AC Drive Ride-Through Techniques

5/7/02

While most AC drive applications do not require the drive to ride through a power interruption, many of those that do are crucial to a process. In those applications where ride through is required, it is often very important that the ride through provided meets the demand of the application to the extent that the process is not adversely affected. The shear number of variables between applications, and variations in drive features of different drives and drive manufacturers can make handling ride through a real challenge. This document can not begin to cover all aspects and implementations of ride through. It is the goal of the author to provide some basic background information as well as present some practical "real world" solutions for better drive performance during utility power disruptions. Special thanks to Jim Ehlert, Jeff Theisen and Gary Woltersdorf for help with this paper.

The term "Ride Through" very often means different things to different people. In most cases it stems from the desire to maintain some degree of order and control of a process during a momentary power interruption. Even the definition of momentary is called into question. 200 milliseconds without power at the motor shaft may be no big deal for some systems while for others it could spell disaster. In some cases it is important to control the motor and or maintain motor speed and torque during the power disturbance. For other situations ride through is the ability to maintain logic functions such as communications and memory so that a graceful and timely recovery from the power disturbance can be achieved. These two main interpretations of ride through can be categorized as "***Power Ride Through***" or "***Logic Ride Through***". For the purpose of discussion in this paper, Power ride through is defined as maintaining output current to the motor while logic ride through is keeping the control circuit active and ready to reconnect to the motor when line power is restored. Both will be explored in this paper with an emphasis on power ride through.

A key element for any discussion on ride through is understanding the "Precharge" cycle of an a AC drive. Precharge is the drives way of protecting itself from current inrush during power up or a power dip or line loss event. For a drive with a diode front end, the precharge method may be a series resister in the DC bus with a relay or solid state switch such as an SCR or transistor in parallel with this resistor as shown in figure 1. When precharge is complete, the parallel switch is closed.

Diode Bridge / Inverter

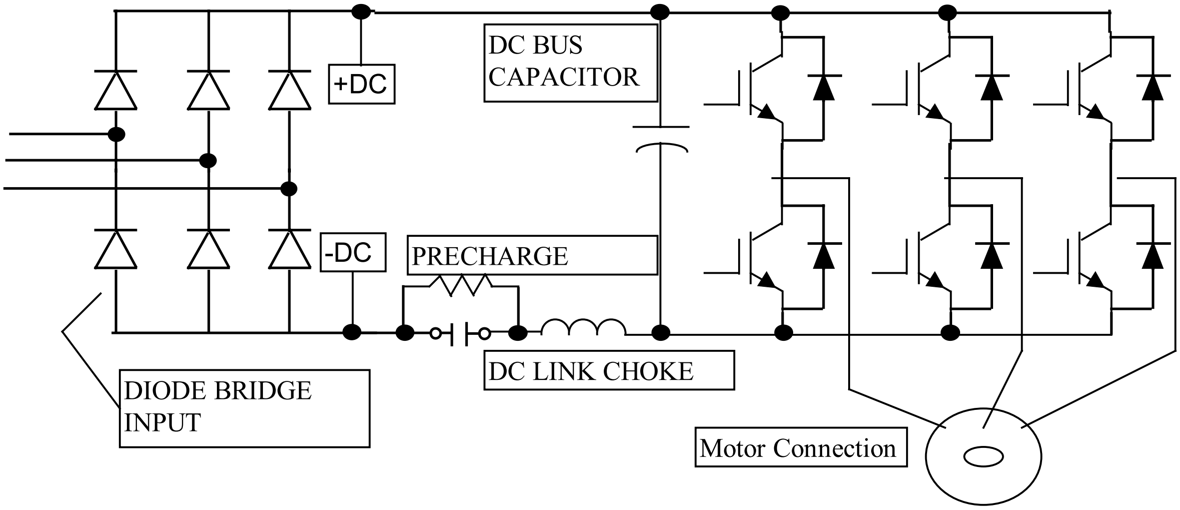


Figure 1

For a drive with an SCR converter bridge as seen in figure 2, precharge is taken care of by phasing up the firing angle (alpha) on the gate of each of the six SCR's. Alpha is the angle of delay for the gate signal of the SCR after it becomes forward biased. The SCR needs to have a gate signal and be forward biased in order to conduct. Delaying each gate signal until the line voltage is slightly higher than the DC capacitor bank allows the bus voltage to be slowly ramped up without excess inrush. During a line dip or power loss, alpha is reduced or " phased back". With ether method of precharge, the inverter section of the drive is disabled since it is not possible to source power through the precharge resistor or through a "phased back" SCR front end.

