This Application Note applies to all AC Drives

A Guide to Sizing and Protecting Dynamic Braking Resistors for AC Drives

The intention of this application note is to provide some basic guidance in applying, sizing and protecting dynamic braking resistors applied to Control Techniques Drives.

Dynamic braking is a very common option used with both AC and DC drives. Calculating the wattage for both type drives can sometimes be difficult and to some degree may require a bit of guesswork. This is because in many cases there is not enough information about the machine inertia and frictional load. In general, for most applications (barring indexing and press drives) an “e-stop” duty rated braking resistor is sufficient for applications requiring occasional stops and some regeneration. In dc drive applications, resistor protection is not needed since once the motor is stopped, there is no longer a source of energy to the resistor. In ac drives on the other hand, even though the motor is stopped, the resistor is still connected across the dc bus of the drive through the braking transistor and the bus is powered directly across the ac line. If for some reason the braking transistor fails (which can be a short); the resistor will be tied directly across the dc bus and thus will continuously dissipate energy. This can equate to 3 -20 times the rated wattage of the resistor depending upon the particular kit. Thus the reason for providing some form of overload protection.

Dynamic Braking Resistor Selection

In order to properly apply dynamic braking resistors three items must be determined:

1. Resistance
2. Wattage
3. Protection Scheme

1. Resistance Value

The value of the resistor sets the maximum value of braking torque. Once this value is chosen, it must be compared to “minimum” allowable resistance for the particular drive model. If it works out to be a value below the “minimum” allowable resistance a decision must be made. The first step is to calculate what torque you can get and determine if that value is sufficient for the application. Remember, if you are close, these calculations do not include the motor and drive losses which can easily be 10% of the motor horsepower. If the resistance works out to be greater than the minimum value, use the value calculated. Using the minimum value can unnecessarily increases the peak power requirements of the resistor which in turn can decrease the maximum allowable “on” time. An example will be used to show the “mechanics” of a typical calculation. This example will be used throughout this document.

Motor Data:	5 HP, 460 Vac, 6.8 amps, 1760 rpm, 0.857 pf, 0.90 eff, rotor inertia = 0.74 lb-ft^2 (TEFC frame vector duty)
Braking Requirements:	150 % of motor rated torque

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The drive we will use is the SP1405 which is rated at 7.6 amps continuous (Heavy Duty).
The basic equation for calculating the braking resistor value is:

$$\text{Power, } P = \frac{\text{Bus Voltage squared } (V^2)}{\text{Resistance } (R)} \qquad R = \frac{(Vb)^2}{P}$$

The Power, P is the braking power of the motor in watts times the percent braking torque required (in per unit)

P = 5 HP X 746 (watts / HP) X 1.5 (percent torque in per unit, i.e. 150%)

For this example: Power, P = 5595 watts

The voltage used is the DC Bus voltage at which the braking transistor turns on. The table below gives the voltage levels for the various drive ratings

Drive Voltage Rating	Nominal Bus Voltage	Brake Turn On Voltage
240	340 Vdc	390 Vdc
480	680 Vdc	780 Vdc
575	813 Vdc	930 Vdc
690	976 Vdc	1120 Vdc

For a 480 Vac drive the voltage is 780 Vdc therefore:

$$5595 \text{ watts} = 780^2 / R \longrightarrow R = 780^2 / 5595 = \mathbf{108.7 \text{ ohms}}$$

The minimum resistance allowable for the SP1405 is **58 ohms**, therefore 108.7 ohms is ok. In this case a standard 100 ohm resistor would be fine instead of ordering a custom value. In the case of a Vector or Servo drive, the drive allows 175% peak torque. A resistance value of 93.2 ohms would be required.

2. Wattage Value

This is the tricky part because the wattage required will be based on the application.
A few basic questions need to be answered as a minimum in order to make an educated guess.

1. What kind of machine is it?

   Extruder, conveyor, fan, pump, press drive, rewind, unwind, pull roll, feed roll, dynamometer….

   The answer to this question can make a tremendous difference on the required wattage.

