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THREE-PHASE ASYNCHRONOUS MOTOR DRIVEN BY A FREQUENCY CONVERTER CONTROLLED WITH PLC

BY

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Abstract. Industrial equipment has been developed among time to be more efficient and meet the requirements at low cost. Three-phase asynchronous motors can be considered the most reliable electrical machines: they carry out their function for many years with reduced maintenance and can be adapted to different performances according to the requirements of both production as well as service applications. With the invention of adjustable speed drives and several other types of motor starters, three-phase motors have become favorable drives for variable-speed applications.

Speed control of an alternating current (AC) motor has been a challenge for engineers. Many approaches have been proposed to solve these problem. In this paper, a speed control method is proposed using frequency converter, as a slave, controlled by a PLC, as a master, all integrated in a PROFIBUS-DP network. The parameters contains inside the Variable Frequency Drive (VFD) are shown on Human Machine Interface (HMI) screen.

Keywords: PROFIBUS-DP; industrial communication; HMI; parameter; control.

1. Introduction

Three-phase motors are of mainly two types: asynchronous motor and synchronous motors. Synchronous motors are special types of motors used in

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constant speed applications, whereas most of the motors used in the industrial applications are of induction type. This article concentrates on three-phase induction motor and control of the speed.

Investigations on the applications of PLCs in energy research, engineering studies, industrial control applications and monitoring of plants are show that PLCs can be used for any applications whether it is of simple or complicated control system (Alphonsus & Abdullah, 2016).

Programmable logic controller is an industrial controlling device and can be used to automate machines and factory assembly lines for different applications (Tiwari *et al.*, 2016; Coetzer & Gouws, 2016; Yılmaz *et al*., 2016).

When a motor is switched on, there is a high inrush current from the mains which may, especially if the power line section is inadequate, cause a drop in voltage likely to affect receptor operation. This drop may be severe enough to be noticeable in lighting equipment. To overcome this, some sector rules prohibit the use of motors with direct on-line starting systems beyond a given power. There are several starting systems which differ according to the motor and load specifications. The choice is governed by electrical, mechanical and economic factors. The type of load driven is also important in the choice of starting the system.

There are some classical starting modes of AC motors: Direct on-line starting, where the motor is directly connected to the mains supply, Star-Delta, Resistor stator starting, Soft starter, Frequency converter.

2. Variable Frequency Drive

The VFD is power electronics based device which converts a basic fixed frequency, fixed voltage sine wave power (line power) to a variable frequency, variable output voltage used to control speed of induction motor. The frequency is direct proportional with the motor speed, so if the frequency rises the motor speed will rise and the other way around.

The frequency converter is special designed to drive AC motors asynchronous and has multiple advantages: variable speed, control of acceleration and deceleration, change of rotation sense, protection of the motor, possibility to supply 3 phase motor from single phase electrical network, monitoring and control from distance, easy connecting with other systems, energy efficiency

The block diagram, in Fig. 1, reveals the main components of VFD and output wave form.

The 3 phase power supply is connected to bridge rectifiers which consist in 6 diodes. The DC voltage on DC bus (filter) has ripples, therefore a capacitor and a filter smooth the ripples. The filter DC bus voltage passes through DC to AC 3 phase inverter. The DC to AC converter consist in 6 fast acting switches materialized with 6 Insulated Gate Bipolar Transistor (IGBT) which convert the DC voltage into voltage pulses of square shape, constant magnitude with variable width.

