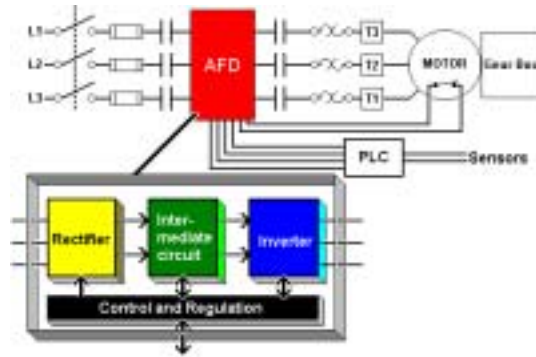


Drives 101

Lesson 3



This lesson covers the basic parts and operation of an Adjustable Frequency Drive (AFD). These parts are divided into 4 sections: Rectifier, Intermediate circuit (DC Link), Inverter and Control & Regulation.

1. AFD in a Larger System

This section covers the parts and operation of the Adjustable Frequency Drive (AFD). It is important to keep in mind that the Drive is just one part of a system. In the diagram above, notice the disconnect switch, fuses, bypass switch, thermal overloads, PLC etc. all play an important part in making an application work correctly.

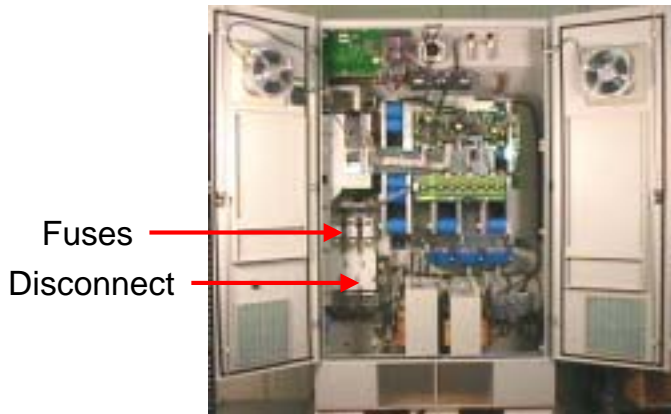
Inside the AFD there are 4 major sections: rectifier, intermediate circuit (DC Link), inverter and control/regulation. This fourth section, control and regulation, interfaces with the other 3 sections.

In very general terms the operation of the drive is as follows. Power first goes into the rectifier, where the 3-phase AC is converted into a rippling DC voltage. The intermediate circuits then smooths and holds the DC Voltage at a constant level or energy source for the inverter. The last section, the inverter, uses the DC voltage to pulse the motor with varying levels of voltage and current depending upon the control circuit. The pattern of the pulses going to the motor makes it appear similar to AC sinusoidal waveform voltage.

Each one of these sections is reviewed in some detail in the pages that follow.



To understand the parts of an AFD better, an example of a 400kW (500Hp) drive is used.

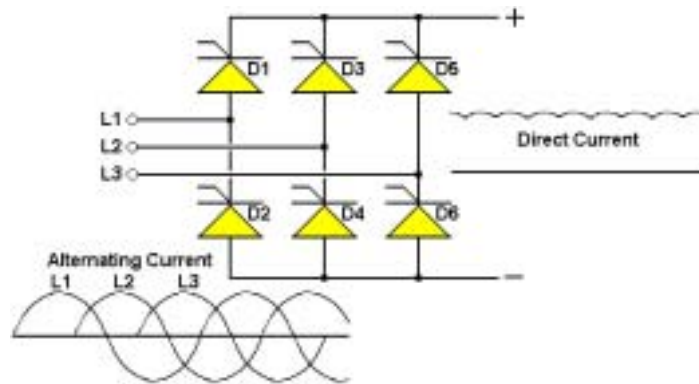


In the picture above notice the fuses and disconnect switch.

As each part is explained pictures of these parts on a 400kW (500Hp) drive are displayed. This large drive is used in this lesson for the size of the parts are easy to identify.

