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S.Y. B.Tech. (ECE)

Trimester: V **Subject: Power Devices & Machines**

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Roll No: 52 **Batch: A3**

Experiment No: 06

Name of the Experiment: Variable frequency drive (VFD) for three phase induction motor

Performed on: 23/11/2023

Submitted on: 23/11/2023

Marks

Teacher's Signature with date

Aim: To study the operation of a variable frequency drive (VFD) for three phase induction motor.

Pre-requisite: Knowledge of power semiconductor devices and variable voltage variable frequency induction motor operation.

Objectives: To understand the constant V/F control technique to achieve full motor torque from very low speeds right upto rated speed with controlled motor current so as to eliminate starting current inrush.

Components and Equipment required:

Sr. No.	Equipment / Instruments	Range/Specification
1)	Amtech Electronics VT 230S 07HA three-phase variable frequency drive (VFD) for induction motor	415 V, 50 Hz, 1HP
2)	Kirloskar Electric three-phase squirrel cage induction motor	415 V, 50 Hz, 0.75 KW/1 HP, 1380 rpm
3)	Mark Electrics separately excited DC generator coupled to induction motor	0.75 KW/1 HP, 1500 rpm, 230 V armature, 230 V field

4)	Advani Oerlikon shaft-mounted DC tachogenerator	200 V/70 mA @ 4000 rpm
5)	Automatic Electric three-phase variac for supply voltage variation	415 V, 15 A, 50 Hz
6)	Single-phase bridge rectifier for field circuit of DC generator	230 V, 50 Hz
7)	Lamp bank for loading DC generator	
8)	Non-contact digital tachometer	
9)	Automatic Electric moving iron AC ammeter	5 A
10)	Automatic Electric moving iron AC voltmeter	600 V

Theory:

For an induction motor working under constant V/f control with low values of slip frequency, the torque vs speed and current vs speed characteristics can be approximated by:

$$T_m = K_1 f_{sl} = K_2 \omega_{sl} = K_3 N_{sl} \quad (1)$$

$$I_m = K_4 f_{sl} = K_5 \omega_{sl} = K_6 N_{sl} \quad (2)$$

where

T_m = motor torque

I_m = motor current

$f_{sl} = f_s - f_r$ = slip frequency, Hz

$\omega_{sl} = \omega_s - \omega_r = 2\pi f_{sl} = 2\pi (f_s - f_r)$ slip speed, radians/sec

$N_{sl} = N_s - N = \frac{120}{p} f_{sl} = \frac{120}{p}(f_s - f_r)$ slip speed, rpm

f_s = applied stator frequency

f_r = frequency corresponding to the motor speed $= (1 - s) f_s$

N_s = synchronous motor speed $= \frac{120}{p} f_s$

N = actual motor speed $= (1 - s) N_s$

s = slip $= \frac{\text{slip speed}}{\text{synchronous speed}} = \frac{N_s - N}{N_s}$

Hence the speed-torque characteristic is:

$$N = N_s - \frac{T_m}{K_3} = \frac{120}{p} f_s - \frac{T_m}{K_3} \quad (3)$$

Description of the variable frequency drive:

1. Power circuit: The power circuit shown in Fig. 1 consists of a three-phase full-bridge IGBT inverter which generates a balanced three-phase variable voltage variable frequency AC supply for the three-phase induction motor. The DC supply to this bridge is obtained by rectifying and filtering the three-phase mains supply using a three-phase diode bridge rectifier followed by a capacitor filter.

The induction motor is mechanically coupled to a separately excited DC generator whose armature **A-AA** is connected to a load (lamp) bank. Varying the number of ON lamps varies the electrical load on the DC generator which in turn varies the mechanical load on the motor.

The field supply **F-FF** to the generator is obtained by rectifying the single-phase AC mains supply by a full-wave rectifier. As the inductance of the field winding of the DC generator is large, no separate filter inductance is required for filtering the field current.

2. Control circuit: A microprocessor-based control circuit using a sinusoidal PWM control technique provides the gate drive signals to the IGBT switches via isolated driver circuits. The switching (carrier) frequency is 4 KHz (nominal).

The control circuit of this drive does not use speed feedback. Hence speed regulation due to load changes is achieved by employing slip compensation which increases the inverter output (stator) frequency as the load torque increases so that the actual motor speed remains nearly constant.

At low frequencies, equations (1) to (3) do not apply as the underlying assumption that the applied voltage is nearly equal to the motor back emf is no longer true as the stator impedance voltage drop becomes a significant fraction of the applied voltage. Hence voltage boost is applied at low frequencies, with the amount of boost determined by the motor current which is roughly proportional to the load torque.