SCR Bridge / Inverter

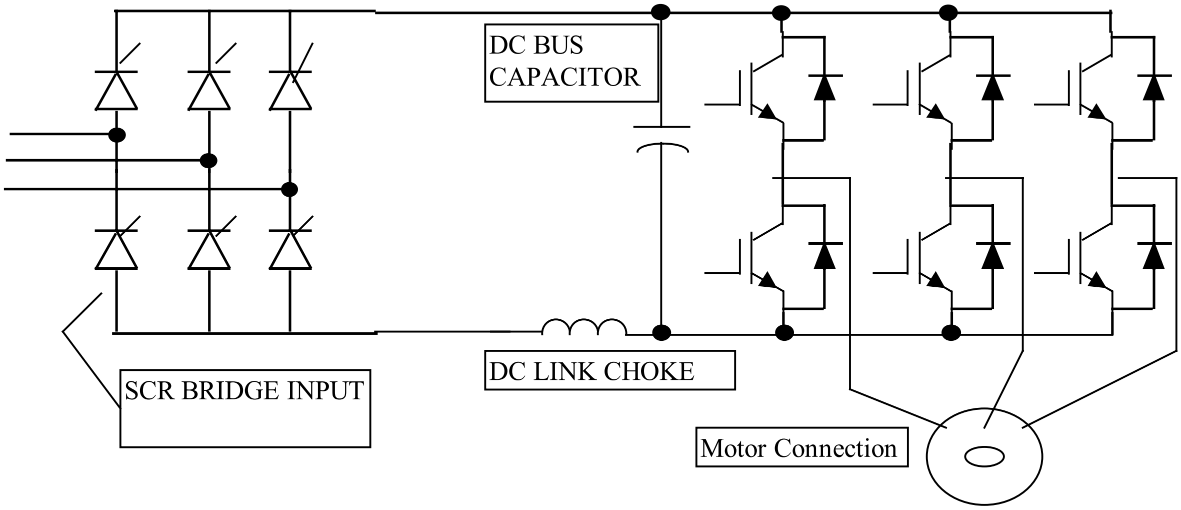


Figure 2.

Often it is the precharge function that is responsible for knocking the drive off line during a power line disruption. The drive is de-coupling itself from the line in order to protect itself from potentially excessive inrush. When the DC voltage level drops low enough (typically 15 to 20% of a rolling, time weighted average) the drive pre-charge mode is invoked as shown in figure 3.

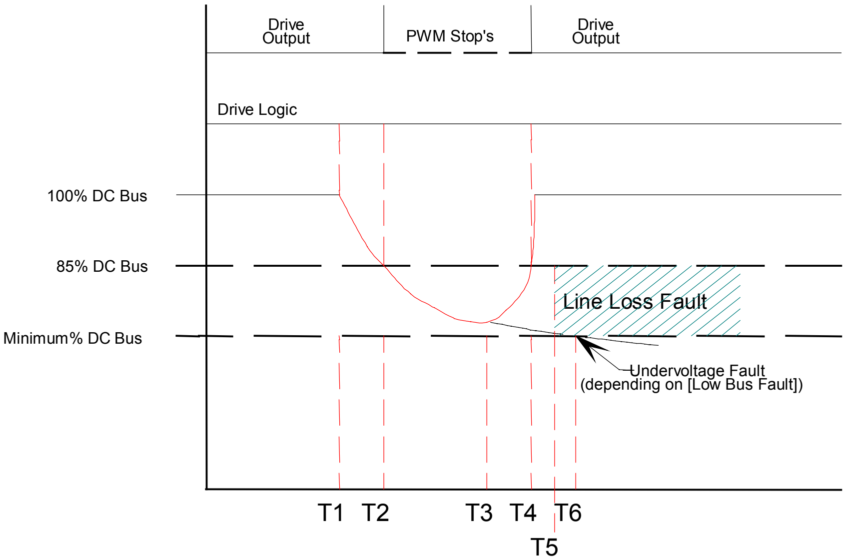


Figure 3 Pre-charge Level

While this diagram does not apply to all drives, it does illustrate some important points. Power into the drive is lost at T1 and DC bus voltage begins to drop rapidly. T2 is the level where the drive goes into precharge. With some drives this can be a fault or perhaps a configurable fault that may be disabled. In any case, output to the motor stops. Between T2 and T3 the drive is in " Logic ride through" and the rate of decay on the bus voltage is much slower since the drive is not producing output power to the motor. In some cases the drive will fault if the DC bus voltage falls below a Minimum level. This minimum DC voltage level may be the lowest safe point to operate the internal control power supply. If the Line voltage is restored at T3, the DC bus will begin to climb. Keep in mind, at this point the input line current is limited by the precharge circuit as it charges the DC capacitor bank. This prevents large inrush currents and controls the rate of rise in DC bus voltage. At T4 the DC bus is back above the precharge level and output to the motor resumes. If we had not restored line power at T3, a line loss fault or undervoltage fault could occur at T5 or T6. The type of ride through is in essence dependant on bus voltage level and precharge level.

Power Loss Ride Through:

Power loss ride through is the ability of the drive to maintain power out to the motor with a power line loss at the input to the drive. In most cases the inherent power loss ride through of a standard drive and motor configuration under a loaded condition is minimal. After an input power loss, DC bus voltage drops and it is likely that the drive will stop modulating output to the motor within 10 to 100 milliseconds depending on load. While the input power is removed, the only source of power available to run the motor is the stored energy in the DC bus capacitor bank. It should be pointed out here that the primary function of the capacitor bank is not to provide "ride through" but rather to filter the DC bus voltage and provide a stable DC source for the inverter section. Any ride through energy is a secondary benefit and subject to the size of the filter capacitors.