One of the options for these large drives 225 – 400kW (300 – 500Hp) is to have fuses and a disconnect switch mounted inside the drive. With smaller size drives fuses and a disconnect are separate but are still part of the overall system as described on the previous page.

2) Rectifier Section



Its function is to change 3-phase AC into DC.

2. Rectifier

The 3-phase AC voltage goes into the rectifier section of the AFD. In the rectifier section there is a group of gated diodes (silicon rectifiers or SCRs). In the vast majority of AFDs, these diodes are in a group of 6 as diagramed above. One AFD manufacturer has stressed that there should be more sets of diodes, 12, 18, even 24. The reasons for and against this are covered in another lesson.

Diodes (D1 through D6) allow current to flow only in one direction when enabled by the gate signal. In this diagram, the AC power on L1 goes into Diodes D1 and D2. Because of the position of these diodes, current flow can only go up. The D1 diode conducts when the AC is positive and D2 conducts when the AC goes negative. This drives the top line (+) more positive and the bottom line (-) more negative.

Diodes D3 and D4 convert L2 power to DC and Diodes D5 and D6 convert L3. A voltmeter or VOM can be used to measure this DC voltage. The positive or red lead is placed on the plus (+) and the negative or black lead is placed on the minus (-). In this type of circuit, the DC voltage is 1.35 times the AC line voltage.

If 240 Vac is coming in, 324 Vdc is generated.

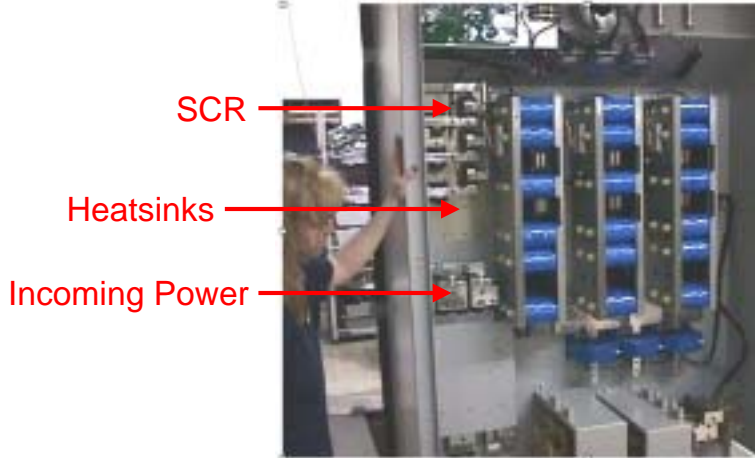
If 380 Vac is coming in, 513 Vdc is generated.

If 460 Vac is the line voltage, 621 Vdc is generated.

If 575 Vac is the line voltage, 776 Vdc is generated. Because of line (power coming in) and load (power to the motor) changes, the DC Voltage level is constantly moving above and above this expected value.

2) Rectifier Section

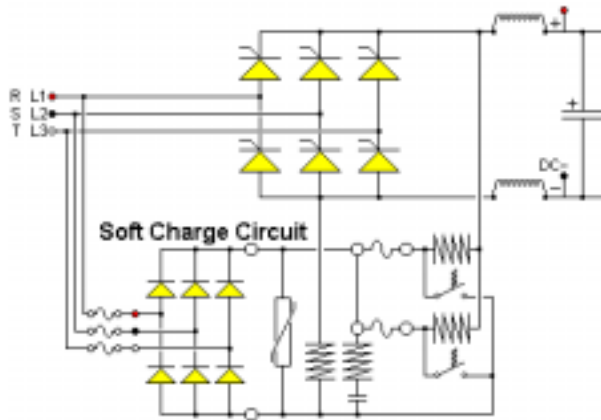
Danfoss



The Rectifier section contains terminals for incoming power, silicon rectifiers (SCR) and heatsinks

In the picture shown above, the rectifier part is indicated. Six SCRs are used to change the incoming power from AC to DC. This rectification can generate a considerable amount of heat, so the SCRs are mounted onto a heatsink. The fins of the heatsink are facing the other way inside a special ductwork where the air flow removes the heat. Four fans mounted across the top of this AFD pull the air across the heatsink. Remember that heat is the enemy both to the drive and to the motor. Anything which makes either run cooler makes them last longer. In this picture, the assembly is not complete. There would be bus bars connecting the rectifiers with the incoming power.