Fig. 14-19[1] shows the schematic and waveforms for a PWM-VSI (Voltage Source Inverter) while Fig. 14-20[1] shows the block diagram for electromagnetic braking in this inverter. Fig. 14-21[1] shows the block diagram of an induction motor speed control circuit in which the motor speed is not measured.

These drives can either be controlled from a remote computer or locally via the front cover-mounted operation panel.

3. VFD front panel: The front operating panel can be divided into three sections. The first (upper) section consists of a five digit seven segment LED display as well as polarity, status and units indication LEDs. The second (middle) section comprises of the parameter operation knob, while the third (bottom) section consists of operation, parameter operation and mode selection keys.

The drive parameters can be set as well as monitored from the operation panel by appropriately selecting one of the four control modes viz. **Monitor Mode**, **Block A Parameter Mode**, **Block B Parameter Mode**, **Block C Parameter Mode** (**Utility Mode** is reserved for future use).

In the **Monitor Mode**, the drive parameters such as inverter output frequency, inverter frequency setting, motor current and voltage are displayed by accessing different sub-modes. Drive parameters cannot be changed in this mode.

In the **Block A Parameter Mode**, frequently changed drive parameters such as inverter frequency setting, acceleration/deceleration times, torque boost can be set.

In the **Block A & Block B Parameter Modes**, infrequently changed drive parameters such as motor rating, overcurrent limit, DC braking, control methods and PID controller settings can be set.

PROCEDURE:

1. Switch-on the drive by pressing the ‘ON’ pushbutton of the three-phase DOL (direct-on-line) starter. Adjust the supply voltage to 390V by means of the three-phase variac.

2. At power-on, the drive enters the **Monitor Mode** and the display shows ‘OFF’. The **LCL** and **Hz** LEDs will also light.

3. Press the **FWD** key. The motor will start rotating in the forward direction and accelerate to its final speed in the preset acceleration ramp time (default value is 10sec). The display, still in the **Monitor Mode**, will show the previously set output frequency (default value is 10Hz) and **FWD** LED will light.

4. Press the **STOP** key. The motor will slowly decelerate to a halt in the preset deceleration ramp time (default value is 20sec) and the display will decrease to '0.00'. The **FWD** LED will flicker while DC dynamic braking is applied.

5. Press the **REV** key. The motor will now start rotating in the reverse direction and accelerate to its final speed in the preset acceleration ramp time. The display, still in the **Monitor Mode**, will show the previously set output frequency and **REV** LED will light.

6. Press the **STOP** key. The motor will slowly decelerate to a halt in the preset deceleration ramp time. The **REW** LED will flicker while DC dynamic braking is applied.

7. To change the motor speed, the drive output frequency has to be changed. For this, press the **RST/MOD** key once. The display enters the **Block A Parameter Mode** and the display will alternate between 'A00-0' and the previously set output frequency. Now press the **SET** key once. The display will show the previously set output frequency and the last digit will flicker. The digit to change can be selected by repeatedly pressing the **LCL/←** key. The frequency can now be incremented or decremented with the parameter operation knob and the motor will slowly accelerate or decelerate accordingly. To set the selected frequency, press the **SET** key. Repeatedly pressing the **RST/MOD** key will now cycle the display through the **Block B Parameter Mode**, **Block C Parameter Mode, Utility Mode** and back to **Monitor Mode**.

8. Measure the *N*/*f* (motor speed vs output frequency) characteristics, for different drive output frequencies for forward direction.

Observations:

1. *N/f* characteristics at rated supply voltage (415 V) and on no-load

Sr. No.	*f* Hz	Forward Direction	Reverse Direction
		N rpm	*N* rpm
1	50		
2	45		
3	40		
4	35		
5	30		
6	25		
7	20		
8	15		
9	10		
10	5		

Graphs and calculations

1. *N/f*

1.1 Plot the motor speed (*N* rpm) vs output frequency (*f* Hz) curve

CONCLUSIONS:

References:

1. N. Mohan, T.M. Undeland & W.P. Robbins, Power Electronics: Converters, Applications & Design, Third Edition, John Wiley & Sons, 2002.