In some drives the pre-charge point can be adjusted to a lower level. The ride through benefits of this change are, for the most part miniscule while the risk of damage due to inrush current is increased significantly. We will see with the following calculations to what extent lowering the pre-charge level extends the power ride through. For this discussion, all of the energy supplied to the motor during a power ride through is supplied by the internal dc bus capacitors in the drive power structure. It is then necessary to know the total drive DC bus capacitance, DC bus voltage and load level to determine ride through time. The equation for stored energy in a capacitor bank is:

$$J = \frac{1}{2}CV^2$$

Where J is in joules or watt-seconds, C is capacitance in Farads and V is DC bus voltage.

From this equation we can see that the stored energy in a drive is directly proportional to the DC bus capacitance and proportional to the square of the voltage. However, all of this energy is not available for the drive to provide output power to the motor. We only get the energy between the starting voltage before the power loss event and the voltage level at the point where the drive goes into pre-charge mode. Thus the ride through energy for a drive can be calculated:

$$J = \frac{1}{2}C(V_1 - V_2)^2$$

Where J is in Joules, C is DC bus capacitance in Farads V1 and V2 are the DC bus voltage levels at the instant of the input power loss and the DC voltage at the pre-charge point respectively.

Example:

30 horsepower drive and motor running at a 55% load.
Nominal DC bus voltage of 640 volts.
Pre-charge drop level of 20%.
DC bus capacitance value of 4,700 mfd.

Let's calculate ride through for this 30 horsepower 460 volt drive.

The energy available in Joules is = $\frac{1}{2} C (V1 - V2)^2$ or $\frac{1}{2} * 4{,}700 \times 10^{-6} (640 - (640 * 0.8))^2$. This gives us about 38.5 Joules.

Since the stored energy in the capacitor bank is proportional to the square of the voltage, a major share of the energy is given up with a relatively small drop in the DC bus voltage. Thus lowering the pre-charge level (V2) in incremental amounts gives us a diminishing return in energy for each equal increment.

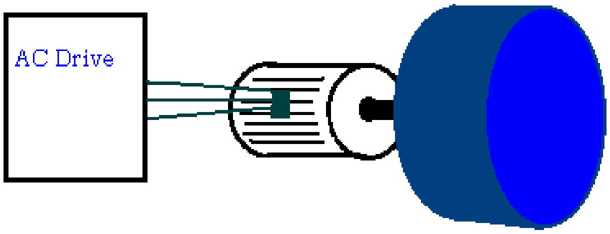
Now that we know the stored energy available, let's calculate ride through time. Since a Joule is a watt second, we can divide Joules by the load wattage to get the ride through time in seconds.

There are 746 watts per horsepower giving us a motor kw rating of (30 x 746) or 22.380kW. Multiplying 22.38 by the 55% load level we see that we are running at about 12.309kW.

Power ride through = 38.5 Joules (or watt-seconds) / 12,309 watts = about 3.1 milliseconds.

If we lower the pre-charge point from a 20% drop to a 40 % drop and recalculate, we would get about 154 Joules for a ride through for about 12.5 milliseconds. Adding another capacitor bank can also extend ride through. For the previous example we could double the capacitor bank there by doubling the ride through from 12.5 to 25 milliseconds. In most cases, the actual change in ride through is imperceptible to a human. A few processes may benefit from this added ride through but for many applications this will not result in a significant improvement in the system performance during a momentary line loss of more than 100 milliseconds.

Even though we have extended the ride through we may still have problems here. Remember that the output voltage for and AC drive is proportional to the output frequency. As the DC bus voltage drops, the available maximum AC output voltage is also limited by the same percentage. If we are at 75% of the nominal DC bus voltage and 75% of base speed then the voltage limitation will not be a problem. But, if we try to run at 95% of base speed with 75% bus voltage we may see an increase in slip or perhaps a stalled condition on the motor.



Inertia Ride Through:
This method of ride through requires a load with an inherently large moving or spinning mass and relatively little friction. Under a line loss condition when the DC bus voltage begins to drop, the drive responds by slightly decreasing the output frequency. This causes a regenerative condition and will

restore the bus voltage to a normal level. During a “regenerative condition”, the motor acts as a generator producing an AC voltage that can then be rectified by the anti parallel or “freewheeling” diodes in parallel with each IGBT transistor in the inverter section. Refer to figure 2. These diodes act as a full wave three phase bridge and convert the regenerative AC voltage into DC where it can be used to sustain operation of the drive and motor. In this mode of operation the drive is acting as a bus voltage regulator. It is giving up its’ ability to be a speed regulator in order to “stay alive” as long as possible. Output frequency is lowered as needed to regenerate and convert the stored kinetic energy into electrical energy keeping the DC bus at an appropriate level. The trade off is a loss in speed for continuous modulation to the motor. In reality, this is not a true power loss ride through in the sense that the load is affected by the power loss. The benefit is that when input power is restored, the speed can be brought back quickly since the drive has maintained output during the line loss event and does not have to reconnect to the motor.

Figure 4 shows operation of a drive with inertia ride through active. Notice that the bus voltage level is controlled by converting stored mechanical energy from the rotating load into electrical energy available to the inverter section of the drive. In this particular test, the ride-through time was increased by 8.3 seconds.

