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The Industrial IoT Control Design of Three Phase Induction Motor using Conventional V/F Method

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Abstract – **Nowadays, the Internet of Things (IoT) is inseparable from the industrial revolution 4.0 and society 5.0. IoT allows all aspects to be connected at the same time. In industrial processes, the IoT controls the actuator and monitors the behavior system. Industrial IoT (IIoT) applied for an Induction Motor (IM) is designed in open-loop conventional control using industrial standard component. ATV12 combined with Human Machine Interface (HMI) C7S and CP1E controller is used as main IM speed control instrument. The communication between the ATV12 as a Variable Speed Drive (VSD) and HMI C7S using Modbus protocol which is connected with RS485. The conventional control of IM controls supplies frequency and voltage simultaneously. The success parameter of the proposed systems is a rotor speed response and voltage in various supply frequencies. The results show that the 5 Hz supply frequency makes the absolute error of rotor speed response 11.43% for tachometer measurement, 0.67% from VSD data, and 12.67% for rotary encoder measurement. This absolute error will decrease significantly when the supply frequency exceeds 20 Hz, or the rotor speed response exceeds 1200 rpm. IIoT makes IM control possible anytime from any location by changing the frequency supply in the VSD. An increase in the supply frequency at the VSD causes the rotor voltage and speed to increase proportionally as the supply frequency increases.**

Keywords: IIoT, IM Control, Scalar Control, Speed Control

I. INTRODUCTION

The IM control research using conventional and vector control methods has been overgrown. This IM is better than other electric motors (direct-current motor, permanent magnet synchronous motor, and switch reluctant motor) regarding control method, reliability, technology readiness level, and price [1] - [2]. Recently, the IM has been widely applied in transportation as the main propulsion engine [3]. In an electric car, The Tesla factory used an IM for Tesla Model S as the prime movers [4].

Scalar control is one of the well-known control methods applied in the industrial sector. The scalar control method or volts/hertz control (v/f control) is easy to control the IM [5]. The scalar control is called a conventional control due to the easy way to control the IM. Lately, scalar control has been widely applied to the industry, transportation, and household sectors with an industrial class instrument [6]-[7]. The scalar control of the stator voltage depends on frequency supply, except in low and above base rotor speed [8]-[9]. On the one hand, the scalar control is easy to implement, low-cost operation, and robust against error feedback. On the other hand, the scalar control cannot control the magnetic flux and low efficiency [10]-[11].

IoT that is applied in industry or more commonly known as IIoT. The IIoT is used to develop a smart factory in which various sensors and wireless instruments connect [12]. In industrial revolution 4.0, the IIoT plays a significant role in realizing the industrial revolution [13]. IIoT uses related services, network technologies, applications, sensors, software, and storage systems to provide solutions and capabilities that enhance information and the ability to monitor and control processes and business assets. IIoT services and applications provide essential solutions for more efficient planning, scheduling, and control of manufacturing processes and systems [14]. In market overview and opportunity, the IoT and IIoT will be marketed primarily in the Asia-Pacific region [12], [15]-[16].

This study involves controlling the speed of the IM rotor using industry-standard instruments coupled with IIoT. The conventional control method is applied to the Altivar 12 industrial inverter, while the IIoT device uses HMI C7S. Modbus communication connects the HMI C7S with the Altivar 12.

II. METHODOLOGY

A. Design System Overview

The control system of IIoT for three-phase IM has been done in open-loop scalar control using an industrial instrument. The industrial component such as ATV 12 as a VSD, HMI C7S for an interface, and programmable logic control (CP1E controller) used to get the success parameter [17]- [18]. ATV12 has the parameter shown in Table 1. The VSD is chosen based on the motor-rated power, nominal current, and supply voltage. Figure 1 shows the design control of the systems. The frequency command is set from the HMI C7S and sent to the VSD

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through the RS 485 cable using Modbus communication protocol. The VSD sent stator voltage data, current and rotor speed. The parameters of HMI C7S are shown in Table 2.

