AC 2008-1075: USING INEXPENSIVE A.C. MOTOR DRIVES IN AN INTRODUCTORY POWER AND CONTROLS COURSE

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Using Inexpensive A.C. Motor Drives in an Introductory Power and Controls Course

Abstract

The induction motor is generally cheaper and more rugged than a dc machine. Thus, ac variable-frequency drives (VFD) have made induction motors the first choice for variable-speed applications in industry. As a result, ac motor drives are an important topic for introductory power or motors courses. The newest generation drives offer the ability to program the drives, either with a human interface module or via a link to a computer. One difficulty with incorporating variable-frequency drives into a laboratory portion of the course is the expense. “Name-brand” drives can cost more than $2,000, even for fractional horsepower motors, and software to communicate with the drives can cost several thousand dollars. Fortunately, the internationalization of power equipment manufacturing has brought about the opportunity to obtain much less expensive drives (about $250) that offer the same functionality as the high-priced brands. The drives were connected to PCs using internet protocols, which allowed them to be programmed “remotely” as well as from the front panel. This paper begins by describing some of the capabilities of modern VFDs, in particular the “generic” drive that was chosen, and how it is used in lab. It then discusses how the drive was used in lab by the students and shows some typical results. Experimental procedures for the laboratory are included.

Introduction

For the past 15 years or so, we have included a lecture and a laboratory session on variable-speed induction motor drives in our introductory electrical power and controls course[1]. This is a very important topic because most of industry now uses variable-speed ac motor drives rather than dc motors[2-5]. When we first began including the laboratory exercise, we used a rather basic drive that literally had two knobs–one to change the frequency and one to go forward, reverse, or stop. We used them because we were able to purchase them at a significant discount, but that was still about $1000 per drive. Of course the capabilities of drives increased dramatically and those drives were become obsolete after a few years. They did, however, have one interesting feature, namely they operated with a single-phase input and provided a three-phase output. As a result we still use those drives for a small portion of the lab, which will be described later.

About 10 years ago, we were fortunate enough to receive a donation of new, state-of-the-art, name-brand variable speed drives. Those drives were three-phase in and three-phase out and featured programming capabilities through a human interface module. We used these quite successfully for eight years, but eventually they too were becoming dated and noticeably larger than new drives on the market. In addition, we were unable to obtain a donation of software to interface the drives to the lab computers and the software was priced at several thousand dollars per station. Thus, we began looking at replacing the drives. Initially we approached the company that had donated the previous drives, but we were unable to obtain a new donation. We then investigated purchasing “name brand” replacement drives. Unfortunately, we found that new drives were about $2000 apiece and software to connect them to the computers was even more. That was not an option, given that we have eight lab stations, so we began looking at other alternatives.

The drive we settled on is the Dura Pulse G3 drive, which is made in China and sold by Automation Direct in the United States, and is shown in Figure 1. Since we use 208 volt, 1/3 hp motors in our lab, we purchased the smallest size drive, rated at 230 volts and 1 hp. The current price for these drives is $235, which meant we could buy drives for all eight workstations for less than the price of a single “name brand” drive. The drives are pulse-width-modulated, IGBT drives and are fully-featured including simple volts/hz control, sensorless vector control with autotune, and adjustable acceleration/deceleration ramps with linear and S-curves, among others. The drive has an RS485 port for communications that can be configured for ethernet communication with an optional interface. The drive is relatively compact, measuring less than 5" wide, 7" tall, and 6.5" deep.

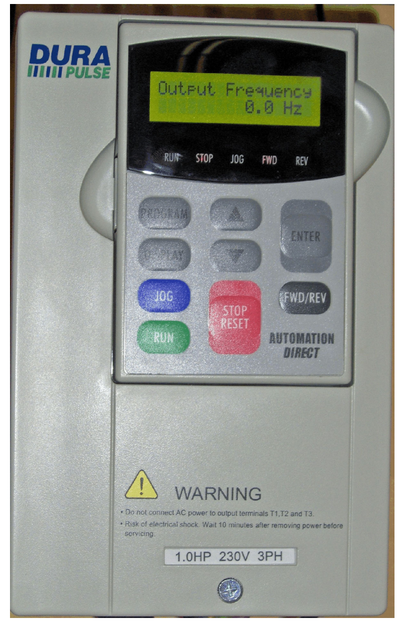

Figure 1: Dura Pulse Drive

The drive can be configured using the human interface module (HIM), which is mounted at the top, right of the drive in Figure 1. A close-up of the HIM is shown in Figure 2. The program, enter, and up-down arrows can be used to access and change parameters for the drive. Table 1 shows the major parameters groups for the drive.

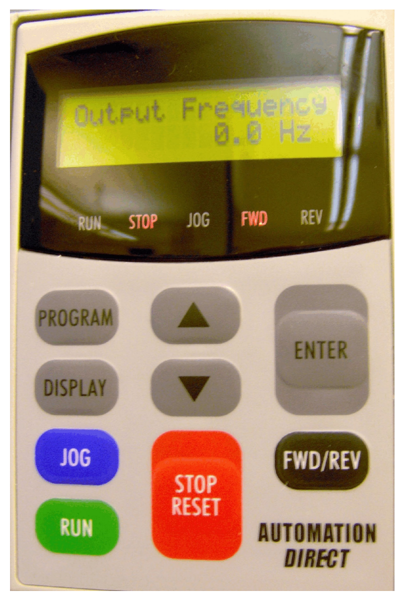

Figure 2: Human interface module

Table 1: Drive parameter groups

Group	Name
P0	Monitoring parameters
P1	Ramps parameters
P2	Volts/Hertz parameters
P3	Digital parameters
P4	Analog parameters
P5	Presets parameters
P6	Protection parameters
P7	PID parameters
P8	Display parameters
P9	Communication parameters
P10	Encoder feedback parameters

Connecting and programming the drive

We elected to add ethernet capability to the drives and mounted them with new PLCs, as shown in Figure 3. The card above the drive, and slightly to the right is the ethernet adapter card for the drive, while the box next to the card is the ethernet switch. Down in the bottom right corner of Figure 3 is a 24 volt power supply and the end of the PLC. The boards that the drives are mounted on are several feet away from the motor benches so cables were necessary to connect the 60 hz input from the bench and the variable-frequency output back to the motor bench. It is extremely important that the input and output not be reversed. Connecting voltages to the output of the drive can destroy it. Thus, we used coded connections, which are explained in the lab procedures that are attached to this paper at Appendix A. This insures that the students don't reverse the connections.