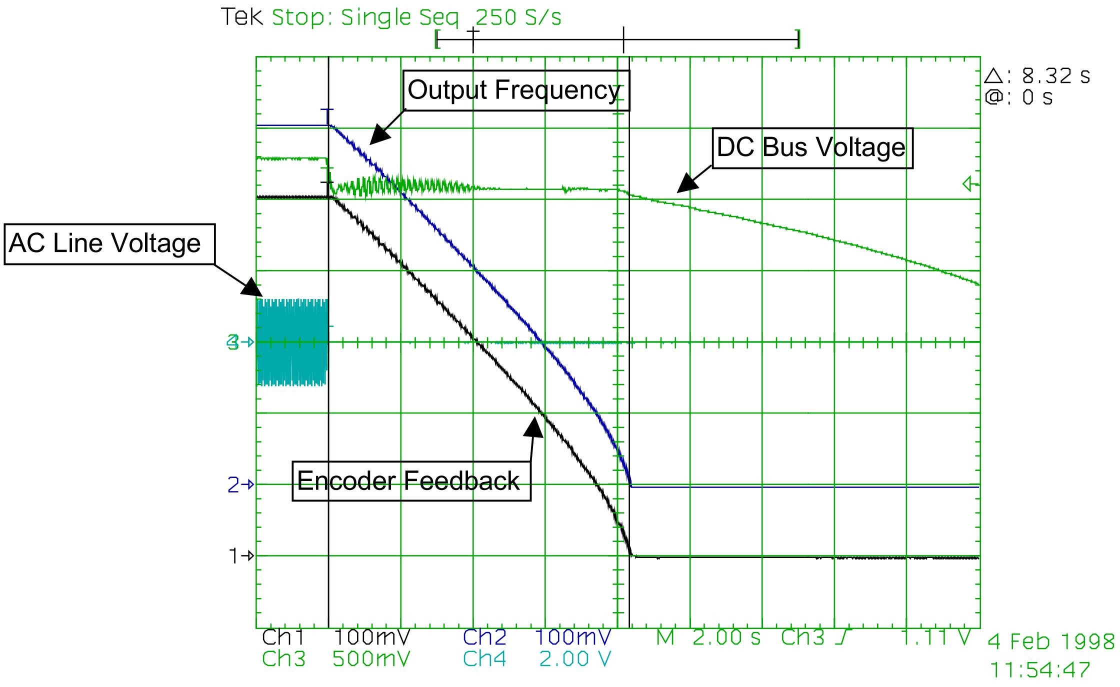


Figure 4

After 8.3 seconds, the load has been pulled down to zero speed and the bus voltage begins to decay.

Figure 5 shows how the drive reacts when power is restored while in inertia ride-through.

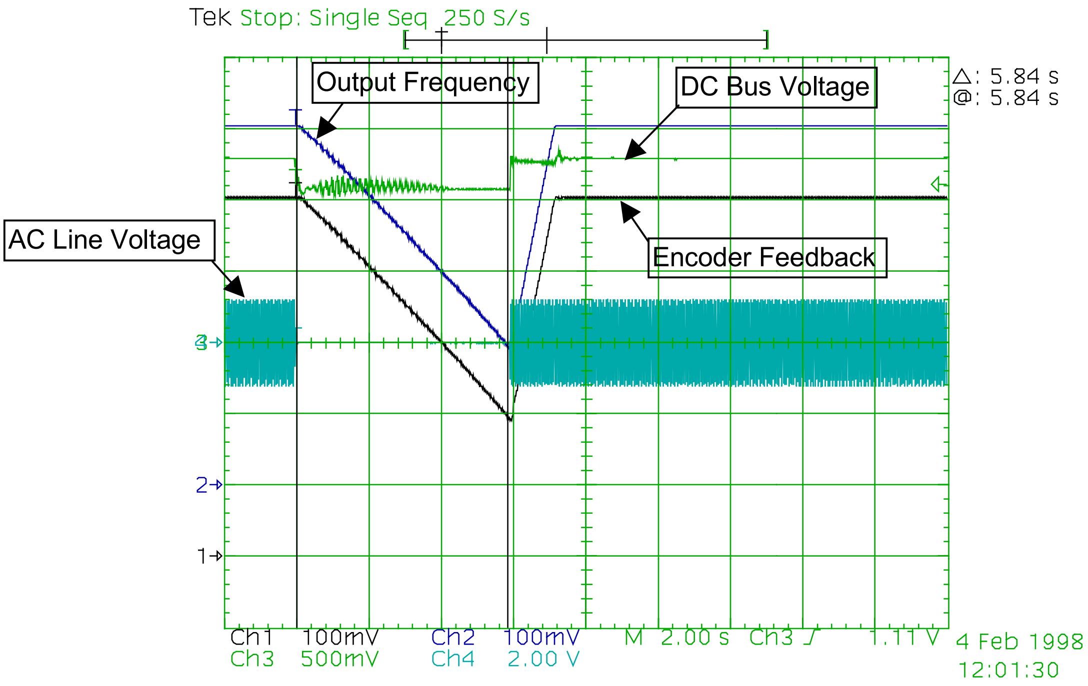


Figure 5

Since the drive never stopped producing output power to the motor, a very quick and smooth recovery can be seen when line power is restored.