An Extruder has a heavy frictional load and pretty much stops very rapidly where as a Press drive is a large “fly-wheel” having very little frictional load and a very high inertial (mass) component which may take 30 minutes or more to coast to a stop. Of course the Press drive would require a good sized braking resistor while the extruder does not require any.

Fans and pumps in general do not require dynamic braking unless they can be “over hauled or driven” by an external force or for some reason the process they are involved in requires rapid changes in speed. Fans and pumps (variable torque) exhibit heavy frictional loads at high speeds and high inertial characteristics at low speeds.

1. How often is the machine stopped?

   Again, the size of the braking resistor can be greatly affected by frequency of stopping. For applications requiring an occasional stop, a resistor rated at 5-10% of the drive rating is adequate where as an indexing application, may require as much as a 50% to 75% of the drive rating.

2. a) How long does it take the machine to coast from full speed to zero?
   b) How long does it take the machine to accelerate from one speed to another speed at a specific torque level?
   c) How much motor load is there when the machine is running?

   Knowing these Items help characterize the machine, i.e. frictional load and inertia.

3. Is the braking used to absorb energy during a speed change?

   In this application you might want to know how often the speed is changed and what the speed change is. This would be very similar to an indexing application.

4. Is the motor being used to provide hold back torque or to prevent the motor from being overhauled?

   This would typically be a continuous duty application where the wattage would be directly proportional to the required “hold-back” torque.

5. What is the machine Inertia?

   Knowing this allows you to calculate the stored energy of the machine and thus more easily determine the required wattage of the brake resistor. This is commonly the case with indexing applications.

In many applications, all the information you’re given is;

I have an SP1405, what DB resistor do I need?

In this case to be on the safe side you would need to use a 4 KW resistor since it is a 4 KW drive, this is clearly not enough information. In almost all cases this resistor is overkill unless the application happens to be a dynamometer. Many applications only require the motor to stop a few times a day and have low inertia (i.e., not a fly-wheel). In these cases a much smaller resistor may be used. As a rule of thumb, a wire wound power resistor can handle about 20 times rated power for 3 seconds (then allowed to cool back down to ambient temperature) while an vitreous enamel (ceramic) power resistor is typically good for about 10 times rated power for 6 seconds. This equates to an energy rating of 60 times the wattage rating of both resistors, the difference being that the wire wound resistor can handle a greater “thermal shock” (i.e. higher peak current) than a ceramic resistor and thus the peak allowable rated wattage is greater than that of the ceramic. The other difference would be the longer cool down period on the ceramic resistor due to its greater mass. Based on this assumption, the lowest useable wattage could be calculated based on the peak power dissipated in the brake resistor divided by 20 (we will use wire wound resistors as standard). This of course refers to E-Stop duty (or limited duty) rated resistors as opposed to repetitive applications (indexers for example) or dynamometer based applications (load stands or applications requiring hold back torque).

$\mathbf{P}_{(peak)} = 780^2 / 108.7$ = 5597 watts
$P_{db\ (min)} = \mathbf{P}_{(peak)} / 20$ = 279.8 watts minimum
$\mathbf{E}_{(max)} = 279.8 * 60$ = 16788 joules

Note that I mentioned previously that the minimum allowable resistance typically should not be used if the calculated resistance is higher. In this case if we had used the 58 ohm minimum allowable resistance for an SP1405, the wattage, based on our “rule of thumb; 20 times rated power for 3 seconds, would be almost twice the value required for the 108.7 ohm resistor.

$\mathbf{P}_{(peak)} = 780^2 / 58$ = 10489 watts
$\mathbf{P}_{db\ (min)} = \mathbf{P}_{(peak)} / 20$ = 524.45 watts minimum
$\mathbf{E}_{(max)} = \mathbf{524.45} * 60$ = 31467 joules

A few other ill effects of using the minimum resistance are, an increase in ripple current and voltage in the bus capacitors, decrease in max on time , lack of brake current sharing in common bus applications and motor overload protection sizing.