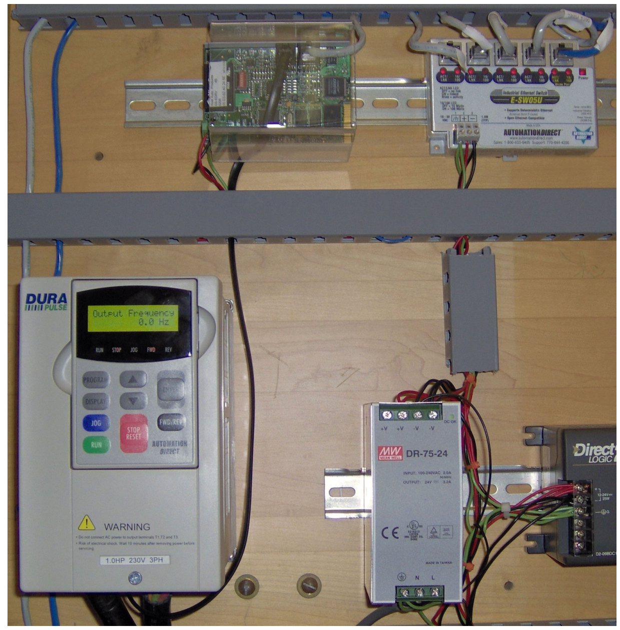

Figure 3: Mounted drive

After the students connect the drive to the motor, they are instructed to follow a series of programming procedures and to obtain information from the drive. To begin, they reset the drive to its default parameters and then measure the time it takes to accelerate the motor, as well as observing a number of parameters both with a 60 hz and 30 hz output. After they become familiar with the operation of the drive, they program it to match their motor. For example, they set the rated voltage and rated speed for the motor. They also experiment with different settings for the acceleration of the motor. The purpose of these exercises is for the student to become generally familiar with the capabilities of a modern variable-speed drive, not to become an expert in setting up this particular drive.

After the students gain some experience with programming the drive through the HIM, they are instructed to connect to the drive from the computer. As previously mentioned, the drives were installed with ethernet capability, so the students merely have to program the drive to accept commands via the RS485 link and then open a web browser and point to the correct IP address. Doing so brings up the screen shown in Figure 4.

As shown in Figure 4, students can access each of the drive parameter groups from the main screen. Clicking on a group brings up the list of parameters for that particular group. For example, Figure 5 shows the drive monitoring parameters. Clicking on any of the parameters in the right-hand box brings up a dialog to change the parameter. For example, clicking on P0.0 allows the student to change the rated voltage of the motor. Using the computer interface, the students are able to start, stop, and reverse the motor.