If we know some basic information such as moment of inertia and speed in RPM of the load, Efficiency of the drive and motor and normal power consumption of the load, we can calculate a maximum time for inertia ride through. Stored energy in a spinning mass is a function of the moment of inertia times the change in Angular velocity or (delta rpm). Since we would normally want inertia ride through to last as long as possible we allow all of the stored energy to be recovered down to zero rpm. Thus for the equation below, delta rpm is equal to the starting rpm.

$$W = J(\Delta rpm \frac{2\pi}{60})^2$$

Where W is in Joules or (watt-seconds), J is moment of inertia in kilogram-meters squared and rpm is revolutions per minute of the spinning mass.

Example:

Moment of inertia for motor and coupled load = 10 kgm^2.
Normal operational speed = 1,500 rpm.
Nominal power consumption 22,000 watts.

$W = 10 \times (1500 (6.28 / 60))^2$

W = 246,740 watt – seconds.

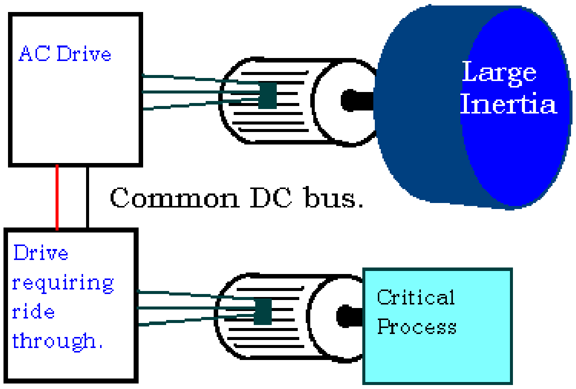
Dividing by 22,000 watts we get a ride through time of 11.2 seconds.

Of course this calculation assumes that the nominal power consumption is a constant 22,000 watts total. In reality the power consumption may not be constant. For a fan or pump load the power consumption will diminish with the inverse square or inverse cube of the speed. Drive and motor efficiency will also have some small and perhaps varying degree of an effect in reducing the theoretical calculated ride through time since the motor and drive will run at varying current levels as the inertia ride through progresses.

Battery Back Up:

For true long term (more than 50-100ms) power ride through during a line loss, it is necessary to keep a reserve source of energy other than that of the spinning load or the DC capacitor bank. This reserve can be tapped to maintain power output during the line dip. This source of energy might be as simple as a battery or it may be an uninterruptable power supply. A battery back up tied to the DC bus through a series diode works well on a common bus type drive or a drive with a simple diode bridge converter. The diode is used to prevent the drive from back-feeding or charging the batteries as a separate battery charger is required. If the converter section of the drive is an SCR based bridge, the drive may detect the loss of the input AC line resulting in a fault. A UPS providing AC power would be required for a drive with an SCR bridge. In this situation, the battery, directly connected or through a UPS, can provide sustained power ride through for minutes or even hours.

Back Up Inertia Ride Through:



Since batteries contain acid and require maintenance, a battery back up system or UPS may be unsuited or undesirable for some Installations. A method of inertia ride through can be employed where the stored energy resides in a dedicated high inertia flywheel coupled to a motor. This high inertia motor and flywheel is in turn powered by an ac drive that has the inertia ride through feature with it's DC bus connected to the DC bus of another drive needing power ride through capability. With this arrangement, the DC bus of the first drive acts as a voltage regulator for both drives. The big advantage is that the drive and motor requiring ride through does not suffer speed loss. One disadvantage is a separate drive, motor and flywheel are required. The length of ride through time will depend on the moment of inertia and speed of the flywheel of the drive and motor providing the ride through, and the power required by the drive and motor needing ride through. The equations for calculating ride through with this arrangement are basically the same as for the standard Inertia ride through. Total power consumption will be much greater though since the drive and motor in the critical process will be producing power.

Because we are using a dedicated inertia & flywheel, we do have some control over the drive, motor and inertia used to provide ride-through and can now look at ways of optimizing ride through time. Reviewing the equation for stored energy in the spinning mass:

$$W = J(rpm\frac{2\pi}{60})^2$$

We see that the energy is directly proportional to the mass and proportional to the square of the speed. For this reason it is better to first concentrate on running at a higher speed and then using a larger mass. A two pole motor would be a good choice since at 60 hertz it runs at roughly 3,600 rpm or about twice the speed of a four pole motor. This two pole motor selection alone would provide four times as much stored energy as a four pole motor given the same flywheel. Also, remember that the drive is likely capable of running more than 60 hertz at the output giving even more stored energy for the same mass. Be careful not to exceed the maximum speed rating of the motor and make sure the flywheel is properly balanced for the speed of operation. We should also take advantage of the flywheel design. Flywheel moment of inertia for a solid cylinder is 1/2mr^2 where m is mass and r is the radius. Moving the mass out from the center (increasing the radius) gives a higher moment of inertia. Thus the best flywheel design will have as much mass at the outer edge and as far out from the center as is possible or practical.

Boost Converter For Brown Out Conditions:

It is harder to quantify the ride through ability during a brown out or line dip. The level of the line dip and how many of the three phases are affected is a big factor. If one phase drops by say 50%, the drive may run a long time on what essentially becomes a single-phase input. The good news for brown out conditions is we can use other methods of ride through as long as some reasonable level of line voltage (roughly 50% or more) is present.