In our example of the 5 HP drive, the motor has an inertia (j) of 0.74 $lb\text{-}ft^2$ (or 0.031 KgM^2), lets calculate just how much inertia we can couple to the motor and stop it from full speed within the constraints of the resistor we selected above.

First of all, what are the equations we need to use? We will use the MKS system since calculations are more direct.

The inertia of the motor (j) as shown above is 0.031 KgM^2 (nothing more that 0.04214 times the $lb\text{-}ft^2$ value).

The motor speed now needs to be expressed in radians / second (w).

$$\mathbf{w} = \frac{rpm \times 2Pi}{60} = \frac{1800 \times 6.28}{60} = 188.5$$

The stored energy is (e):

$$\mathbf{e} = \tfrac{1}{2}\, j\, w^2 = 0.5 \times .031 \times 188.5^2 = 570 \text{ joules for the motor alone}$$

The equation for deceleration time is:

td = (j x w) / (tm + tf)
where tm is the motor braking torque and tf is the frictional load torque

Since the resistor can handle full power (20 times rated wattage) for 3 seconds and the power from the motor linearly decreases with motor speed (a triangular shape) the maximum allowable deceleration time would actually be 6 seconds (2 times the 3 seconds since the area of a triangle is equal to ½ base times height). Therefore:

6 seconds = (j x 188.5) / tm (assuming no frictional load tf = 0)

The motor torque would be:

P = (1.5 x 5 x 746) = tm x w, => tm = 29.76 nm

$$j = \frac{6 \text{ seconds} \times tm}{w} = \frac{6 \times 29.76}{188.5} = .947 KgM^2 \quad => \quad 22.47\ Lb\text{-}ft^2$$

This is equal to 30 times the motor inertia. A flywheel made of steel with a 1 inch thickness and 20 inch diameter would have about this amount of inertia compared to a motor rotor size of 6.3 inches thick and 5 inches in diameter.

As a comparison, the motor by itself could be stopped in less than 0.2 seconds @ 150% braking torque.

A system with this amount of inertia would take about 3 minutes to ramp down to zero speed with 5% braking torque (frictional and drive losses) as opposed to 6 seconds when 150% braking torque is available.

Let's now check the amount of energy stored in the system. The total inertia is 0.947KgM^2, the speed is 188.5 radians / second, therefore:

$$e = \frac{0.947 \times (188.5)^2}{2} = \mathbf{16824\ joules}$$

Very close to the energy rating of the resistor we selected (see page 3).

3. Resistor Protection

As mentioned above, dynamic braking resistors are designed to dissipate energy for a specific period of time and then be allowed to cool back down to “room” temperature or on a continuous basis. The protection device must allow this current to flow during normal operation without tripping. If this time is exceeded, it must open, protecting the resistor. To perform this protective function, a few options exist. These options are shown in figures 1 thru 3 in the pages to follow.

Figure 1

The simplest method, a **manual motor circuit protector** will be used. The overload current for the device for a particular resistor will be selected based on the trip curves, the dynamic braking current and a trip time adequate to protect the resistor. Below are the values we calculated for our example, the first using a resistance value based on motor horsepower, the other using the minimum allowable resistance for the drive size.

$\mathbf{P}_{(peak)} = 780^2 / 108.7$ = 5597 watts (R_{db} = 108.7)
$P_{db\ (min)} = \mathbf{P}_{(peak)} / 20$ = 279.8 watts minimum
$\mathbf{E}_{(max)} = 279.8 * 60$ = 16788 joules
$\mathbf{I}_{(peak)} = 780 / 108.7$ = 7.71 amps

$\mathbf{P}_{(peak)} = 780^2 / 58$ = 10489 watts (R_{db} = 58)
$\mathbf{P}_{db\ (min)} = \mathbf{P}_{(peak)} / 20$ = 524.45 watts minimum
$\mathbf{E}_{(max)} = \mathbf{524.45} * 60$ = 31467 joules
$\mathbf{I}_{(peak)} = 780 / 58$ = 13.45 amps

The above data shows the peak current that will flow in the resistor when the brake transistor turns on. The recommended protection scheme is two-fold; first and foremost, we need to stop the current flow in the resistor if the brake transistor fails to prevent heat related damage in the control enclosure, secondly, set the Full Power Braking Time (Pr 10.30) and the Full Power Braking Period (Pr 10.31) to protect the resistor from “over-use” under normal operating conditions.