3) Soft Charge Circuit



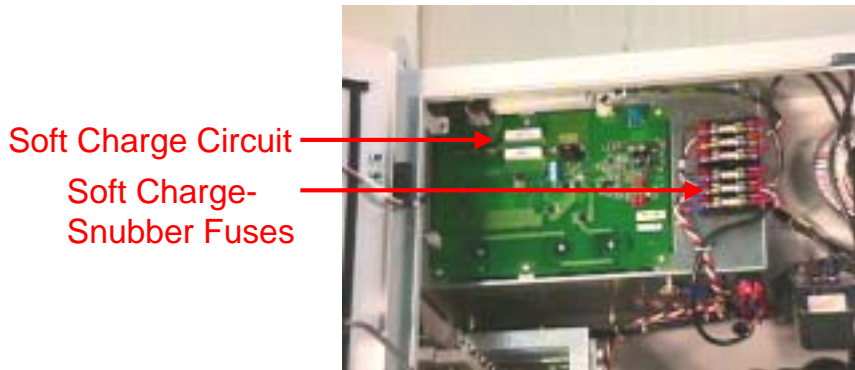
On large drives, 22kW (30Hp) and larger, a soft charge circuit is added in helping charge the cap banks before main power is applied to the rectifier.

3. Soft Charge Circuit

On larger drives, 22 – 400kW (30 – 500Hp), a part of the rectifier section is known as the soft charge circuit which is used to power up the drive. With this circuit, when power is applied, the inrush of current is restricted going to the large capacitors in the DC Link, so that they may charge up slowly (within a couple of seconds). If this circuit was absent, line fuses would be blown every time the AFD was started. The soft charge circuit on some of the AFDs has a resistor or two in line with the current to slowly allow charging of the capacitors. This current resistor even has its own safety, a thermal switch, which shorts out if the current rush is too high in the soft charge circuit. The shorted thermal switch blows fuses on the soft charge circuit preventing the drive from starting.

Once main power is applied to the drive, the SCRs in the main rectifier section remain off. The much smaller rectifier section in the soft charge circuit starts, applying DC power through the current resistors charging up the capacitors in the DC Link. When these capacitors are charged to the DC voltage minimum value, the control section starts the firing of the SCRs in the main rectifier. Because of the amp draw through the current resistors in the soft charge circuit, time is needed to cool them off, so the 22 – 400kW (30 - 500 Hp) drives are limited to 1 start per minute.

3) Soft Charge Circuit

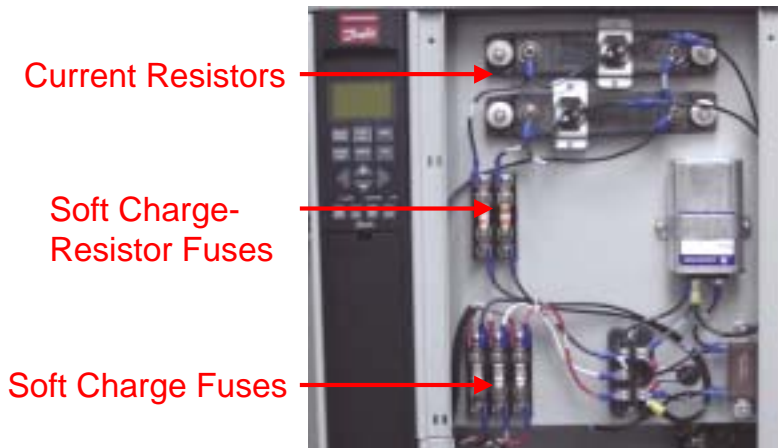


Here is a picture of the soft charge circuit in the 400kW (500Hp) drive.

