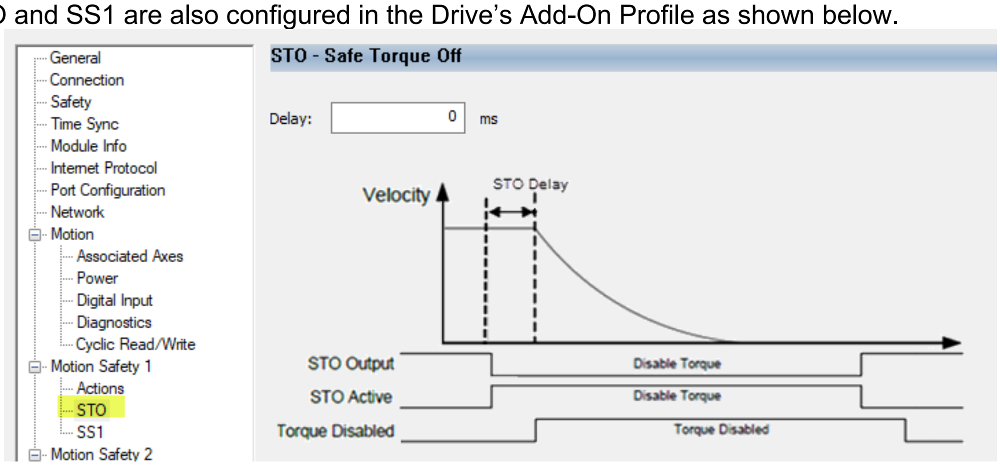
When the safety Ethernet connection is removed, damaged, or affected by its environment (ex. poor cable design) the drive cannot determine the safe state from the controller, so it will use the Safe Stopping Action setting to bring the motor to a known safe state (For example, the drive is not able to produce torque).

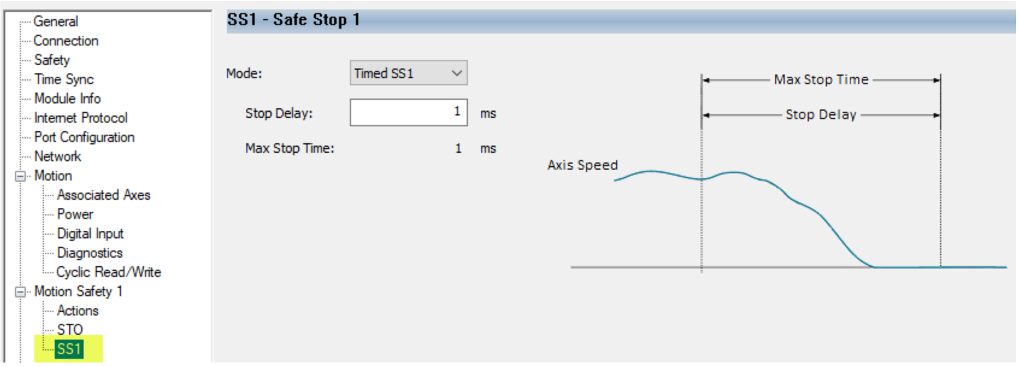


The safety connection uses the configured Action from the Drive Add-On Profile to stop and disable the motor. The connection loss or idle actions can be programmed as SS1 or STO as shown below.



The STO and SS1 are also configured in the Drive's Add-On Profile as shown below.





Note that the loss of the safety connection can only use Drive-based deceleration and disabling, since the drive will no longer have a connection to the controller. Keep in mind that multiple motors cannot be stopped in a coordinated manner if this fault occurs, since the resulting action cannot be configured for *Alarm* or *FaultStatusOnly*.

Resources

Motion Analyzer; Sizing Software

Resistive Brake Module; Product Details

Stober safety brake; Product Details

Bul. 813S Voltage Monitoring; Product Details

Installation Instructions; RBM

M3500DB-Bonitron RBM Installation Manual

Safety Function Application Technique; SAFETY-AT178

Safety Function Application Technique; SAFETY-AT175

Vertical Load and Holding Brake Management; MOTION-AT003

Kinetix 5700 User Manual; 2198-UM002

Drives in Common Bus Configurations with Kinetix 5700 Bus Supplies; MOTION-AT007

Drives Engineering Handbook; DRIVE-AT001

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