Nidec
All for dreams

Overload Sizing

The overload current setting should be based on the average current, $I_{(ave)}$, that would flow through the resistor if it was connected directly across the dc bus of the drive. The following equation should be used:

$$I_{(overload)} = \frac{1.35 \text{ X Nominal Line voltage}}{6 \text{ X Resistance}} = \frac{I_{(ave)}}{6}$$

In our example the nominal line voltage was 480 Vac and the resistor was 100 ohms (108.7 calculated).

$$I_{(overload)} = \frac{1.35 \text{ X Nominal Line voltage}}{6 \text{ X Resistance}} = \frac{1.35 \text{ X } 480}{6 \text{ X } 100} = 1.08 \text{ amps (ie 1 amp)}$$

We would therefore use a 1 amp overload device. Looking at the trip curves below you would see the trip time with a class 10 overload would be 10 seconds, a class 20 overload would be 20 seconds and a class 30 overload would be 30 seconds for a current of 6 times the rated overload current. The actual trip time based on the peak current during normal braking would be somewhat less since it is 7.7 times the rated overload current (~ 7 seconds for the class 10 and 14 seconds for the class 20). In our application we would be using the class 10 overload since the max on time (Full Power Braking Time, #10.30) was 3 seconds.

Drive Overload Parameter Setting

The drive software would be used to protect the resistor from being used too much, which if it was selected properly, would only be due to some abnormal condition. We know we need to set parameter **Pr 10.30 to 3 seconds**, but what about #10.31? #10.31 can be determined from the formula below;

Pr 0.31 $= \frac{\#10.30 \text{ X } P_{(peak)}}{\text{Rated Wattage}} = \frac{3 \text{ X } 5597}{279.8} =$ **60 seconds**

This limits the rms power dissipation in the resistor to its rated value.

Remember, this is a protection device and therefore will only need to open under a transistor failure. Since the device was designed for ac and not dc current, each time the device opens there will be some arcing in the contacts which will decrease the life of the device.

In Summary: For our 5 HP example we would need:

300 Watt (279.8 is not a standard value) 100 Ohm Resistor (108.7 is not a standard value)
(- note you could use the exact values but it would be a custom value and probably cost much more than the standard value)

A 1 amp class 10 manual motor circuit protector

Set parameter Pr 10.30 = 3 and Pr 10.31 = 60 --- a 5% duty cycle

If the 58 Ohm resistor was used instead of the 108.7, the only difference is that a 2 amp manual motor circuit protector would be required since the overload current would be twice that of the 108.7 ohm resistor. The drive settings would be slightly different since the resistor wattage is twice that of the 108.7 ohm resistor and the energy stored in the system (in our example) is the same for both cases, the value in Pr 10.31 could be 30.

