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Variable speed control of DC motor using four quadrant controlled rectifier based on Human Machine Interface

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ABSTRACT

Various industrial equipment uses dc motors as its drive. In order for the dc motor to operate as needed, it needs to be controlled. Some of the controls applied to dc motors include control of rotation direction, speed, braking, and starting current starting. This paper proposes controlling the speed of the dc motor using a 4-quadrant controlled rectifier or phase controller using a programmable logic controller (PLC) and human machine interface (HMI) as the control center. The system design is implemented on a 1.3 HP separate amplifier dc motor. The proposed control system design is tested and validated at varying speeds. Variations in motor speed are set on the HMI screen according to needs. The test results show that the design of the dc motor speed control system using a four quadran phase controller has worked as desired. The speed of the motor can be controlled through the HMI display.

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1. INTRODUCTION

Direct Current (DC) motors are one of the motors that are widely applied in various fields as a driving force from an electric power source. Because this DC motor has several advantages, such as easy to control, large initial torque and so on [1]. Many types of DC motors can be used, including separately excited DC motors, self-excited in the form of series, shunt or compound circuits [2] - [3]. Separately excited DC motors are widely used because they are easier to control, both from the field coil side and the anchor coil side [4].

DC motors used for various purposes operate in various modes. In order for the DC motor to operate according to the desired needs, the DC motor needs to be controlled. DC motor control includes speed control, braking rotation direction and starting for large-power motors [5] - [6]. DC motor speed control is generally done using a power converter, where the type of power converter used is determined by the power source that will be connected to the DC motor. Some types of converters used include controlled rectifiers or phase control on AC sources and DC-DC converters on DC sources [7] - [8]. The converter structure used is determined by the operating capacity of the motor, where DC motor operations can be divided into four quadrants, namely quadrant 1 for forward motoring operations, quadrant 2 for reverse generating operations, quadrant 3 for reverse motoring and quadrant 4 for forward generating operations [9]-[10]. In this study, a DC motor control system is proposed using a four-quadrant controlled single-phase rectifier, so that it can be operated for all four quadrants of electric machine operations.

In working, the motor can experience interference, both due to internal influences and the influence of external parameters [11]-[13]. To minimize the interference that occurs and to improve the reliability of machine operations, a supervised machine control system has been developed. Several devices have been applied for this supervised DC motor control, such as using the Human Machine Interface [14]-[24] and based on the Internet of Things (IoT) [25]-[35]. In this study, the DC motor speed control is supervised using HMI as the control display and the Siemens S7 1200 PLC as the control center. HMI and PLC are one of the control system devices that are widely used because of their reliability in the field [36]. The proposed control system is expected to increase the reliability of DC motor speed control.

2. METHOD

DC motor speed control using a four-quadrant phase controller based on HMI is carried out in the form of an experiment in the laboratory. The experiment starts from the design, hardware assembly, PLC and HMI program creation as well as testing and analysis. The DC motor speed control system proposed in this study can be seen from the block diagram in Figure 1 below. The control system consists of a separate amplifier DC motor as the object to be controlled, a 4-quadrant controlled 1-phase rectifier as a DC motor speed control driver, a Siemens S7 1200 1215C DCDCDC PLC as a control center, a TP700 Comfort HMI as a controller display device, a current to voltage signal converter as a tool to convert control signals from the PLC analog output in the form of a 0-20 mA current signal into a 0-10 Volt voltage signal to control the rectifier, a PC as a place to program the PLC and HMI using TIA Portal software, a 24 Volt DC power supply for the PLC and HMI and a 220 Volt 1-phase AC supply for the controlled rectifier.