Rotor speed readings are directly carried out in this system using a rotary encoder with the parameters shown in Table 3. Rotor speed data read through the CP1E control will be sent to HMI C7S with a serial communication protocol. The CP1E controller also manages IM manually via the L11, L12, and L13 pins on the VSD, which are connected to the CP1E controller. These pins represent IM controls for forward and reverse movement. In manual mode, the IM will be at nominal speed.

Table 1. VSD Parameter

Parameter	Value
Reference	ATV12H037M2
Range of product	Altivar 12
Communication Port Protocol	Modbus
Frequency	50 / 60 Hz ± 5%
Rated supply voltage	200…240 V – 15…10 %
Nominal output current	2.4 A
Motor power HP	0.55 HP
Motor power kW	0.37 kW
EMC Filter	Integrated
Physical interface	2-wire RS485
Continuous output current	2.4 A at 4 kHz
Method of access	Server Modbus serial
Sampling duration	20 ms, tolerance ± 1 ms for logic input 10 ms for analogue input

Table 2. HMI C7S Parameter

Parameter	Value
TFT Screen	7" (800 x 480 pixel)
Storage	4G + 512 M + SD
LAN	1
USB	2
COM	3
WiFi	No
Dimension (mm)	200 x 146 x 37

Table 3. Rotary encoder parameter (E6B2-CWZ6C)

Parameter	Value
Power supply voltage	5 to 24 VDC
Output form	NPN open collector output
Resolution (pulse per rotation)	360

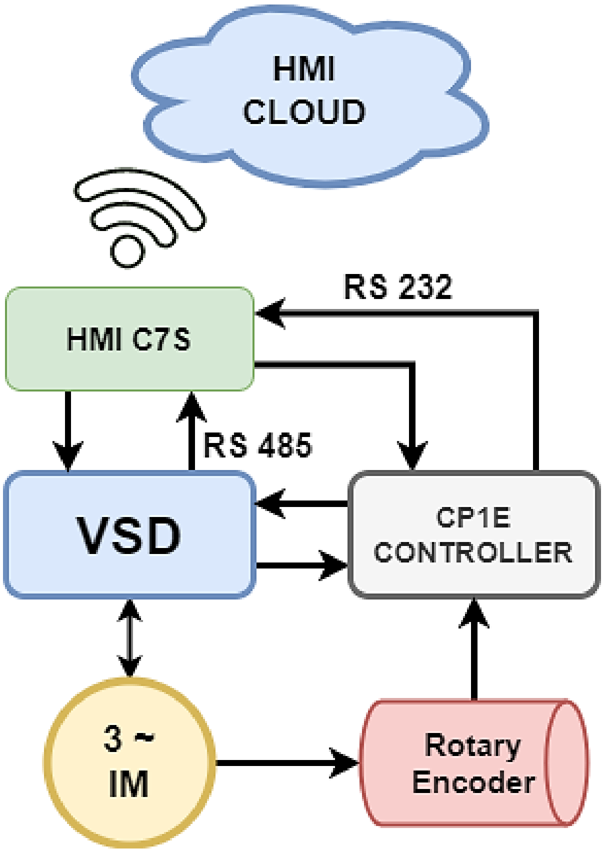

Figure 1. Diagram design of IIoT for IM control

Figure 2 is the realization of the diagram design in Figure 1. The IM can be controlled from HMI C7S, the button in the panel, and the smartphone. However, the button command in the panel can only control the start-stop of the IM, unlike the HMI and smartphone interface, which can control the rotor speed from 0 to 3000 rpm. The IM is controlled from the frequency setting parameter, which is sent to the three-phase inverter using RS485 from an interface shown in Figure 3. Modbus communication is used to send the frequency parameter. Furthermore, Altivar 12 sent the voltage and current data of IM to the HMI C7S using Modbus communication. The protection instrument for IM was added to the panel using Thermal Overload Relay (TOR) shown in Figure 3. The TOR devices use TeSys LRD. The TOR is designed to be at least 10 percent higher than the rated current of an IM.