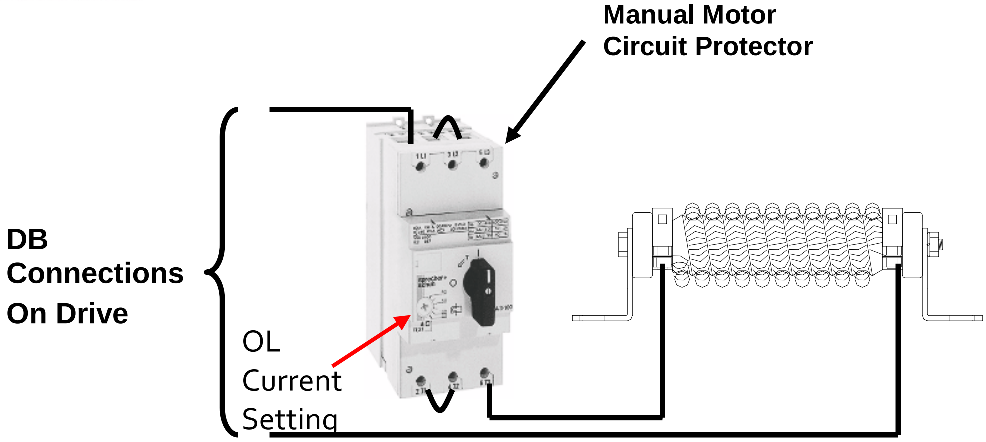
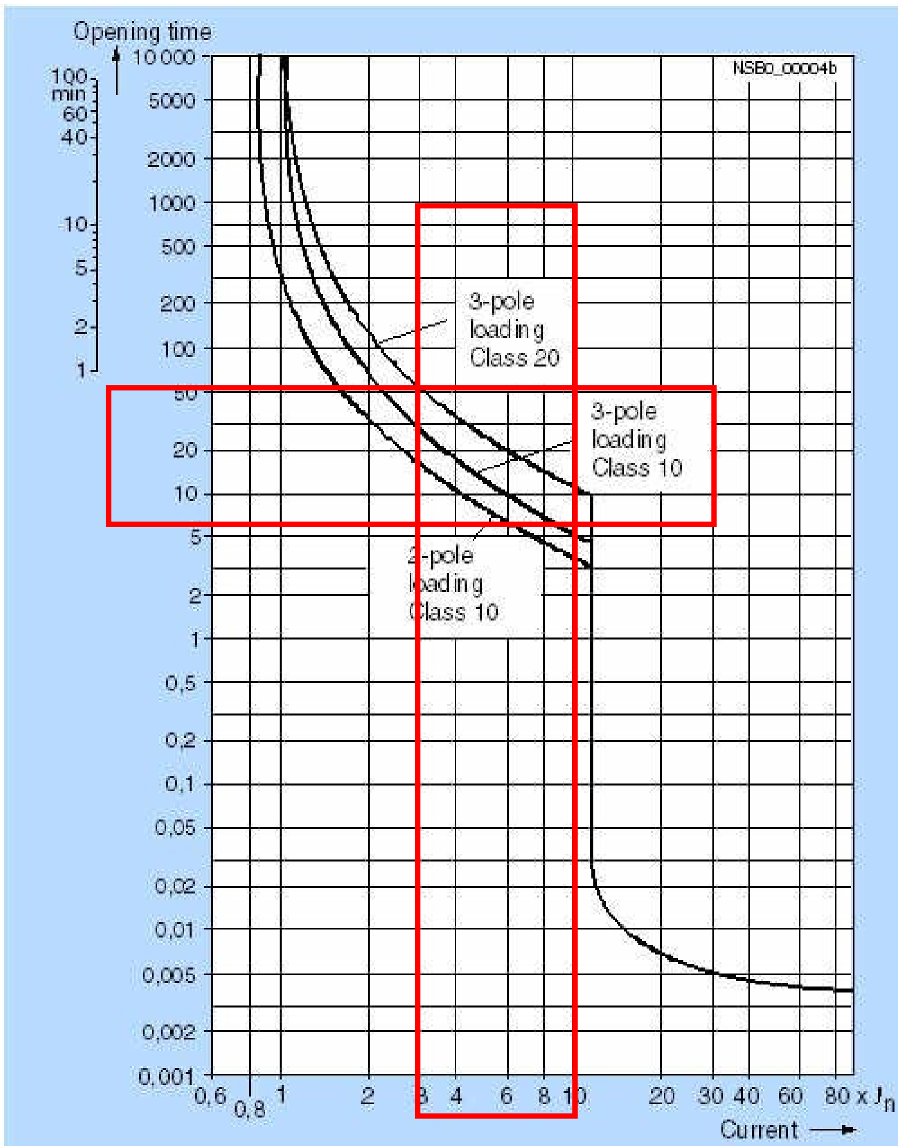

Manual Motor
Circuit Protector
DB
Connections
On Drive
OL
Current
Setting

Figure1


Opening time
10 000
5000
2000
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500
200
100
50
20
10
5
2
1
0,5
0,2
0,1
0,05
0,02
0,01
0,005
0,002
0,001
100
min
60
40
10
5
2
1
NSB0_00004b
3-pole
loading
Class 20
3-pole
loading
Class 10
2-pole
loading
Class 10
0,6
0,8
1
2
3
4
6
8
10
20
30
40
60
80 x I_n
Current