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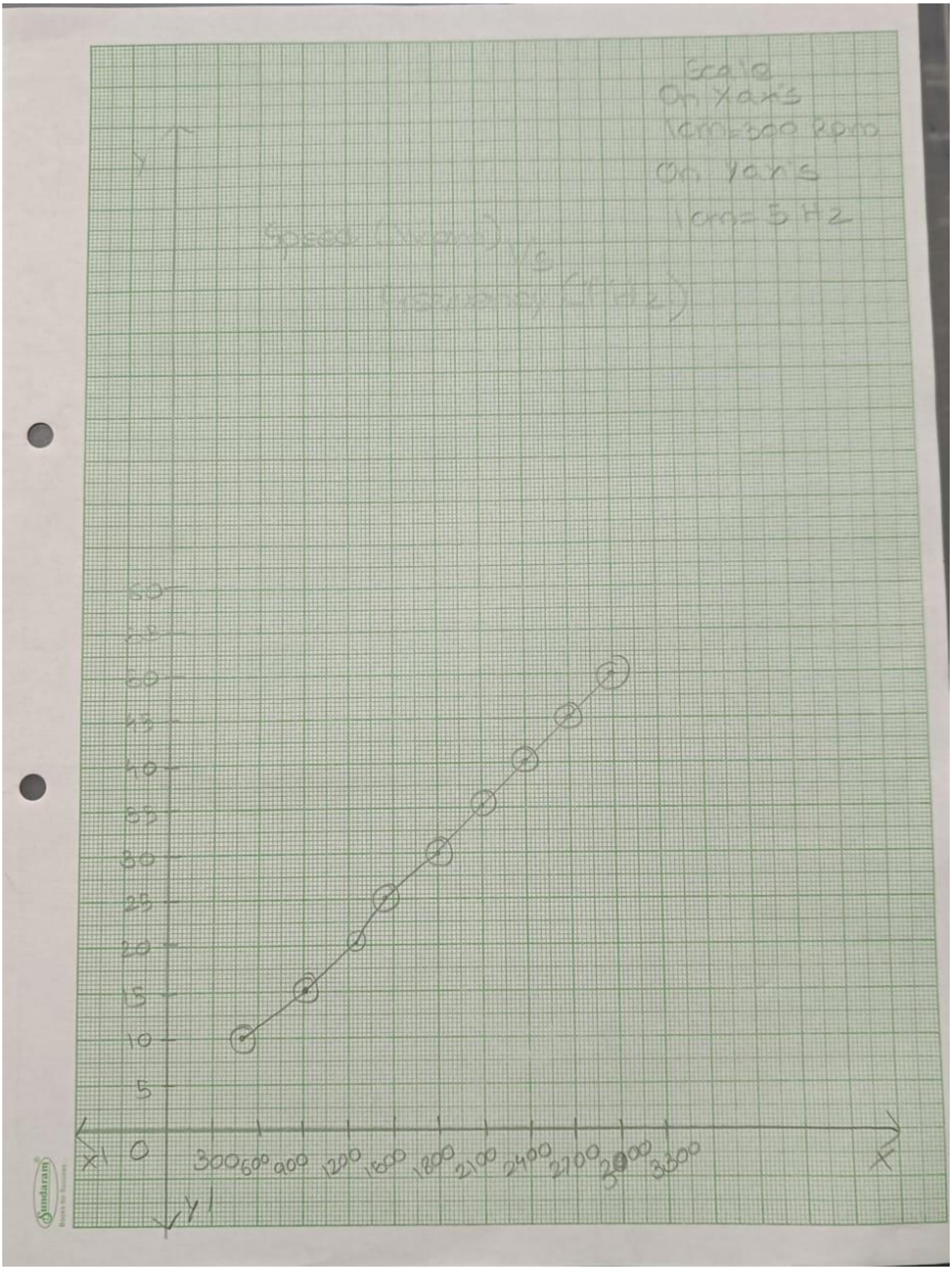
* observations:

N/f characteristics at rated supply voltage (415V) and on no-load

Sr No.	f Hz	Forward D N rpm	Reverse D N rpm
1	50	2996.7	-2996.2
2	45	2700.6	-2698.1
3	40	2400.4	-2398.7
4	35	2100.9	-2096.5
5	30	1801.9	-1797.6
6	25	1498.8	-1498.2
7	20	1257.2	-1198.3
8	15	956.3	-898.2
9	10	563.1	-670.6


Scale
On X axis
1cm=300 Rpm
On Y axis
1cm=5 Hz
Speed (Rpm) Vs Frequency (Hz)
Y
X'
X
Y'
0
5
10
15
20
25
30
35
40
45
50
55
60
300
600
900
1200
1500
1800
2100
2400
2700
3000
3300