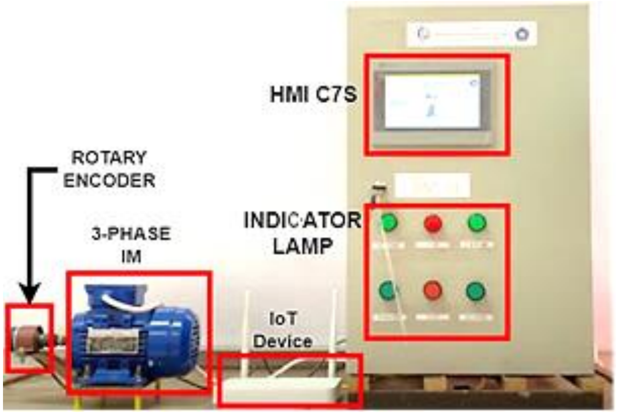

Figure 2. User interface

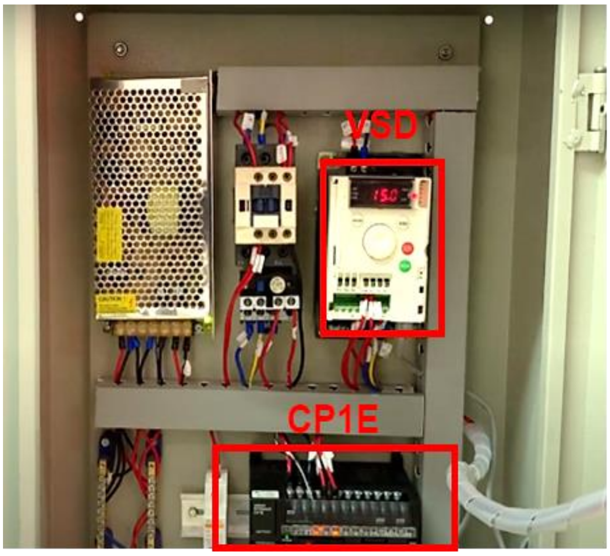

Figure 3. Hardware design

B. *Conventional V/F Method*

Three-phase IM is an electric motor that has a constant speed. It makes the IM challenging to control. In olden times, the IM combines with the gearbox to convert the speed. This technique sacrifices its power, efficiency, and power factor. Scalar control is a conventional method to control the IM. The synchronous speed equation of an electrical AC machine is shown in Equation (1) [19]. The percentage of the difference between synchronous speed and rotor speed is slip, shown in Equation (2).

$$n_s = 120 * f \,/\, P \tag{1}$$

$$S = \left({}^{(n_s - n_r)}\!/_{n_s} \right) \times 100\% \tag{2}$$

where,
n_s = synchronous speed
f = frequency (Hz)
P = number of pole
S = slip
n_r = rotor speed

The electromagnetic torque in IM is inversely proportional to the speed. The electromagnetic torque depends on the rotor electric magnetic field (emf), rotor resistance, inductive resistance, and the synchronous speed stated in Equation (3). This research uses the IM parameters shown in Table 4.

$$T = {}^{3}\!/_{2\pi n_s} \times {}^{s\,E_2^2\,R_2}\!/_{R_2^2 + (s\,X_2)^2} \tag{3}$$

where,
E_2 = the rotor emf
R_2 = the rotor resistance
X_2 = the rotor inductive reactance

Table 4. Induction Motor Parameter

Parameter	Value
Power (kW)	0.18 kW
Power (HP)	0.25 HP
Voltage (∇ / Y)	220 V / 380 V
Frequency	50 Hz
Speed	3000 RPM
Pole Pairs	2
current	0.53 A
Cos θ	0.8

The scalar control is based on varying two parameters, i.e., supply frequency and voltage. This control method keeps the constant ratio between the voltage and supply frequency [20]. The scalar control can be designed using open-loop and close-loop systems [10], [21]- [22]. On the one hand, the open-loop system has advantages: low price, simplicity, and resistance to the error feedback signal shown in Figure 4. On the other hand, the open-loop scalar control is not robust against the disturbance. Addition of control method such as a proportional-integral-derivative controller, fuzzy logic controller, sliding mode controller can be done in close-loop system shown in Figure 5 [23]-[24].