Figure 2

This set up is exactly the same as Figure 1 as far as sizing the overload device is concerned. The thermal switch contact is then used to control a motor contactor supplying power the drive. This circuit also has the advantage of dropping out power to the drive during a momentary power loss; preventing damage to drive's capacitor pre-charging circuit. An IEC AC-1 rating may be used in the input of AC Drives. In applications requiring some form of agency approval, method #2 or method #3 would probably be required.

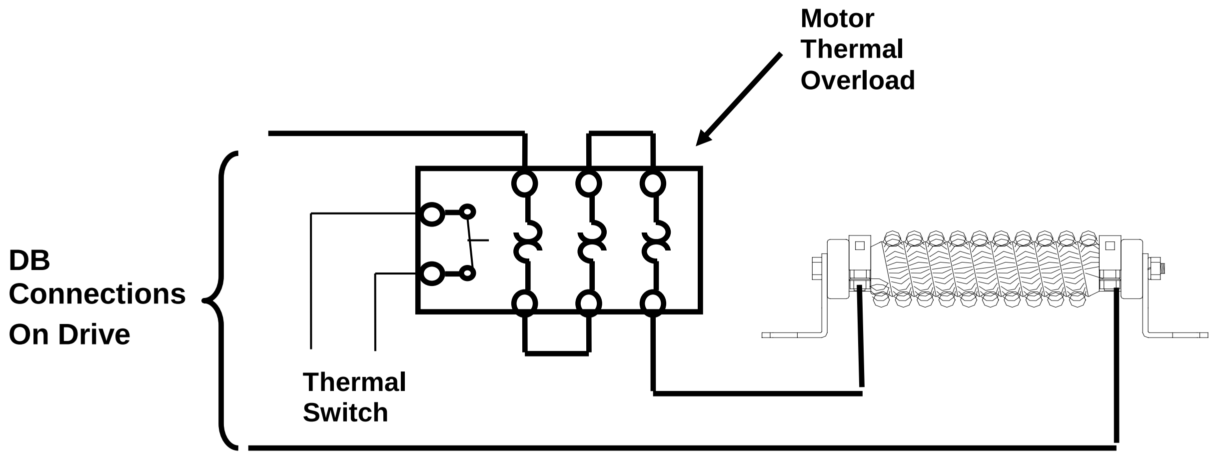


Figure2

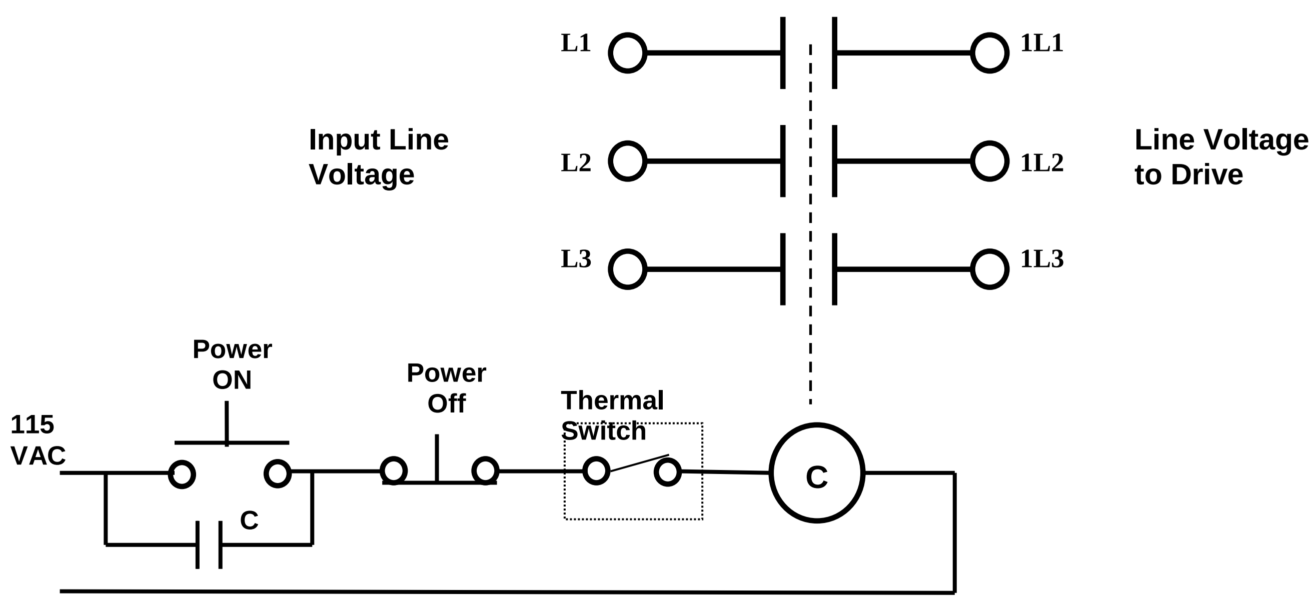


Figure 3

This set up should be used for any applications having very large inertia loads or indexers with high indexing rates where high wattage