In the picture above, the soft charge circuit card is shown. This circuit card on the 400kW (500Hp) drive is in the upper left corner, just above the rectifier section. Notice that the soft charge fuses are just to the right of the circuit card. The soft charge circuit card on the 225-400kW (300-500Hp) drives uses small IGBTs instead of resistors to limit power going to the capacitors. This is referred to as an active soft charge.



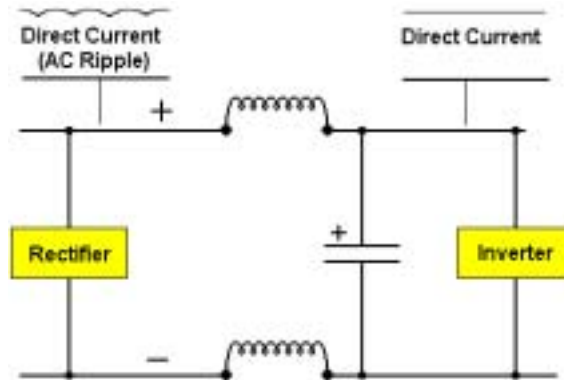
3) Soft Charge Circuit



Here is a picture of the soft charge circuit in the 110kW (150Hp) drive.

In the picture above, on the 110kW (150Hp) drive the soft charge circuit is exactly like the schematic diagram shown on the previous page. Notice the 2 large black current resistors used to limit power going to the capacitors in the DC Link section.

4) Intermediate Circuit (DC Link)



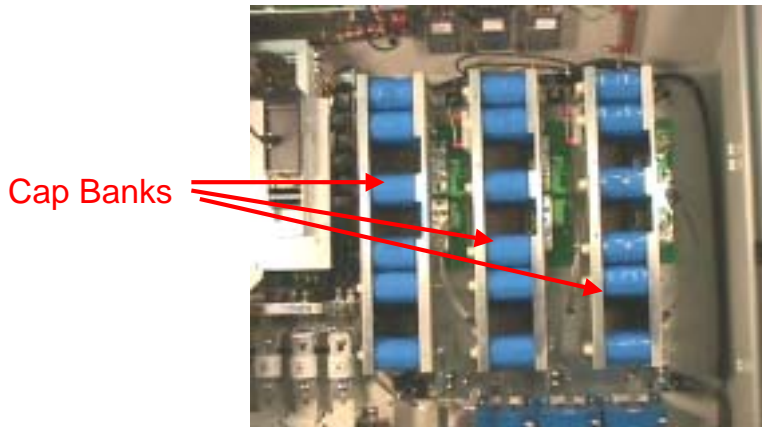
Using a large bank of capacitors and DC reactors the rippling DC voltage becomes more stable.

4. Intermediate Circuit (DC Link)

The Intermediate Circuit also known as a DC Link can be seen as a power storage facility for the next section, the inverter section of the drive. There are 2 major components to the DC Link section, capacitors and coils. In the diagram above only one capacitor is shown but it is always a series of capacitors. With Danfoss AFDs, this intermediate section always uses DC coils also known as DC Line Reactors or DC chokes. For cost considerations, most other AFD manufacturers do not offer these DC Line Reactors as standard equipment. Danfoss regards these coils as essential for two main reasons; one is the ability to reduce harmonic noise (interference) by 40% the other is the ability to ride through a temporary loss of power. This allows this drive to avoid numerous nuisance shut downs.

In the diagram above notice that the rippled DC voltage coming in has now been filtered to a relatively constant voltage. Remember that this DC Link Voltage is 1.35 times the input voltage. The value of the DC Link voltage can be read from the display on the front of the drive. When ever working around the drive always be careful and give it a healthy respect. The largest drive produces 620Vdc at 750 A.