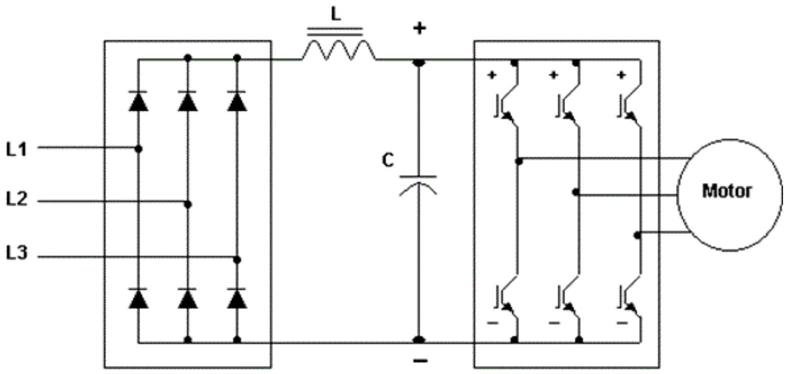
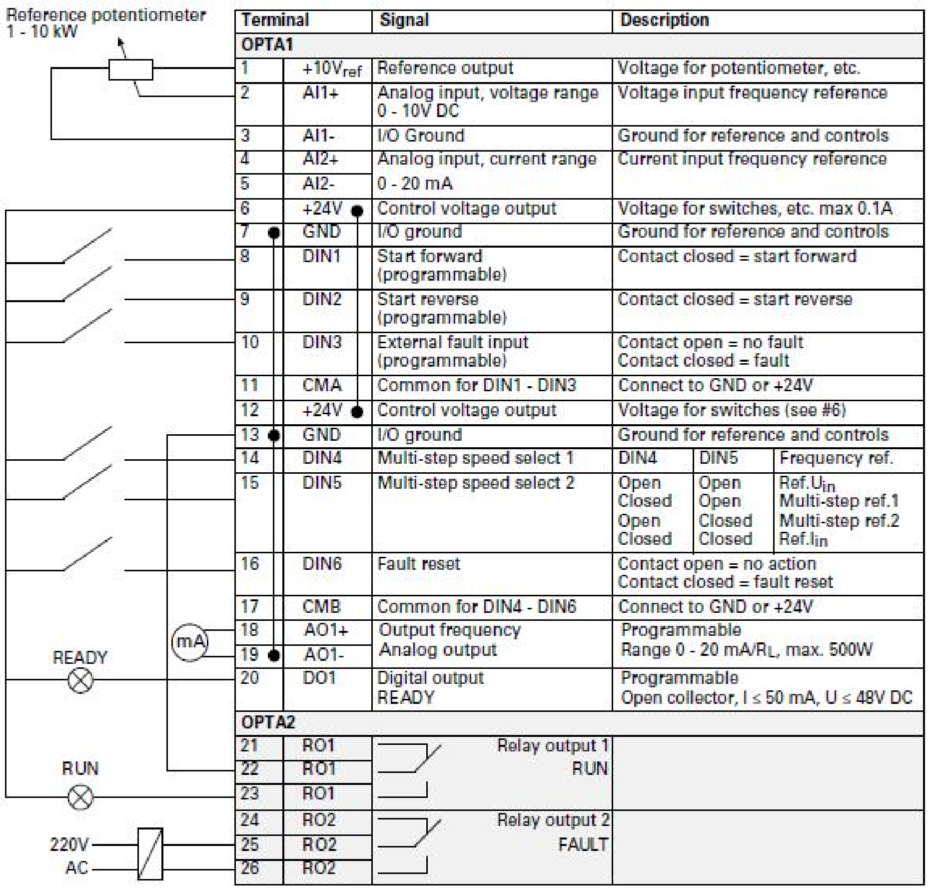


Fig. 1 – VFD diagram block.



Terminal		Signal	Description
OPTA1			
1	+10V$_{ref}$	Reference output	Voltage for potentiometer, etc.
2	AI1+	Analog input, voltage range 0 - 10V DC	Voltage input frequency reference
3	AI1-	I/O Ground	Ground for reference and controls
4	AI2+	Analog input, current range	Current input frequency reference
5	AI2-	0 - 20 mA	
6	+24V	Control voltage output	Voltage for switches, etc. max 0.1A
7	GND	I/O ground	Ground for reference and controls
8	DIN1	Start forward (programmable)	Contact closed = start forward
9	DIN2	Start reverse (programmable)	Contact closed = start reverse
10	DIN3	External fault input (programmable)	Contact open = no fault Contact closed = fault
11	CMA	Common for DIN1 - DIN3	Connect to GND or +24V
12	+24V	Control voltage output	Voltage for switches (see #6)
13	GND	I/O ground	Ground for reference and controls
14	DIN4	Multi-step speed select 1	DIN4 / DIN5 / Frequency ref.
15	DIN5	Multi-step speed select 2	Open / Open / Ref.U$_{in}$ Closed / Open / Multi-step ref.1 Open / Closed / Multi-step ref.2 Closed / Closed / Ref.I$_{in}$
16	DIN6	Fault reset	Contact open = no action Contact closed = fault reset
17	CMB	Common for DIN4 - DIN6	Connect to GND or +24V
18	AO1+	Output frequency	Programmable
19	AO1-	Analog output	Range 0 - 20 mA/R$_L$, max. 500W
20	DO1	Digital output READY	Programmable Open collector, I ≤ 50 mA, U ≤ 48V DC
OPTA2			
21	RO1	Relay output 1	
22	RO1	RUN	
23	RO1		
24	RO2	Relay output 2	
25	RO2	FAULT	
26	RO2		

Fig. 2 – Standard application default I/O configuration.