resistors are used. The thermal switch contact is then used to control a motor contactor supplying power the drive. This circuit also has the advantage of dropping out power to the drive during a momentary power loss; preventing damage to drive's capacitor pre-charging circuit. In some applications, a class 30 overload may be useable but one needs to be careful that the rms current flowing through the overload does not exceed the continuous current rating of the overload. All of our enclosed dynamic braking kits are provided with an internal thermal switch for resistor protection. In applications requiring some form of agency approval, method #2 or method #3 would probably be required.

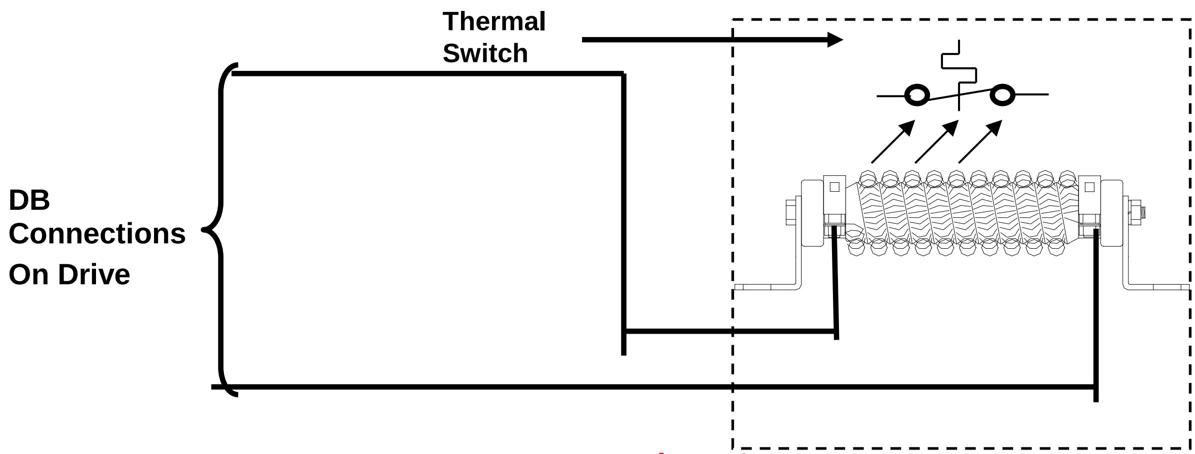
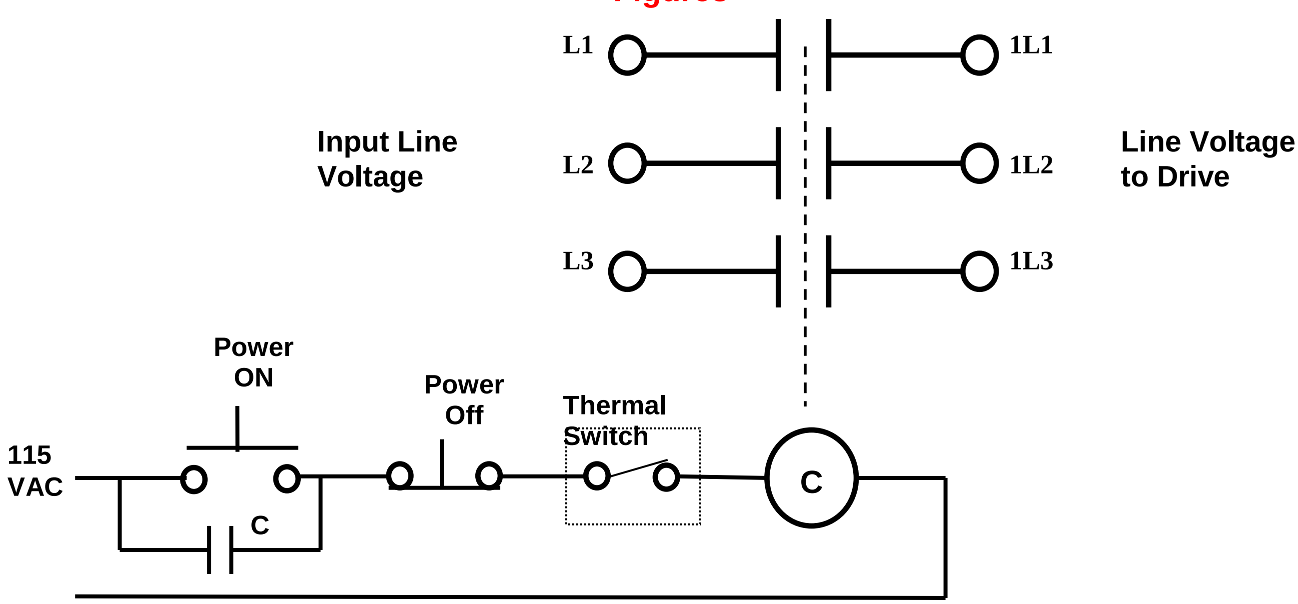