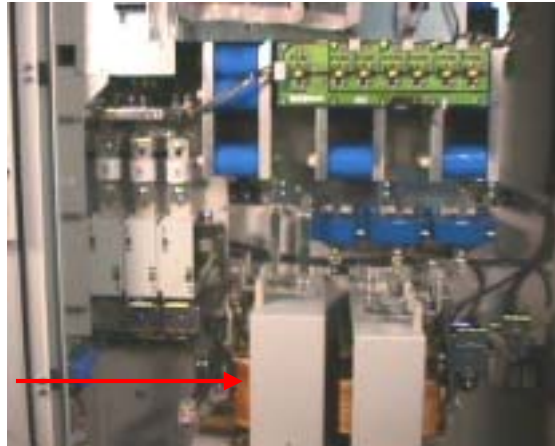
4) Intermediate Circuit (DC Link)



The blue capacitors banks are a major part of the DC Link and store a great deal of energy.

When looking at a drive, some of the most striking components are the 2 devices that make up the DC link. The 3 banks of blue capacitors on the 400kW (500Hp) drive are quite prominent. There are in the center of the drive, just to the right of the rectifier section. There are 3 banks of 12 capacitors in each bank for a total of 36 capacitors. Capacitor numbers vary with each size of drive. This 3-bank arrangement is to allow for easier service. The plate on the right side of each capacitor bank has full voltage.

4) Intermediate Circuit (DC Link)

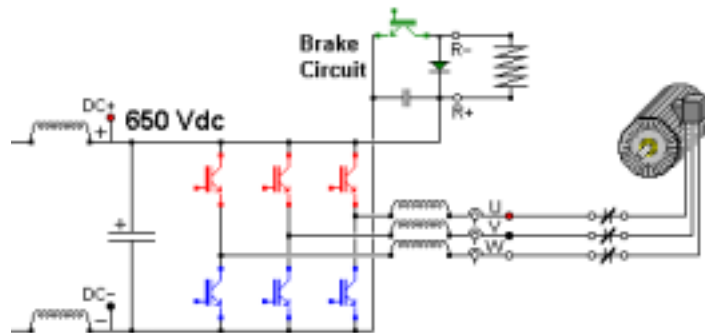


DC Reactors

There are 2 sets of coils shown above. The DC Link coils are always the ones with 2 terminals, shown on this size drive here on the left.

In the picture above there are 2 sets of coils. The coils on the left at the bottom center of the drive, the ones that have 2 connections (DC +, DC -) are the DC Coils, also know as DC Reactors or DC Chokes. The other set of coils to the right, which 3 terminal connections, are discussed in the pages that follow.

5) Brake Circuit



When drives are ordered with dynamic braking, the drive comes with a Brake IGBT. When the voltage gets too high on the DC Bus, the brake IGBT activates sending power to the brake resistor.

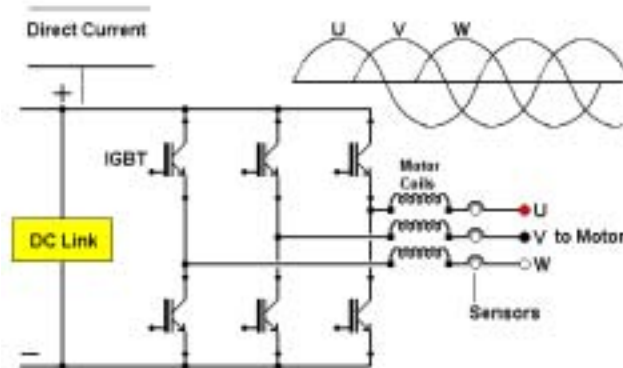
5) Brake Circuit

This is an optional circuit that can be added to the drive when ordered. In many applications where quick stopping is essential, a brake circuit also known as dynamic braking is used. In all hoist applications dynamic braking is needed. There is a special circuit, which is added to the drive at the factory when the standard with brake (SB) or extended with brake (EB) brake option is ordered.

When the brake circuit is added, it includes a special transistor known as a brake IGBT. This dynamic brake circuit monitors the DC Link voltage and the brake IGBT fires when the DC Link Voltage rises too high.

The external brake resistor which is ordered separately is attached to the R+ and R- terminals and it receives the excess voltage, dissipating it as heat. The extended brake option EB can also use the brake resistor for quick discharge of the capacitors when the drive is shut down.