The inverter output is not a true sine wave but an approximation based on PWM. The Pulse Width Modulation (PWM) drive the motor because of the large induction of the motors coils. The larger period that the switches are ON, the higher is the output voltage and in this way the torque of the motor can be controlled. Increasing the frequency of the output signal of the VFD, the number of revolutions of the motor will increase.

The VFD presented in this paper is EATON 9000X Series (www.eaton.com) drives which can accommodate a wide selection of expander and adapter option boards to customize the drive for your application needs. The drive's control unit is designed to accept a total of five option boards.

The 9000X Series factory installed standard board configuration includes an A9 I/O board consist in 6 DI, 1 DO, 2 AI, 1AO, 1 +10V DC ref, 2 external +24V DC and an A2 relay output board, which are installed in slots A and B represented in Fig. 2 .

The PROFIBUS communication card, OPTC3, will link the PLC and VFD trough PROFIBUS cable. The PROFIBUS Network Card OPTC3 is used for connecting the 9000X Drive as a slave on a PROFIBUS-DP network. The interface is connected by a 9-pin DSUB connector (female). The baud rates range from 9.6K baud to 12M baud, and the addresses range from 1 to 127.

3. Programmable Logic Controller

A programmable logic controller is a specialized computer used to control machines and processes. It therefore shares common terms with typical PCs like central processing unit, memory, software and communications. Unlike a personal computer though the PLC is designed to survive in a rugged industrial atmosphere and to be very flexible in how it interfaces with inputs and outputs to the real world.

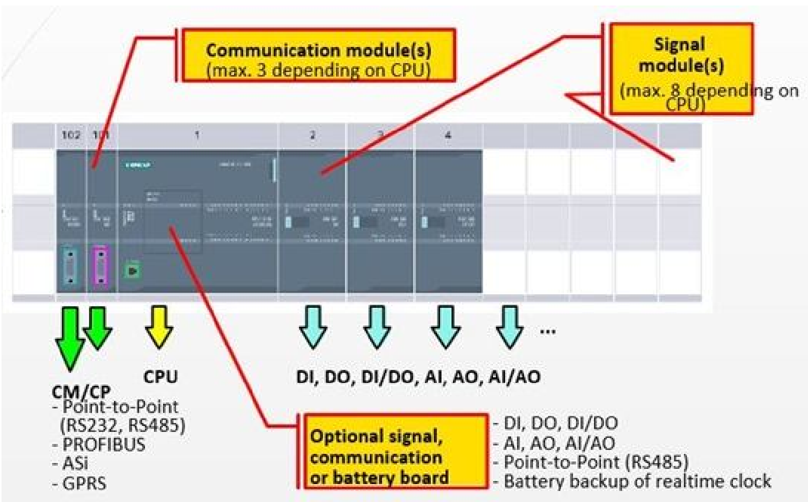


Fig. 3 – PLC configuration.

SIMATIC S7-1200 Basic Controllers are the ideal choice when it comes to flexibly and efficiently performing automation tasks in the lower to medium performance range. They feature a comprehensive range of technological functions and integrated IOs as well as an especially compact and space-saving design according to Fig. 3.

Siemens TIA Portal is a powerful integrated software solution for automation, and includes the programming environment for Siemens programmable logic controllers (PLCs). This software provides unique and powerful programming tools with multiple benefits including: creation of reusable logic, a structured program architecture, and single project integration of multiple automation devices (Siemens, 1999).

GSD (General Station Description) files contain information about the basic capabilities of a device. All devices are shipped with a GSD file, or a file can be downloaded from this web site or the vendor's own web site. With a GSD file, system integrators can determine basic data such as the communications options and the available diagnostics.