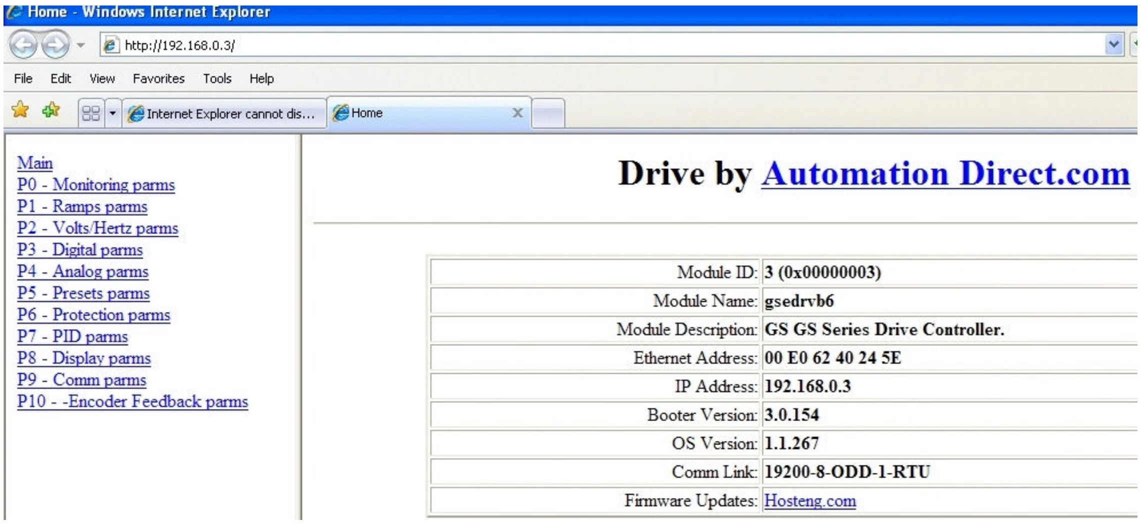

Figure 4: Drive setup menu via web browser

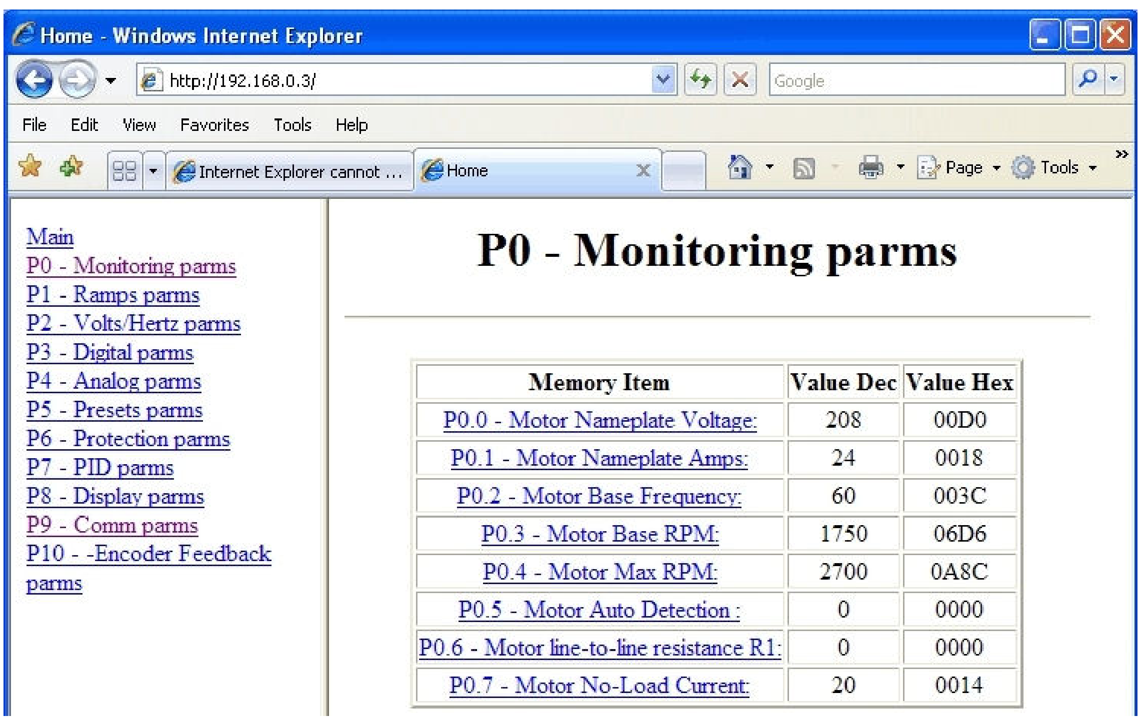

Figure 5

In answer to an obvious question, the laboratory computers are firewalled so no one can access them from outside the lab, which could present a safety hazard. However, if one were interested in distance learning, one could allow remote access, assuming the motors and drives were properly isolated. Following their drive programming exercise the students are required to take data, concerning the operation of the drive.

Voltage, speed, and harmonic measurements

The students are required to set the drive frequency to 90 hz and then measure the motor speed with a tachometer and the output voltage of the drive with both analog-responding and true-rms meters. The frequency is then adjusted in 5 hz increments down to a minimum of 5 hz and the same data are collected at each operating frequency. The purpose of this is for the student to verify that speed is a linear function of frequency and that voltage has two regions: above and below rated frequency. Figure 6 shows a plot of the motor speed as a function of frequency and Figure 7 shows the voltage, as measured by two meters, as a function of frequency.

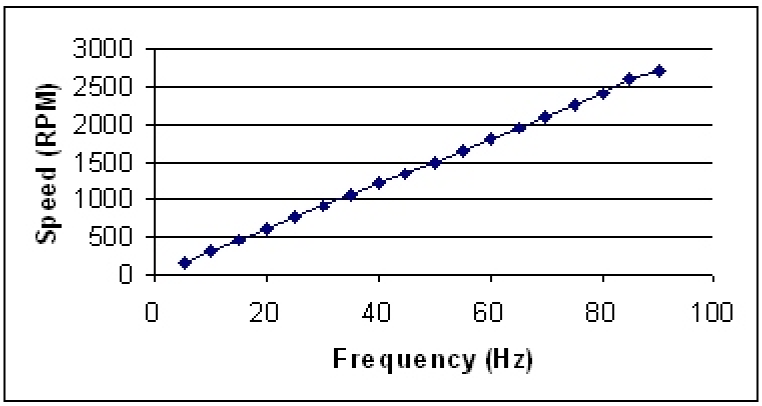

Figure 6: Graph of motor speed vs. applied frequency

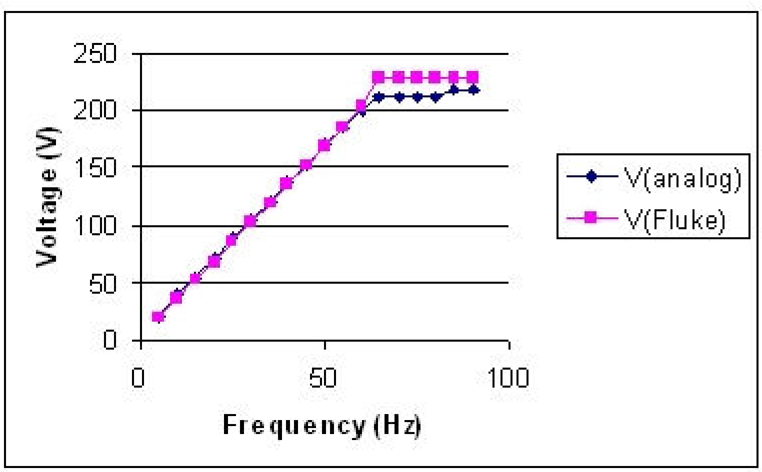

Figure 7: Drive output voltage vs. output frequency

It is evident from Figure 6 that the motor speed is a linear function of the applied frequency, as would be expected from theory. Similarly, Figure 7 illustrates the constant volts/hz regime below rated frequency (60 hz) and the constant volts region above 60 hz. When the students create these plots, the concepts become much more real than the lecture that covered these topics. Figure 7 also illustrates that there is harmonic content in the drive output voltage and that one must use a true-rms meter to correctly measure the voltage. In the region above 60 hz, the analog meter consistently read lower than the true-rms meter.

As mentioned in the introduction, we still have the original single-phase input drives in the lab. This allows the students to observe the difference between single-phase and three-phase rectifiers; i.e., the difference in the harmonic currents drawn by the two drives. Figure 8 shows the input current to the single-phase drive, along with its harmonic spectrum, while Figure 9 shows the same for the three-phase drive.