Figure3



4. Overload / Braking Resistor Wiring Guide

In order to determine the appropriate wire size to connect a dynamic braking resistor to an AC Drive, you need to know the resistance value and voltage class of the drive. The resistance can either be measured with a digital multi-meter or if it was obtained from Control Techniques, the part number of the kit contains the resistance value.

DBR-0100-03000-enc This would be a 10 Ohm , 3000 Watt resistor

DBR-XXX.X (ohms) – XXXXX (watts)- enc (enclosed unit)

The current through the resistor can then be calculated based on the resistance value and the "Nominal Bus Voltage" in the table below.

For a 480 Vac drive with the 10 Ohm resistor, the current would be 680/10 = 68 amps. The wire gauge would be based on this current, the maximum ambient temperature whether the wires are run in "free air" or conduit. This info can be found in the National Electrical Code handbook and or Local electrical codes.

Drive Voltage Rating	Nominal Bus Voltage	Brake Turn On Voltage
240	340 Vdc	390 Vdc
480	680 Vdc	780 Vdc
575	813 Vdc	930 Vdc
690	976 Vdc	1120 Vdc

When referring to wiring within the resistor enclosure (not exiting the enclosure) the following applies (note that this wire is still useable to wire to the drive as well, its advantage is the smaller gauge size) ;

Internal wiring connecting to heating circuits shall have a temperature rating of 200°C per UL508A 2005 Edition, 26.4.4.

Wire Gage / Current Rating*	**HP @ 240 VAC**	**HP @ 480 VAC**
14 awg / 54	1 - 15	1 - 30
12 awg / 68	20 - 60	40 - 125
10 awg / 90	75	150

Table based on highest HP in column and the drives minimum allowable resistance

- Based on single conductor in free air

Resources: can be found on our website: www.controltechniques.com
For help contact techsupport.cta@mail.nidec.com, or
call Technical Support at 952-995-8000, 24/7/365