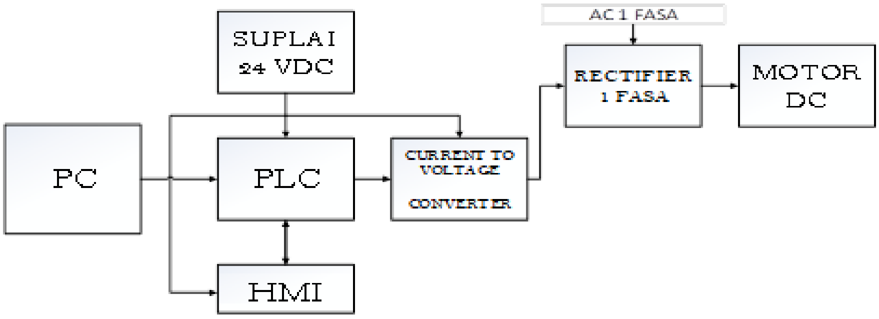

Figure 1. DC motor control block diagram

Figure 1 shows that the PLC functions as a controller center that will regulate the DC motor reference speed through the analog output terminal. The control signal will be a reference in setting the SCR switch firing angle on the controlled rectifier. This reference speed value is inputted to the HMI layer. The concept of controlling motor speed with a rectifier is done by regulating the motor anchor voltage. This anchor voltage regulation is done by regulating the SCR firing angle. The 1-phase four-quadrant rectifier used in this study consists of two controlled rectifiers in opposite directions, as shown in Figure 2 below

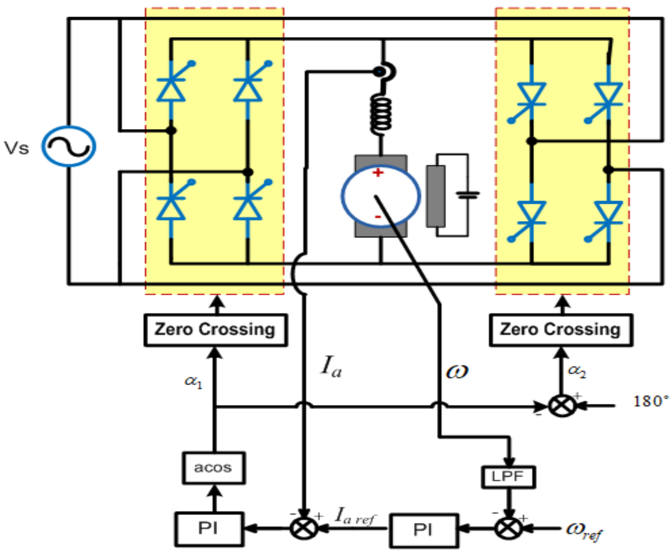

Figure 2. Scheme of DC motor speed control using four quadrant controlled rectifier

The reference speed in Figure 2 wref is input from the HMI which is controlled by the PLC. The reference speed value inputted to the HMI in rpm units is converted into a 0-20 mA current signal according to the analog output signal of the PLC. The current signal is converted into a 0-10 Volt DC voltage value using a converter according to the external input signal rating on the existing four-quadrant phase controller trainer. Figure 3 shows the hardware circuit of the DC motor speed control system using a four-quadrant phase controller based on HMI.