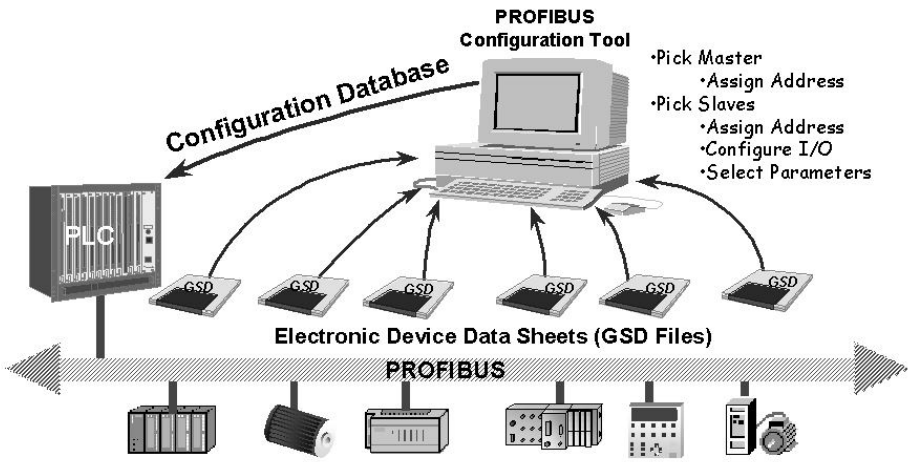


Fig. 4 – Configuration devices with GSD files.

4. Human Machine Interface

Human Machine Interface is the user interface that connects an operator to the controller for an industrial system.

The HMI can be connected by PROFINET protocol with PLC to exchange information as shown in Fig. 5. The PLC have Data Blocks (DBs) used for reading and writing the data to or from HMI. The HMI has the ability to record data or alarms which are very useful used later for other purposes, such as troubleshooting mechanical problems and/or adjusting settings.

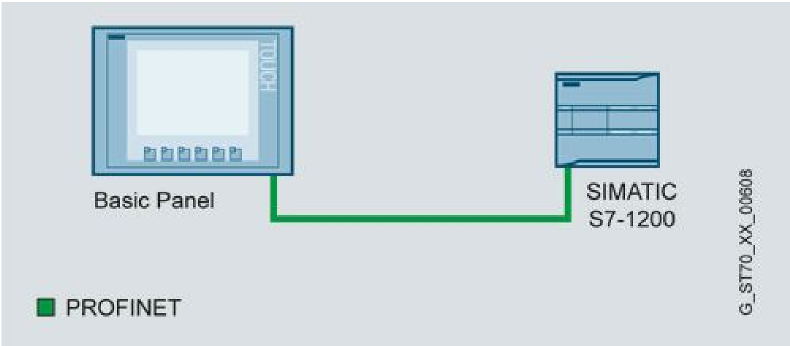


Fig. 5 – HMI connection with PLC.

5. Test Bench

The test bench contains a Siemens S7-1200 CPU connected by PROFINET with the HMI and by PROFIBUS with Eaton SVX 9000 VFD. The electrical motor is a 3-phased asynchronous motor, power 1.5 kW, 1450 rpm, delta 230 V, 6.4 A and power factor 0.82 (Fig. 6). The motor is mechanically fixed to electromagnetically sliding brake trough electromagnetically sliding couple. The motor is connected to the PROFIBUS network structure with a frequency converter EATON SVX 9000, Drive 3AC, 0.75HP, 240 V, 3.7 A.