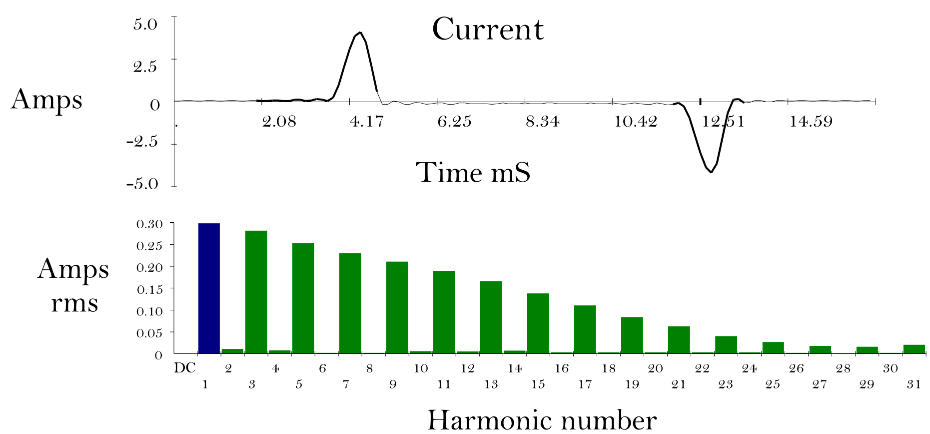

Figure 9: Input current and harmonic spectrum for drive with single-phase input

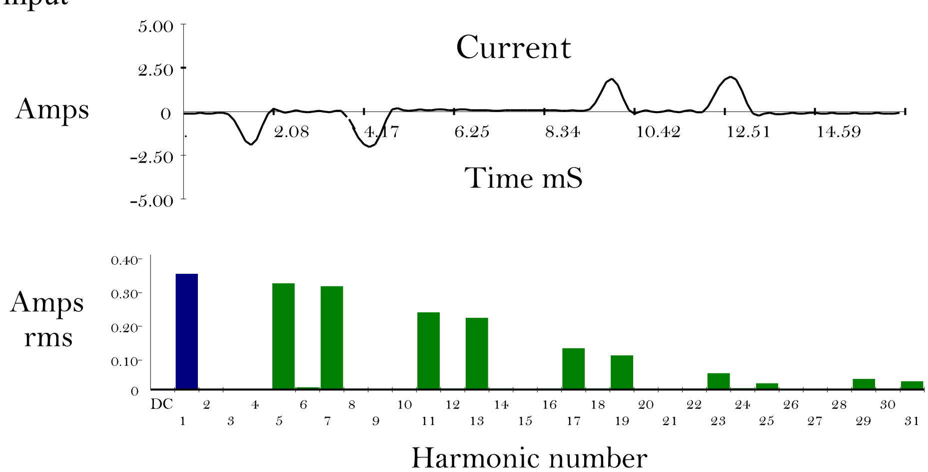

Figure 8: Input current and harmonic spectrum for drive with three-phase input

Looking at Figures 8 and 9, the difference in the harmonic spectra is striking. In particular, it is evident that the drive with a three-phase input (rectifier) has no third or other triplen harmonics, while the drive with the single-phase input has a large third harmonic component, as well as all the other triplen harmonics. When the students see these results, they are surprised, even though they have been told that in class.

Conclusion

Inexpensive, three-phase, variable-frequency motor drives have been used for three semesters. While there has not been any formal assessment of the student learning as a result of their use of the drives, it has been observed that all students were able to program the drives and obtain the required data for the lab. Their lab reports generally showed a good understanding of the operation of variable-frequency drives. Overall these drives have proven to provide as good a learning experience for the students as the previous "name brand" drives. In addition, for a relatively modest cost, we added ethernet connectivity that allows communication to the drive via a web browser, eliminating the need for expensive communication software. The drives have proven to be reliable. During the first year, one did fail and it was replaced within a week by the distributor. For the future, we are looking at the possibility of developing an additional experiment with the drives, utilizing more of their capabilities.

References

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Appendix A

Variable frequency operation of an induction motor

OBJECTIVE

After conducting this experiment, the student should be able to:

a. Describe the relationship between motor speed and applied frequency
b. Describe the relationship between applied voltage magnitude and frequency
c. Describe how the inverter provides a soft start capability for the motor
d. Compare the harmonic spectrum of currents drawn by a single-phase rectifier to that of a three-phase rectifier.

EQUIPMENT

Three-phase induction motor (e.g., Hampden IM-100)
Fluke 41 Harmonic Analysis Meter
0 to 140/240 V variable AC power supply
Tachometer
Danfoss VLT 1000 AC variable frequency motor drive
Automation Direct variable frequency motor drive

BACKGROUND:

The relationship between motor speed and frequency

The AC induction motor is a relatively simple, inexpensive, and rugged device which requires little maintenance. However, the induction motor is virtually a fixed speed device when operated from a constant frequency source. Since some applications require a fairly wide range of operating speeds, DC machines were often required. With the advent of power electronics, devices have become available that allow induction machines to be operated over a range of speeds. It is now frequently possible to buy an induction machine with an electronic drive for about the same price as a comparable DC machine. Furthermore, variable speed induction motors can also be used to drive pumps or fans more economically than the mechanical means which are often used to provide variable flow.

The upper limit on speed for an induction machine is determined by the frequency of the applied voltage and the number of poles on the motor:

$$n_s = \frac{120f}{P}$$

Thus for 60 Hz operation, a 2 pole motor can go no faster than 3600 rpm. As load is added to the shaft of an induction motor, the machine slows slightly and develops torque. The difference between the machine speed and synchronous speed is called slip. The general purpose induction motor (Class B) may be expected to operate with a slip of about 2 or 3% at full load. Thus the motor would run at 3492 to 3528 rpm (say 3500 rpm as a round number). In order to change this operating speed we must change the frequency of the applied voltage.

Again considering the 2 pole motor, if the frequency were changed to 30 Hz, the motor would run somewhere around 1750 rpm while at 120 Hz it would run at approximately 7000 rpm. Two questions have to be considered. First can the motor operate at frequencies other than 60 hz and second how do we get variable frequency voltage?

The effect of variable frequency on the motor

Most general purpose induction motors were designed without the thought of variable frequency operation in mind. A couple things have to be considered. First, most motors have an internal fan to cool the machine. If the speed of the machine is lowered, then so is the cooling effect of the fan. It may be necessary to reduce the current into the machine at lower speeds. Therefore, the machine may not be able to produce full load torque when the speed is reduced. Of course, many loads such as a fan or pump require less torque as the speed is reduced so this may not be a problem.