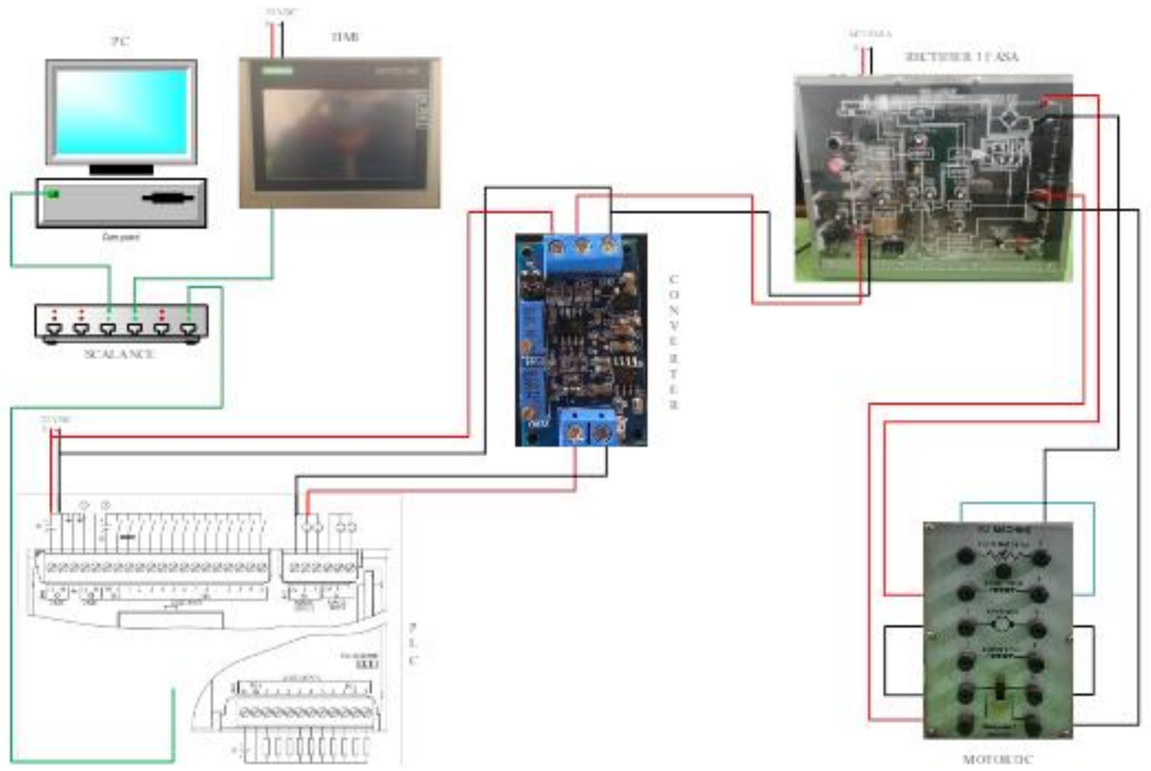

Figure 3. Circuit Schematic of DC motor speed control using four quadrant controlled rectifier based on Human Machine Interface

3. RESULTS AND DISCUSSION

The DC motor speed control system using a four-quadrant phase controller based on HMI proposed in this study was tested at varying speeds to see the validity of the reference speed inputted in the HMI layer with the real speed of the motor. Figure 4 shows the hardware installation during testing.

Figure 4. Experimental hardware setup

The first test was conducted by inputting the motor reference speed on the HMI 200 rpm. In this first test, the motor worked at a speed of 174 rpm with an anchor voltage of 30 Volts and an anchor current of 0.096 Ampere. The results of this test indicate that the actual motor speed is close to the same as the actual motor speed measured on the tachometer with an error of 26 rpm. Figure 5 shows the results of the first test.