6) Inverter Section



The Inverters take the voltage from the DC Bus and using Pulse Width Modulation (PWM) sends a signal which appears to the motor as an AC signal.

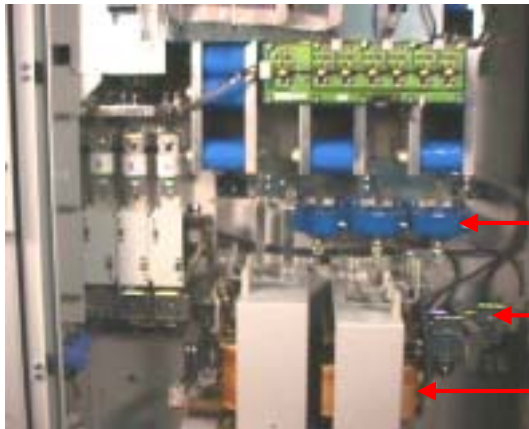
6) Inverter

The next part of the AFD is the Inverter section. This section takes the DC voltage from the intermediate section and with the help of the control section fires each set of IGBT (Insulated Gate Bipolar Transistors) to the U, V and W terminals of the motor. This firing of the IGBTs is known as Pulse Width Modulation (PWM) and is described in the next couple of slides.

Notice in the diagram above that sensors monitor the current going to each terminal of the 3-phase motor. Unlike many other manufacturers, Danfoss monitors all 3 phases continuously. There are some manufacturers who in an attempt to cut costs only have 2 sensors and guess on the output to the 3rd and others that only monitor the outputs when the first run command is given.

Another component that Danfoss insists on including are the motor coils on any drive larger than 18.5kW (25Hp). These coils smooth the waveform going to the motor. The smoother the waveform the less heat is generated at the motor and the longer the motor lasts. The standard distance used by Danfoss between its drive and the motor is 300m (1000 feet) using unshielded cable. There are other manufacturers that are limited to shorter distances 100m (330 feet) or less. Some end users have used this distance as a sign of quality. The longer this distance the better the quality.

6) Inverter Section



Current Sensors

Terminals

Motor Coils

Motor coils, current sensors and motor terminals are located in the lower right corner of the 400kW (500Hp) drive.

The current sensors monitor the current going to the 3-phases of the motor. These sensors detect and alarm when a short circuit or grounded circuit is discovered. Some manufacturers only check for short circuits or grounding on the first run command, but Danfoss monitors for these faults all the time. This allows Danfoss to place a motor disconnect between the drive and the motor. If the motor is disconnected from the drive during operation, the drive might trip, but because of this constant monitoring the drive suffers no damage. A disconnect switch between the motor and drive is not allowed by any other manufacturer. If a disconnect switch is used on some other drives, it causes severe damage – in other words the smoke is let out.

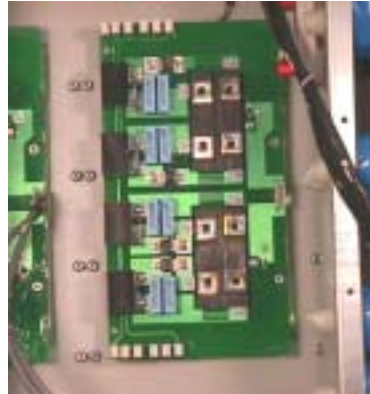
6) Inverter Section



IGBTs



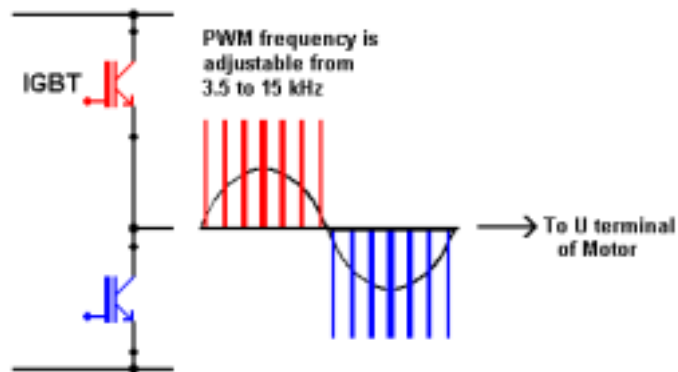
IGBT snubber card



The inverters, IGBTs and snubber card, are mounted on heatsinks under each of the 3 cap banks.