In operating a motor with a variable frequency source, we must also consider the relationship between voltage, frequency, and flux. Recall:

$$V_{rms} = 4.44fNB_{max}A$$

Clearly, if a constant voltage is applied to the motor and the frequency is reduced, the flux density in the motor would increase. This would drive the motor iron far into saturation causing excessive excitation current and core loss. To prevent this, we must make the applied voltage directly proportional to the applied frequency, making the flux density constant. When the frequency is raised above the rated value, the voltage must be held constant at its rated value. Thus, the flux in the motor decreases above rated frequency.

The result of the flux considerations is that the motor can produce rated torque below rated frequency, but must produce less than rated torque above rated frequency. Since power is proportional to the product of torque and rotor speed, the motor produces less than rated HP below rated frequency and rated HP above rated frequency.

Variable frequency sources

Since virtually all the electrical power in the U.S. is produced at 60 Hz, it is necessary to change the frequency. Before power electronics devices became available, this was a very expensive proposition. Thus, DC machines were normally used when variable speed was required. Now, however, it is possible to economically change the frequency of the AC supply and drive an induction motor over a wide range of speeds.

This is most commonly done by rectifying the 60 Hz AC power from the power system and then inverting it back to the desired frequency. Some variable frequency supplies use a DC chopper between the rectifier and inverter to control the level of DC voltage into the inverter. There are many different techniques for providing variable frequency to the motor. Two common techniques will be mentioned here.

The first type is the "Variable Voltage Inverter." VVIs develop an output voltage waveform in a staircase fashion as shown in figure 1. The waveform in figure 1 is a six step wave, others use 12 or more. The more steps that are used, the better the approximation is to a sine wave and the fewer will be the harmonics. (Harmonics are undesirable because they produce no useful torque but they can cause vibration, noise, and heating.) To change the RMS amplitude of the wave, it is necessary to change the DC input to the inverter so the steps will change size. Frequency is controlled by
changing the duration of the steps.

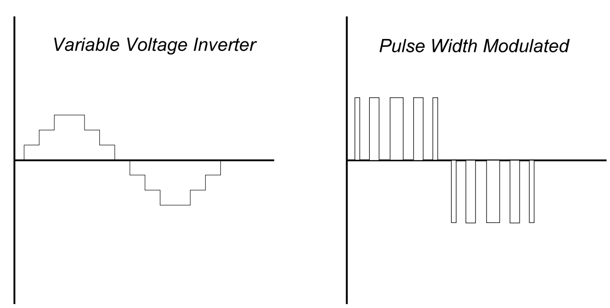

Figure 10.

The second type is the "Pulse Width Modulated, which is also shown in figure 1. Here the output of the inverter consists of a series of pulses all with the same amplitude but with different duration and spacing. Amplitude of the output AC voltage is controlled by changing the width of the pulses. Frequency is controlled by changing the number of pulses and their spacing. PWM often use a special purpose microprocessor to control the drive. With proper selection of the pulses, it is possible to eliminate the lower harmonics (third, fifth, etc). Of course there will be more of the higher harmonics.

The Danfoss VLT 1000 motor drive

The VLT 1000 is a microprocessor controlled pulse width modulated variable frequency motor drive. The input to the device is single phase, 60 Hz. The output can be 0-120 Hz, three phase. These units have been internally set to a maximum frequency of 90 Hz. Figure 2 shows a sketch of the unit, which shows the controls with labels. The actual units only have the international symbols on them. The units you are using in lab have manual controls installed in them for conducting the experiment. However, these units can also be controlled by a Programmable Logic Controller (PLC), allowing them to become part of a larger manufacturing process.

Note there are three LED indicators on the unit. The top one indicates power on, the middle one indicates the unit is at or above 90% of rated maximum current, and the bottom one indicates the unit has tripped.

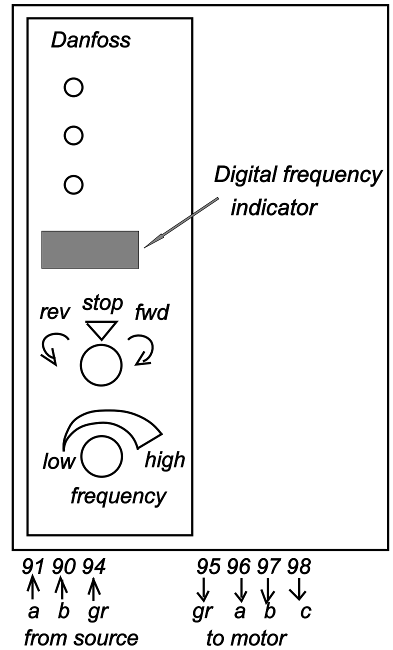

Figure 11.

The Automation Direct motor drive

The Automation Direct drive is a microprocessor controlled, pulse-width-modulated, variable-frequency motor drive. The input to the device is three-phase, 60 Hz. These units can be programmed manually or via a web interface and can also be controlled by a Programmable Logic Controller (PLC), allowing them to become part of a larger manufacturing process.

PROCEDURE

Part I: Danfoss Drive

1. Connect lines a and b of the 140/240 V variable supply to the voltmeter (Fluke 41). Turn on the power and set the voltage to 208 V. Leave the voltage set for the remainder of the experiment. TURN OFF POWER. **Disconnect the voltmeter**.

2. Connect the circuit of figure 3. Use analog bench meters in the circuit. Remove the plastic terminal block cover from the Danfoss inverter and check the connections. Power to the VLT 1000 should come into terminals 90 and 91. Terminals 94 and 95 should be grounded. Terminals 96, 97, and 98 will provide the variable frequency three phase power to the motor. After wiring the circuit, REPLACE THE TERMINAL BLOCK COVER.