One method of handling a brown out is to employ a type of “boost converter” as shown in figure 6. This circuit is placed in the DC bus between the input rectifier and the drive DC capacitor bank. Typically this unit will have a Choke (L1) used as an energy storage device and a switching transistor (Q1) driven by a square wave with a varying duty cycle used to regulate voltage. With the transistor switch closed, current begins to ramp up on the choke building stored energy. When the transistor switch is turned off, this energy is released. The voltage on the choke rises and charges the DC bus capacitors to a higher level. The technique is called “voltage ring up”.

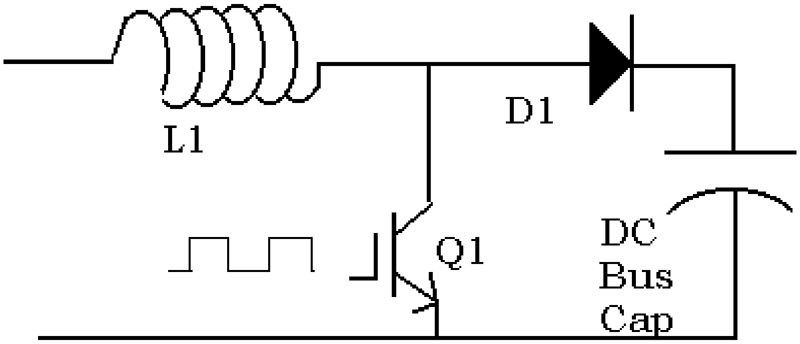


Figure 6.

Another method for brown out ride through is to replace the drive diode or SCR converter front end with an active front end as shown in figure 7. Note how much this arrangement looks like an inverter.

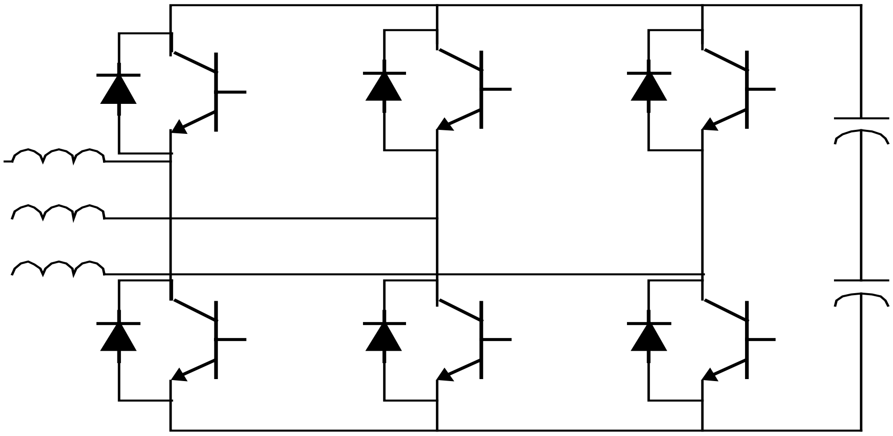


Figure 7.

In fact it is identical to an ac drive inverter power structure. The major difference is that the transistor output section is connected to the AC line through a required line reactor of about 10% impedance. The DC bus of this inverter is the DC source for the drive.

Like the “DC ride through module”, it is possible to boost the DC bus voltage to a desired set point with this device. The active front end uses energy stored in the input reactor to “boost” the DC bus voltage and keep it at the set point. In addition to boosting the DC bus voltage, this circuit can also be used to “suppress” the DC bus voltage under high line conditions.

With each of the ride through boosters we have a true power loss ride through since we can maintain speed and torque, and run full power at the output. Again however, we have a trade off. Since the output power of the motor is maintained, input power must also be maintained. With the reduced input voltage, the only real way to maintain the power level is to increase the current draw by the ratio of the voltage drop. Thus a 25% drop in line voltage will require a 33% increase in line current such that the product of current and voltage remains constant. It might be a questionable practice to increase current demand during a brown out condition. For many critical processes the risk is worth the benefit. When deciding to use the active front end, other benefits such as such as an input power factor near unity and low harmonic content should be considered.

Voltage Head Room For brown out conditions:

Though the active front end is an excellent technical solution, it does add cost and complexity to the system. Another brown out ride through solution is to run a higher voltage drive with a lower voltage motor thus providing “Voltage head room”. For example a 13amp 230volt motor could be used on a 13 amp 460 volt drive. The drive is set up to run at 230 volts output under normal operating conditions. Though the DC bus voltage may be over 620, the PWM output will keep the RMS voltage at the correct level for the motor. The pulse widths at the output of the 460 volt drive are narrower then they would normally be for a 230volt drive with a 310 volt DC bus. The Pulses will become wider as the 620volt DC bus drops due to a power dip, thereby keeping the RMS voltage to the motor at the proper level. For this to work, the control firmware must allow the drive to run with reduced DC bus voltage. The motor insulation must also be able to handle the higher applied peak voltage. The main disadvantage is that the higher voltage drive will cost a bit more, but probably not as much as a standard drive with the active front end. Also, since the “precharge” level is lowered, current inrush could be an issue. An input line reactor might be required to reduce current inrush when the power line recovers. This technique would also work with a 575 volt drive and a 460 volt motor though the head room would not be as great as in the previous example.