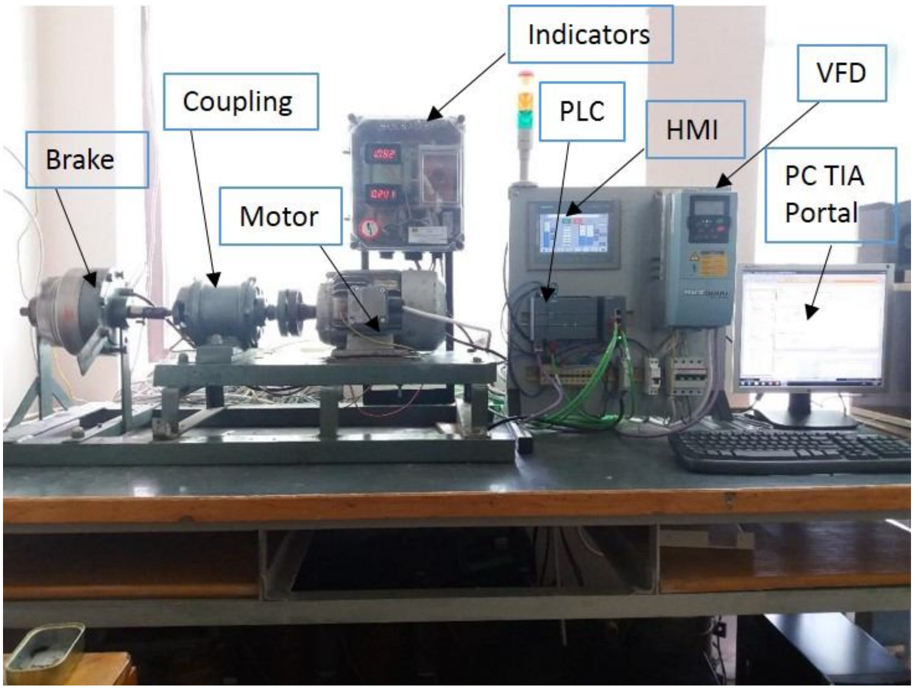


Fig. 6 – Test bench configuration.

TIA Portal is the software for network configuration and programming. The VFD can control the asynchronous three phase motor from local panel or remote by HMI.

The electrical system is controlled by HMI by changing the speed reference and visualization of the parameters like voltage, frequency, current. In case of constant speed, the torque has hysteresis when the measurement is done, first increasing the excitation current of the electrical sliding brake and then decreasing the value of the excitation current as result in the Fig 7.

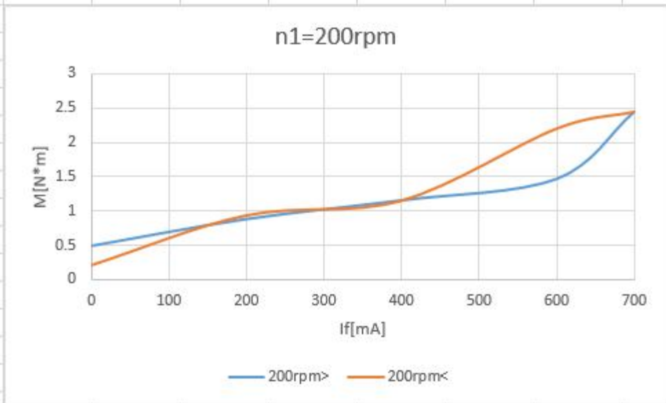


Fig. 7 – Hysteresis for motor speed 200rpm.

By changing the motor speed, the hysteresis is maintained as in Fig. 8. The result is the coupling forces between the motor driver and the load are the consequence of the retention phenomenon of hard magnetic materials.

By decreasing the electromagnetic field from maximum of H towards 0, the values of the magnetic induction remains at higher values than the previous and when the magnetic field is null, the material remains with residual electric induction.

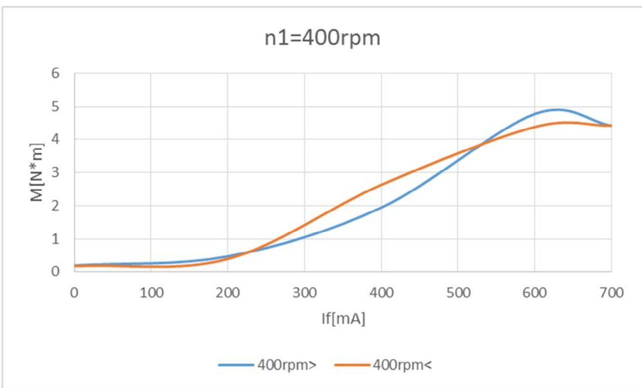


Fig. 8 – Hysteresis for motor speed 400 rpm.

6. Conclusions

Control of the asynchronous three phase motor by frequency converter consumes less energy than direct connection to main line supply. Also by variation of the frequency from the output of the converter, the motor has a smooth revolution. Control can be done from the distance through PROFIBUS-DP protocol and also could be in the future from World Wide Web.

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COMANDA UNUI MOTOR ASINCRON TRIFAZAT CU UN CONVERTIZOR DE FRECVENȚĂ CONTROLAT DE PLC

(Rezumat)

Echipamentele industriale au evoluat în decursul timpului cu scopul de a fi mai eficiente şi la un preț scăzut. Motorul asincron trifazat cu rotorul în scurt circuit poate fi considerat una dintre cele mai eficiente maşini electrice. O dată cu invenția convertizorului de frecvență, motorul trifazat a devenit o unealtă potrivită pentru aplicațiile de control a vitezei. Acest articol propune o metodă de control a vitezei unui motor asincron trifazat cu ajutorul unui convertizor de frecvență comandat de un Automat Programabil.