3. Turn the frequency adjustment rheostat (see figure 2) fully clockwise and set the selector switch to off (middle position). Turn on the power on the Hampden bench. **READ THE REST OF THIS PARAGRAPH BEFORE DOING ANYTHING**. Turn the VLT 1000 selector switch to the run position (counter clockwise). Observe the frequency indicator on the VLT

1000, the ammeter, and the voltmeter as the motor accelerates. Answer question 1 in the analysis section.

4. Connect the Fluke 41 to measure the line to line voltage, V_{AB}, at the source (Hampden bench) and the line current, I_A, from the bench to the drive. Turn the drive back to the forward direction and set the drive frequency to about 30 Hz. **Save the data to a disk or flash drive** using the FlukeView software. Turn off the drive.

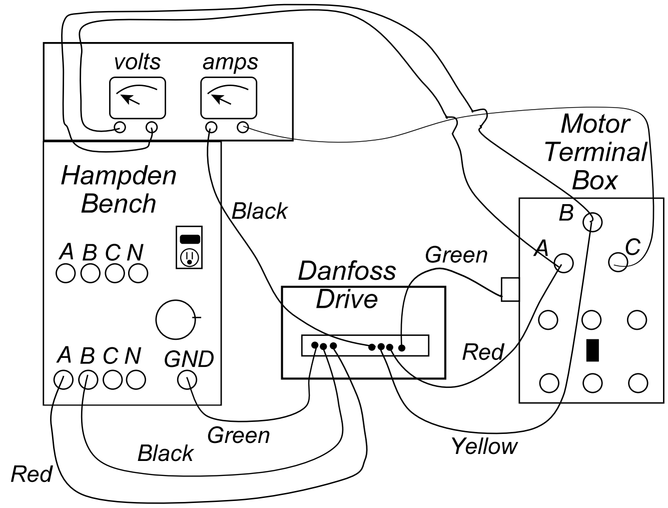

Figure 12.

5. Turn the drive off. How does the drive stop the motor? ________________________

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6. Turn the drive back on. Once the motor is running, turn the drive selector switch to the reverse direction. Describe what happens.

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7. Turn the frequency up to 60 hertz and then reduce it in steps of 5 hz down to 20 hz. Observe the sound of the motor at various frequencies and consider your response to question 2 of the analysis.

8. Turn of the power and disconnect the Danfoss VLT 100.

Part II: Automation Direct Drive

A. Drive familiarization

1. The Automation Direct GS3-2-1P0 drive is mounted on the panel over the wood bench adjacent to the Hampden bench. Be sure to switch off the 24 Vdc power switch for the PLC. On the front of the drive is a human interface module (HIM), which is used to program the drive or to obtain data. Figure 4 shows a picture of the HIM. At the top is an LCD display. Below the LCD display are buttons for programming, displaying data, and operating the drive. Programming is done with the PROGRAM, ENTER, and UP/DOWN keys.

2. Below the programming buttons are several more buttons and indicators. The UP and DOWN arrows are also used to change the frequency of the voltage that is applied to the motor. The RUN and STOP/RESET buttons are on and off, respectively and the FWD/REV button is used to change the direction of rotation.

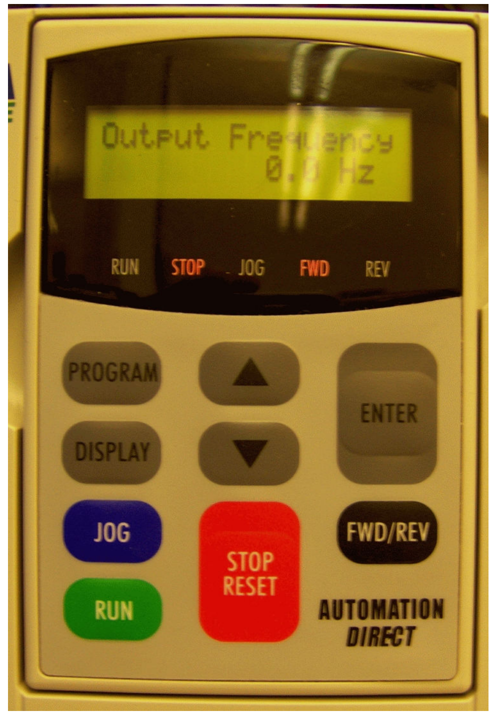

Figure 13

3. Wire the Automation Direct drive as shown in Figure 5. The cable that ends in jacks (shown in right side of Figure 6) goes to the Hampden bench power supply, while the cable with a socket (left side of Figure 6) on the end couples with a plug to go to the motor. **Have your instructor verify your connections.**

4. The first task will be to set the drive back to its factory defaults. The drive can be set to default configurations by setting the value of parameter P9.08 to 99.

- Turn on power to the drive.
- Press the PROGRAM (P) key. Then use the UP/DOWN (U/D) arrow keys to move to group 9 (the comms group).
- Press the ENTER (E) key and use the U/D keys to move to parameter 9.08 (Restore Default).
- Press the E key to select this variable and then use the U/D keys to change the value to 99. NOTE: press and hold the UP key and the value will change fairly quickly.
- Press the E key to accept the value, which resets the drive to factory defaults.
- Scroll back to parameter 9.08 and select it again. What is its value now?

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- Use the DISPLAY (D) key to display the Output Frequency (as shown in Figure 4).

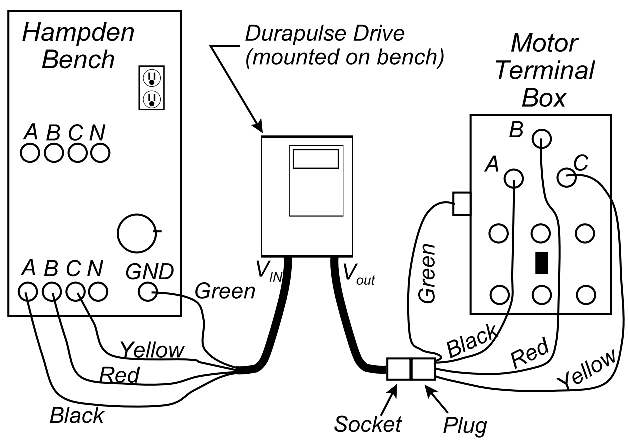

Figure 14

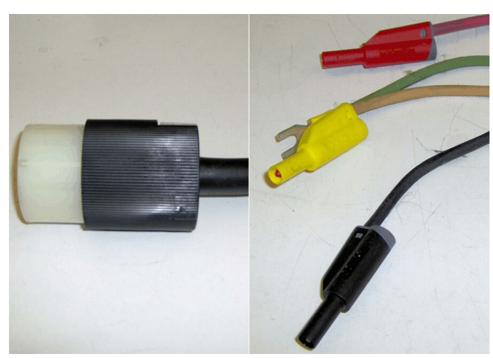

Figure 15

5. You are almost ready to start the motor. Time how long it takes for the drive to reach its maximum frequency. Press the RUN (R) key to start the drive and motor.

