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Photo or Graphic File

Parameter	Code	Value	Units
Acceleration Time	C1-01	5	Seconds
Deceleration Time	C1-02	5	Seconds
Max Voltage	E1-05	230	V
Motor Current	E2-01	1.7	A
Magnetizing Current	E2-03	0.3	A
Poles	E2-04	4	-

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Overview

Variable frequency drives (VFDs) are becoming standard equipment to power most AC induction motors. These VFDs are common in industrial and automation applications and typically provide robust control of the motor in speed, torque, or position modes. The VFDs tested and simulated in this experiment focus on speed and open-loop control with constant voltage to frequency ratio (V/f) control. The induction motor typically operates at a rated stator flux, and this flux is approximately proportional to the V/f ratio. To maintain constant stator flux, the voltage and frequency applied to the stator are maintained at a constant ratio, which is the V/f ratio. The VFD used in this experiment is a 1 hp Yaskawa V1000 drive, but the procedure applies to most commercially available general purpose drives.

Principles

VFDs typically include a rectifier stage for AC/DC conversion, followed by an inverter stage for DC/AC inversion. The inverter and rectifier may be single-phase to supply single-phase motors, or three-phase to supply three-phase motors. Rectifiers may also have a power factor correction stage, so the VFD and motor are seen at a high power factor from the grid side supplying the rectifier, to reduce current drawn from the grid into the VFD and motor. Inverters are usually switched with pulse width modulation (PWM), which is a switching pattern very close to a sinusoid. Having PWM voltages fed from the inverter into the motor makes the motor see voltages close enough to sinusoids, since most motors are designed to be line-fed, (*i.e.*, directly fed by the grid). In PWM switching, the VFD can adjust based on user input or by automatically controlling the frequency of the sinusoid into the motor, and the voltage magnitude. Most commercial VFDs use open-loop control, where the V/f ratio is maintained as constant, when operating the motor at or below rated voltage; this maintains motor flux at a rated value. Other more advanced VFDs use "vector control," which is a closed-loop control scheme that provides tight speed or torque regulation.

> **Commented [AM1]:** Please provide background information on the equipment itself.
>
> Every video has an overview section, which discusses what the equipment is, how it is used and why it is important.
>
> Then each video has a principles section with theoretical information- How does this piece of equipment work? What is VFD?
>
> **Ali: Done**

Procedure

1. Make sure the three-phase disconnect switch is off.

2. Check that the VARIAC is at 0%.

3. Perform the following connections at the machine and VARIAC terminals:

    3.1 Connect the induction machine stator terminals to the drive output (right-side connectors, when looking at the front of the drive).

    3.2 Connect the drive input (left-hand set of connectors, when looking at the front of the drive) to the VARIAC output.

3.3 Connect the VARIAC input to the three-phase receptacle on the bench.

3.4 Before power is applied, turn the dial on the VARIAC up to 75%. This starts the drive at about 210 V line to line later in the experiment.

3.5 Turn on the three-phase disconnect switch. The main screen on the VFD should turn on and display "F000".

4. Press the Lo/Re button once to put the drive in local mode – the red light on that button should turn on.

   4.1. The Lo/Re button allows the user to make a selection between the local (Lo) frequency setting and the remote (Re) frequency setting.

   4.2. The user is able to change the frequency (f), and the drive automatically sets the corresponding voltage (V) to maintain a constant V/f ratio.

5. Check that the drive parameters are the same as those shown in **Table 1**.

6. To perform basic voltage, current, and frequency measurements:

   6.1 Cycle through the menu and find the display with a "0.0u" after it – this displays the measurement of the voltage fed to the motor.

   6.2 From there, scroll up once to a screen that reads "0.00A" – this displays the current measurement when the drive is running.

   6.3 The next screen up from that reads "0.00" – this is the frequency measurement.

7. To set a different output frequency, and thus set a different motor speed since speed and electrical frequency are proportional:

   7.1 Go back to the main screen and search for the letter F.

      7.1.1 Change the frequency by pressing enter and then manipulating the value using the up and down arrows.

      7.1.2 Use the > (right arrow/reset) button to change between the column of values.

      7.1.3   Enact any changes by pressing enter.

      7.1.4   Cancel changes and continue to run at the present frequency by pressing Esc.

8. Set the frequency to 10 Hz.

    8.1 Press the green Run button.

    8.2 Scroll to the voltage, current, and frequency readings and record their values.

    8.3 Repeat for the following frequencies: 25, 45, 60, and 70 Hz.

    8.4 Note that a maximum frequency limit might have been set to prevent the user from exceeding 60 Hz, so adjust the maximum frequency limit from the E2 menu.

9. Note that if the drive overloads or faults: Press the red Stop button, and then press the > (right arrow/reset) button.

Representative Results

VFDs typically provide a constant voltage-to-frequency ratio to maintain stator flux in an induction machine close to a constant. If a machine is rated at 60 Hz and 208 V (line-to-line, RMS), then the V/f ratio is $208/60 = 3.467$ V/Hz. Therefore, when the machine is run at a lower frequency to reduce its speed, the voltage is weakened to maintain a V/f ratio at a constant. For example, if the machine is run at 30 Hz, voltage should be reduced to 104 V. Or, if the machine is run at a frequency of 15 Hz, then the voltage should be reduced to 52 V. Under no load conditions, current typically drops as voltage drops, since the machine's reactance drop with lower frequencies.

At higher than rated frequencies, VFDs are usually programmed to maintain rated voltage; therefore, a constant V/f does not apply. This is mainly due to the voltage ratings of the machine, where higher voltages than rated are kept away from to avoid breaking the machine insulation or causing more current to flow into the machine. For example, if the frequency for a 60 Hz machine is set at 70 Hz using a VFD, the voltage is maintained at 208 V instead of 242.67 V.

Applications

VFDs have a wide use in commercial, industrial, and automation systems, and they can save significant amounts of energy, as they adjust the operating point of a motor to draw as much energy as needed under variable speed operation. Inverters used in VFDs are also common in many motor control applications including transportation systems with more electric vehicles, in heating, ventilation, and air conditioning applications, and many others.

Legend
Table 1: Main VFD Settings