The IGBTs are mounted on the heatsinks behind the capacitors in the middle of the 400kW (500Hp) drive. The picture on the right shows two IGBTs with the circuit card which is used to help control them, known as a snubber card. The picture on the left shows the IGBTs without the snubber card. The correct mounting pattern for the 6 screws (done in a rotating manner) on each is critical, so that there is proper contact between the IGBT and the heatsink.

7) Pulse Width Modulation

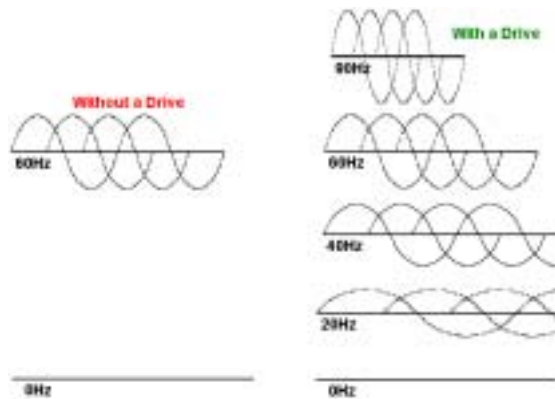


All manufacturers of drives use PWM, but there are differences when it comes to the shape of the pulses going to the motor.

7) Pulse Width Modulation

In the diagram above, a close up view of the waveform that goes to the motor shows the switching frequency of the IGBTs. The switching-pattern shown above is known as pulse width modulation or PWM. As the length of time is increased for the IGBT to be ON and then OFF, the motor responds to it as a sinusoidal waveform. The positive IGBT fires first in the diagram followed by its negative counterpart. Only one terminal (U) is shown but the same type of activity would appear on V and W. The PWM frequency can vary from 3.5 to 15 kHz, which means it is audible.

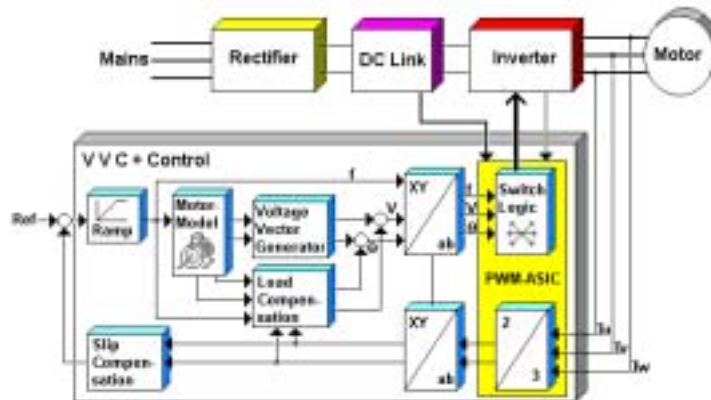
7) Pulse Width Modulation



Without a drive, the motor can go full speed or OFF;
With a drive, the motor can go to a number of
different speeds.

At first glance the function of a drive might look rather confusing. Taking 50Hz or 60Hz power input then changing it to DC only to change it back to look like AC to the motor. Due to the electronics in the drive, the DC voltage can be manipulated in a much easier and adaptable fashion. In the example, without the drive, the only signal the motor sees is ON (50Hz/60Hz) or OFF (0Hz). With a drive the motor can operate with 20Hz, 40Hz, 60Hz, 90Hz or any frequency in between, making it much more adaptable to any application.

8) Control & Regulation



The control and regulation section monitors the other 3 sections, making numerous calculations and adjustments to the outgoing signal.