How does the drive start the motor? ______________________________

How long did it take to accelerate? _______________________________

What is the speed (rpm) on the tachometer? ________________________

While the motor is running, press the UP arrow on the drive. What happens?

____

With the motor running at 60 Hz, press the D key to display the following values (record them)–you will have to skip over some other parameters.

Output Frequency ____

Motor Speed ____

Output Current ____

Output Voltage ____

DC Bus Voltage ____

Frequency Setpoint ____

Press DISPLAY to return to the output frequency.

Now press the DOWN arrow and set the drive to 30 Hz. (NOTE: Settings will change faster than the actual frequency to the motor).

What is the speed on the tachometer? ____________________________________

With the motor running at 30 Hz, press the D key to display the following values (record them)–you will have to skip over some other parameters.

Output Frequency ____

Motor Speed ____

Output Current ____

Output Voltage ____

DC Bus Voltage ____

Frequency Setpoint ____

Press the STOP/RESET (S/R) button. How does the drive stop the motor?

____

When the motor is fully stopped, restart it by pressing the R key. What frequency and speed does it go to?

______________ Hz ________________ rpm

Use the Up arrow to return the drive to 60 Hz. Stop the drive.

6. Now you will set the drive to the correct parameters for the motor you are using.

- Press the P key. The display should indicate "Motor Group." If it does not, scroll through the groups until it does. Press enter to select this group and then use the arrow keys until the motor voltage parameter (P0.00) is displayed. Press enter to select it and display the setting What is it?

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- Change the motor voltage setting to 208 V by using the arrow keys. Press enter to accept the setting.
- Find parameter P0.01, motor nameplate amps, and set it to the value on the motor's nameplate.
- Set parameter P0.02 to 60 Hz
- Set parameter P0.03 (motor base rpm) to the value you obtained from the tachometer when the motor was operating at 60 Hz.
- Set P0.04 (motor maximum rpm) to 2700 rpm. Press and hold the up arrow and the speed setting will advance at an increasingly faster rate.
- After accepting the value for P0.04, press P to return to the Group level. Now scroll to Group 1. Select Group 1 by pressing enter and scroll to P1.00 (Stop Methods). A value of 0 (default) ramps to a stop, while a value of 1 allows a coast to stop. Set it to 1 and then press display. Start the drive, allow the motor to accelerate, and then press Stop. What does the drive do?

  ____

- Return to parameter P1.00 and restore it to 0.
- Set P1.01 (accel time) to 10 sec
- Set P1.02 (decel time) to 10 sec.
- Return to the group level by pressing P and move to parameter 3.16 (desired frequency). Set it to 90 Hz.
- Start the drive. What frequency does it stop at? ______________ Hz
- Now use the Up arrow to adjust the frequency to 90 Hz. While running at 90 hz, press Stop.
- Start the drive. What frequency does it stop at now? ______________ Hz.

– Scroll through the display and record the following values:

Output Frequency ____

Motor Speed ____

Output Current ____

Output Voltage ____

DC Bus Voltage ____

Frequency Setpoint ____

– How does the speed (rpm) displayed on the drive compare to the tachometer?

____

– Use the down arrow to reduce the frequency to 30 Hz. Stop the drive. When the motor is fully stopped, restart the drive. What frequency and speed does the drive display?

________________ rpm ______________ Hz

– Stop the drive.

7. Control of the motor via Internet Explorer.

– Table 1 shows the IP addresses for the drives by bench number. Note the bench number is the number of the wood bench that the drive is mounted on.

Table 1: IP addresses for the Automation Direct motor drives

Bench Number	**Drive IP Address (Verify withinstructor)**
1	192.168.0.260
2	192.168.0.147
3	192.168.0.145
4	192.168.0.146
5	192.168.0.250
6	192.168.0.003
8	192.168.0.148
9	192.168.0.106
10	192.168.0.091

– From the display menu on the drive, restore the frequency setpoint to 90 Hz.

– Use the Program key to navigate to parameter P3.00 (Source of Operation Command). Set it to 3, which will have the operation determined by the RS-485 interface. Press Display to return to the output frequency display
– Press Start on the drive. What happens?

____

– Open Windows Explorer and enter the IP address for your drive. You should see a simple screen like the one shown in Figure 7.