Logic Ride Through:

For some applications power ride through may not be critical, while maintaining the drive control logic is important. Once the output to the motor stops, most of the energy in the capacitor bank is available to run logic power. In most cases the logic power is supplied by a switch mode power supply tied to the DC bus. The switch mode power supply can operate under a wide ranging DC bus voltage level, typically down to about 250 volts DC for a 460 volt drive. In theory this should be able to provide logic power for several minutes on a large drive. Generally the limitation is an Underwriters Laboratory requirement for the drive to have less than 50 volts on any internal component within 1 minute of a power shut down. To comply with this requirement, an active discharge circuit is often used to discharge the capacitor bank in under a minute. In many cases the logic ride through can be extended indefinitely by using a separate, low voltage logic supply, if the drive has this input capability.

After a “logic ride through” event, we need to be concerned with reconnecting to the motor. The first question is; What speed is the motor at? For some high inertia loads, the motor may still be coasting at nearly the same speed it was running when the drive went into logic ride through. Other loads may be overhauling the motor and in some cases driving it in reverse. Starting the drive from a 0 Hz output may work, but often it will not give the best response/reconnect time. For a faster reconnect let’s look at “Flying start”. This feature (available on some drives) requires that the drive has motor speed information. Perhaps the best way to know the speed is to use an encoder, giving the drive a very accurate actual speed and a very fast reconnect. If an encoder is not present, a “voltage feedback” circuit might be used by the drive to detect frequency resulting in a reconnect time that is slightly slower than the encoder method. Some drives may have a “speed search” feature resulting in a reconnect time that depends on where the motor speed is relative to where the drive starts searching. If the user has some Idea where the motor speed will be when the line is restored, the speed search can be started just above that known level resulting in a reasonably fast reconnect.

Typical operation of a drive during a power loss condition is to draw power from the stored energy in the capacitor bank. Under load this usually only lasts for less than 1 or 2 line cycles. The drive monitors DC bus voltage and turns off the outputs when the bus dips to about 85% of nominal. This action increases the Logic ride-through of the drive, since the logic power is created from “switch mode power supply” derived from the dc bus voltage. Figure 8 shows operation of the drive during a power loss with Line Loss and Low voltage Fault disabled.

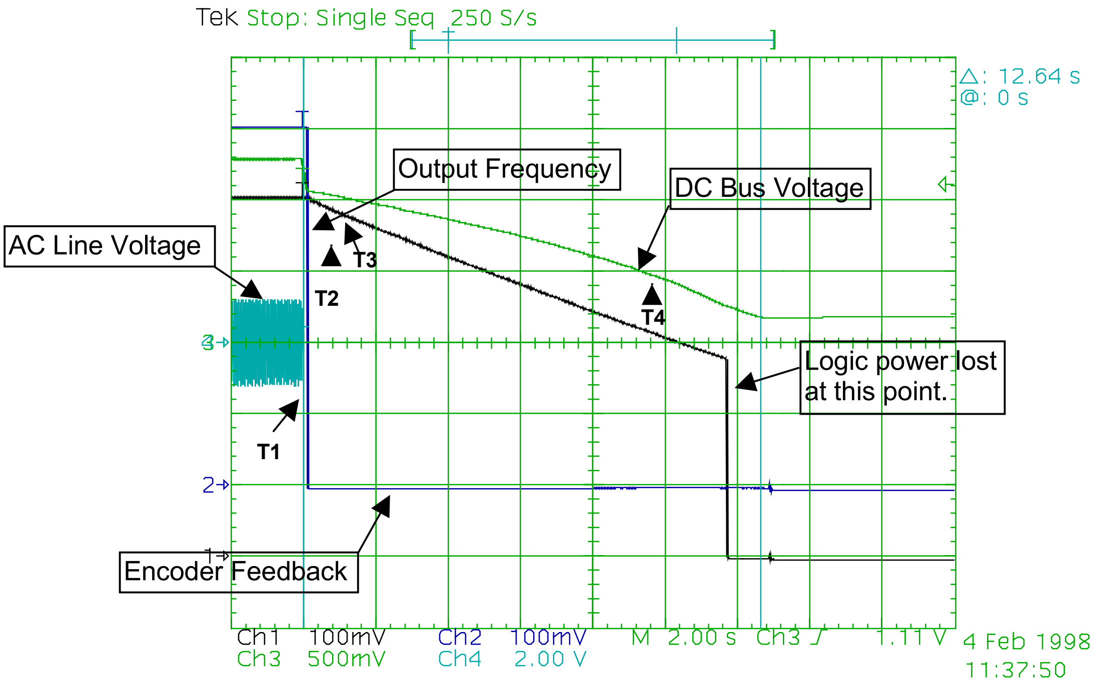


Figure 8.