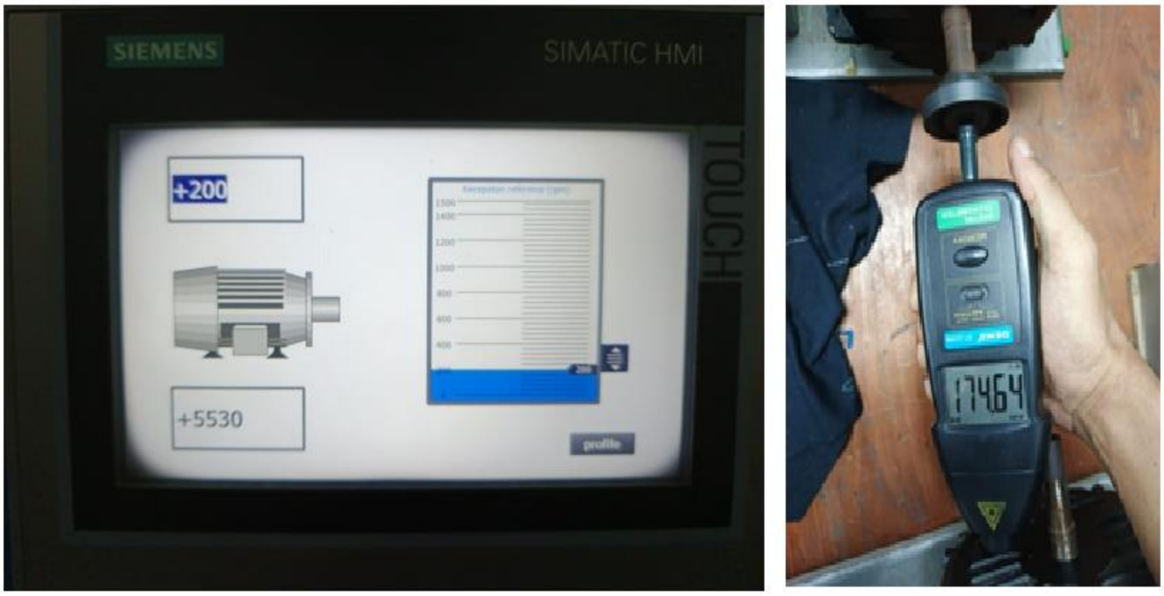

Figure 5. First test results

Next, testing was carried out with a motor reference speed on the HMI layer of 400 rpm. In this test, the actual motor speed read on the tachometer measuring instrument was 373 rpm, so there was a speed error of 27 rpm. In this test, the motor anchor current read on the measuring instrument was 0.106 Ampere with an anchor voltage of 60 Volts. The first and second tests showed that the motor anchor voltage increased when the motor reference speed was increased. This shows that the controlled rectifier can operate well in controlling the motor speed by regulating the anchor voltage. This anchor voltage regulation is done by adjusting the firing angle of the SCR switch on the rectifier. Figure 6 shows the results of the second test.

Figure 6. Second experimental results

Next, the third test was conducted with a motor reference speed of 800 rpm. In this test, the actual motor speed was obtained at 775 rpm with an anchor current of 0.124 Ampere and an anchor voltage of 127 Volts. Figure 7 shows the results of the third test.

Figure 7. Third experimental results

The results of all tests can be seen in Table 1 below. The description in Table 1 shows that the increase in speed is linear with the increase in armature voltage and armature current. This occurs because the speed control is done by adjusting the rectifier output voltage through the ignition angle setting. Figure 8 shows a graph of the rectifier output voltage when the motor speed is 200 rpm.

Table 1. Test Results

Speed reference in HMI (rpm)	Measurable speed (rpm)	Armature current (Ampere)	Armature voltage (Volt)
200	174	0,096	30
400	373	0,106	60
800	775	0,124	127

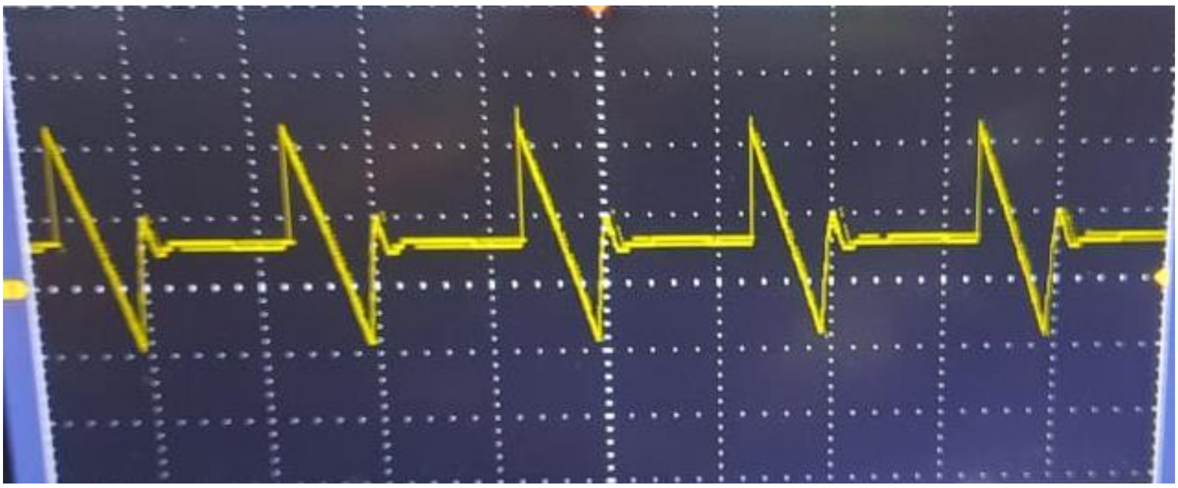

Figure 8. Rectifier output voltage graph

4. CONCLUSION

This study proposes a supervised DC motor speed control system using a four-quadrant phase controller using HMI as a motor monitoring and control device. The design of the control system was tested with varying motor speeds. The test results show that the motor speed can be controlled via HMI, where the actual motor speed value read by the measuring instrument is close to the same as the motor reference speed inputted on the HMI layer. The test results also show that the motor armature voltage changes linearly with changes in motor speed. This shows that the controlled 1-phase rectifier has successfully controlled the motor speed through the armature voltage regulation, where this voltage regulation is done by adjusting the firing angle of the SCR in the controlled rectifier.

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