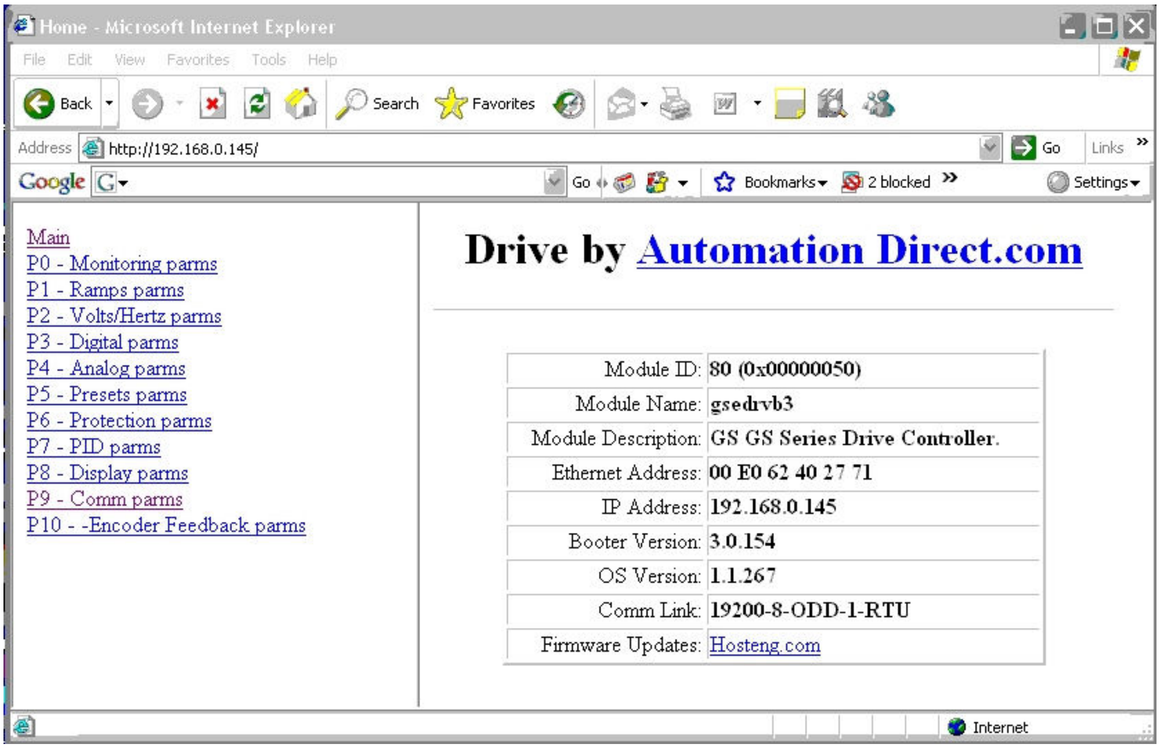

Figure 16: Internet Explorer link to Automation Direct motor drive

– Click on the P9 parameter group in the left window. That will bring up a list of the group parameters and their settings in the right window. Scroll down to and select P9.27. Click Run and then the send button. What happens?

____

– Use parameter 9.28 to reverse the motor. Did the motor reverse? ____________
– Turn off the drive
– Click on parameter group 4 and then select parameter P4.00. Set the frequency command source to, "*frequency determined by RS-485 communication interface*."
– Now return to parameter group 9 and select parameter P9.26 (RS485 Speed Reference). This value is in 10^{th}s of hertz; i.e., a setting of 900 is equivalent to 90 Hz. Set the command to 60 Hz and then send a Run command. What does the motor do?

____

– Stop the drive

- Click on parameter group P0. Note that the values you entered via the HIM are displayed (current is in 10ths of an amp). Now you will return the drive to manual control.
- Select parameter group P9 and reset P9.26 to 900 (90 Hz).
- Select parameter group P4 and reset P4.0 to, "*frequency determined by digital keypad*."
- Reset P3.00 to, "*operation determined by digital keypad*."
- Verify that you can start the drive from the HIM on the drive.
- Turn the drive off

Part III: Voltage and speed measurements for variable frequency operation

1. Verify that the frequency setpoint is at 90 Hz. At the Hampden bench, turn off power to the drive.

2.Connect a Fluke F41 and an analog bench meter to measure the line to line voltage from the drive to the motor terminals. Set the tachometer to read the motor rpm.

3. Turn on the power and start the drive. With the motor running with the 90 hz input, record the line voltage (both analog and Fluke 41 readings) and motor speed in table 2.

4. Use the arrow keys on the HIM to vary the frequency from 90 Hz down to 5 Hz in approximate steps of 5 Hz and complete table 2. Observe the noise level of the motor at lower speeds. **Do not leave the motor running at low speeds for any longer than necessary to take data**. Adjust the frequency back to 60 Hz when Table 2 is complete.

5. Push the FWD/REV button on the drive. Describe what happens. Turn the drive off.

____

____

Table 2: Variable speed data

f	90	85	80	75	70	65	60	55	50
V (analog)									
V (Fluke)									
n									
f	45	40	35	30	25	20	15	10	5
V (analog)									
V (Fluke)									
n									

6. Turn off the power. Move the voltmeter connections to the source (A and B) and put the current probe around the phase A lead (from the bench power supply to the drive). Turn the power on and start the drive. Use the arrow keys to reduce the frequency to 30 Hz. Download the F41 readings to the computer using the FlukeView software and **save the file**. Turn the drive off.

ANALYSIS

1. What type of start does a variable-frequency drive give the motor? Describe the apparent operation of the drive as it starts the motor (explain what you observed on the analog amp and volt meters).

2. What did you notice about the noise of the motor at lower speeds? What do you think causes this? Discuss the effects of harmonic currents on the motor.

3. Using a spreadsheet and your data from table 2, plot the applied voltage (plot the values obtained from both meters) and the motor speed as functions of the applied frequency (i.e., frequency on the x-axis). **If you put both speed and voltage on one chart, be sure to use separate y-axes.** Paste the graph into your report, with figure number and caption.

a. Your graph of voltage vs frequency should show two distinct regions—above and below rated frequency. Describe the two regions and explain why each region appears as it does. Compare the voltages you measured with the two meters.

b. What is the relationship between motor speed and frequency? Why does it look that way?

4. From FlukeView, **copy and paste both the current waveform and the harmonic spectrum drawn from the source by the Danfoss Drive**. Put figure numbers and captions on the figures. **Repeat for the Automation Direct (AD) drive**. Compare the harmonic spectrum of the current drawn by the two drives. What is the advantage of using a three-phase rectifier (AD) instead of a single-phase rectifier (Danfoss)?

Name____________________________

Pre-lab Assignment

1. What two types of drives (manufacturer and model number) are you going to use in this experiment?

   -

   -

2. What type of inverter do these drives contain?

3. What is the purpose of the five pushbuttons immediately under the LCD on the Automation Direct drive?

4. What is parameter P0.04 in the Automation Direct drive?

5. Why does a variable speed drive reduce the voltage to the motor when the frequency is reduced below its rated value?

6. What are you going to plot from the data you take in this experiment (Table 1)?