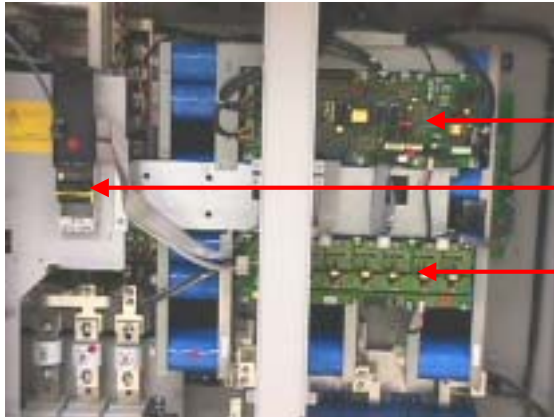
8) Control & Regulation Section

The control section of the drive is where signals are coordinated and regulated. This is where numerous calculations are completed to properly switch the IGBTs. This control section uses Vector technology, which separates the torque producing current from the magnetizing current. In the diagram above the current going to the AC motor is being monitored.

The Danfoss VLT 5000 has a special program, algorithm, called Automatic Motor Adaptation (AMA), which determines the electrical parameters for the connected motor while the motor is at a standstill, a unique feature to Danfoss. Most competitors must decouple and spin the motor for tuning. Because the AMA measures the resistance and reactance of the motor's stator establishing a motor model, the magnetizing current can be calculated. This motor model is used to calculate the slip and load compensation.

The control section uses the frequency (f), voltage (V) and phase angle (θ) to control the inverter. This means that the torque producing current can be controlled more accurately. This robust sensor-less regulation scheme Voltage Vector Control (VVC+), which is patented by Danfoss, can compensate for rapid load changes. It also provides 100% torque at zero speed as well as excellent speed regulation at low speeds.

8) Control & Regulation



Power Card

Control Card

Gate Card

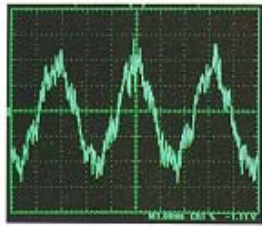
Three cards make up the control and regulation section, the control card, the power card and the gate card. On smaller units the power and gate cards are combined.

In the picture above, on the 400kW (500Hp) drive, 3 circuit cards make up the control and regulation section for the drive. These cards are mounted onto the frame used for the capacitor banks.

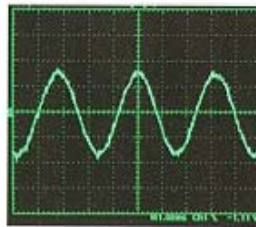
The Control Card is the same card used on all drives from 0.75 – 400kW (1 - 500Hp). The Local Keypad (LCP) fits into this control section. The LCP is used to program and monitor the drives operation. The next card is known as the power card, which is specific for a particular size of drives. It relays signals to the gate card, monitors the current from the current sensors, coordinates the fan operation and a number of other functions. The third is known as the gate card, whose major function is to send signals to the IGBTs. On smaller drives these last 2 circuit cards are together on one card.



Summary



Conventional PWM



Danfoss VVC +

The function of all the parts of the drive, Rectifier, DC Link, Inverter and Control/Regulation is to make a clean waveform to the motor.

The operation of the control and regulation section produces a very clean waveform going to the motor. The picture to the left shows an oscilloscope trace of a motor phase current provided by a conventional pulse width modulation system with harmonic elimination. To the right is the output from the Danfoss VVC+ system. The more sinusoidal the waveform going to the motor the easier it is on the motor and the less heat resulting in longer motor life.

Here are some of the advantages of the control and regulation program that is in the Danfoss drives.

Advantages of Voltage Vector Control (VVC +)

Up to 160% motor torque for 1 minute.

Up to 180% breakaway torque for 0.5 second.

Accurate slip compensation.

Full torque (up to 100%) down to 0 rpm in open loop control.

Full holding torque (up to 100%) at 0 rpm in closed loop control.

High speed stability

High resolution of output frequency

Fast system response to speed and load changes (3 ms updates)

Disconnect switch allowed between the drive and motor

No motor derating

High stability to impact loads

Self tunes to the motor without motor shaft rotation, AMA.

Long Cable lengths (1000' unshielded) between drive and motor