T1 = Loss of power
T2 = Bus voltage level at 85% of nominal, output power shut off
T3 = 500msec time out, Line Loss Fault Point
T4 = Minimum Bus Voltage Level, Undervoltage Fault Point

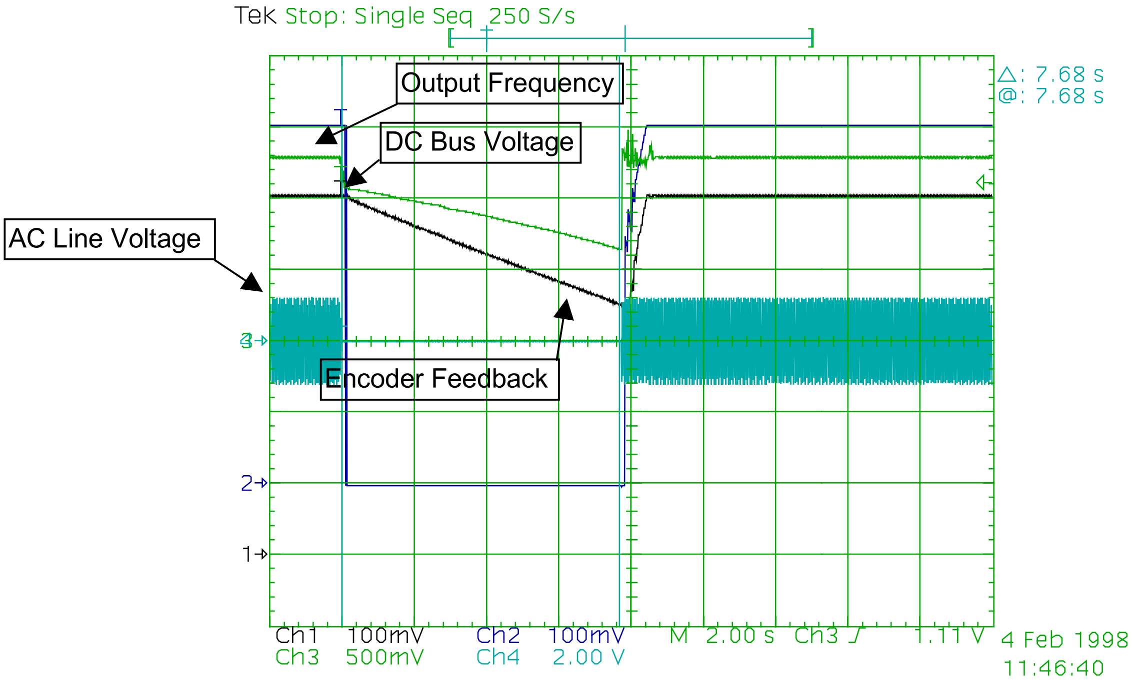


Figure 9.

Figure 9 shows a logic ride through event similar to figure 8 only this one has the drive programmed to recover and run after power is reapplied.

Run On Power Up:

Though not technically a ride through feature, run on power up can be useful in some applications where it is important for the drive to run anytime input line power is applied. One example of where this is used is for remote / unmanned pumping stations where a temporary power loss can occur but it is not practical for someone to go on site and restart the system. An expansion of “run on power up” is “run / reset”. This feature is used to clear non destructive faults such as over-voltage or under-voltage conditions. Attempts to clear faults can be limited to a preprogrammed number of tries at a preprogrammed time interval. Once Faults are cleared, the drive is started automatically.

What Method Should be Used? :

When possible, a measurement should be done to determine the operating or load point for the drive in terms of kilowatts. A reasonable effort should also be made to determine how much ride through time is required. It may not make sense to extend the ride through time for the drive beyond the point where other elements of the system begin to adversely affect the process. Once the ride through time and load levels are determined, the product will be the required energy. Typically we would take the load wattage times the ride through time in seconds giving us Joules of energy required. This energy requirement can be compared to a calculation of available energy in the drive’s DC capacitor bank as discussed in the section titled Power Loss Ride Through. If the ride through time is under one second, it is very possible that the energy requirement may be met by the internal capacitor with no further thought to the subject. If however, the energy required is only slightly more than the stored energy in the drive capacitor bank, several options can be considered.

1) Increase the ride through energy available by lowering the precharge point. Keep in mind that inrush may increase. A reactor may be needed.
2) Consider oversizing the drive to increase the capacitor bank and recalculate the available energy.
3) Add an additional capacitor bank to the DC bus. Make sure the drive precharge system can handle the extra capacitor load.

If the ride through time required is more than one second with any significant load on the systen, it is likely that added hardware for energy storage will be required. In this situation it might make sense to use:

1) One of the previously discussed methods of Inertia ride through.
2) A DC battery bank back up or an uninterruptable power supply (UPS).

Ride through modules, active front ends and the voltage head room technique should really only be considered solutions for brown out conditions where line voltage does not drop below 50%. These solutions keep motor voltage levels correct by requiring more line current at the input. They do not store a significant amount of energy.

In the final analysis it must be stated that we are constrained by simple laws of physics. True “Power Loss Ride Through” requires a reserve of stored energy that can safely and quickly be delivered to the drive. Without this “energy reserve”, power ride through is not possible and we must resort to “Logic Ride Through”. This too requires energy but at much lower levels. Determining what method of ride through, if any, should be used, is mostly a function of the process. The cost of the power interruption to the process must be carefully weighed against the cost of the additional hardware required for ride through. Reliability of the local utility line, the likelihood and frequency of a power disturbances, and the willingness to take on the risk of a power loss also play a part.