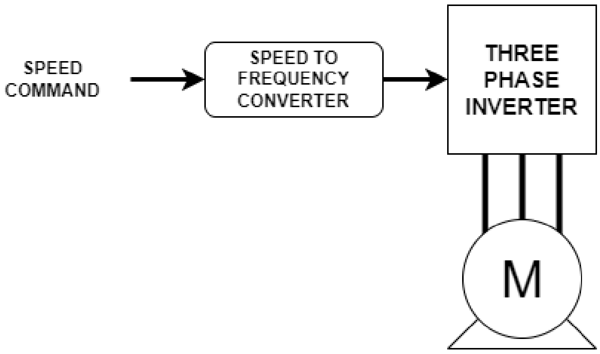

Figure 4. Open-loop scalar control system

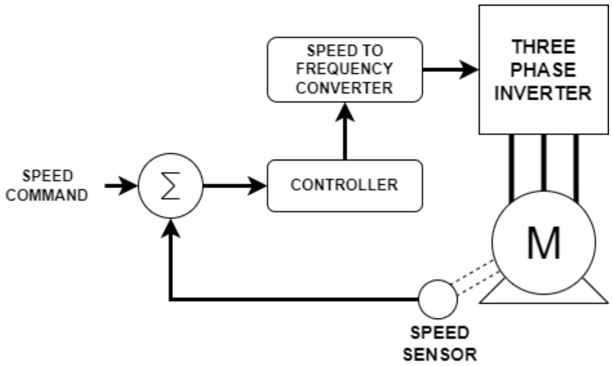

Figure 5. Close-loop scalar control system

III. RESULTS AND DISCUSSION

The proposed systems test has been done by measuring the rotor speed and the stator voltage. The rotor speed is measured with a non-contact tachometer shown in Figure 6, the rotary encoder as a speed sensor, and the data sent from VSD. RS485 sends the rotor speed data from VSD to the HMI. Besides the rotor speed data, the VSD sends the current and voltage data. Modbus communication is used as a communication protocol between VSD and HMI. The data address parameter in VSD is shown in Table 5. The data from VSD is displayed in the HMI dashboard, Supervisory Control and Data Acquisition (SCADA) for personal computers and smartphones via the Haiwell cloud [25]-[26]. The IIoT of this system enables control of the IM from anywhere and anytime via smartphone. The HMI dashboard of this system is shown in Figure 7. Meanwhile, the smartphone dashboard is shown in Figure 8.

Table 5. VSD address

Parameter	Address
Output velocity	16#219C = 08604
Estimated motor frequency	16#0C82 = 03202
Estimated motor current	16#0C84 = 03204
Voltage	16#0C87 = 03207

Open-loop scalar control is used to control the IM with an IIoT. The IM rotor speed response was carried out in the supply frequency range of 5 to 50 Hz with a frequency range of 5 Hz, as shown in Table 6. The results show that the IM is hard to control in low-speed response. It can be seen from the absolute error of rotor speed response. Figure 9 shows the absolute error for 5 Hz of supply frequency using tachometer measurement is 11.43%, VSD is 0.67%, and the rotary encoder is 12.67%. This value decreases when the supply voltage is 10 Hz. The absolute error decreases significantly when the supply frequency exceeds 20 Hz, or the rotor speed response exceeds 1200 rotation-per-minute (rpm). The absolute error of rotor speed response in 20–50 Hz of supply frequency is in error steady-state tolerance (less than 5%). This absolute error is an important parameter in designing a robust and stable control method. The supply frequency changes in the conventional V/F constant method will affect the voltage. Increasing the supply frequency on the VSD that adopts the conventional V/F method will increase the voltage magnitude proportionally.

Figure 6. Rotor speed measurement using a tachometer

Figure 7. HMI and SCADA Dashboard

Figure 8. Mobile Dashboard

Table 6. Three Phase Rotor Speed Response

F (Hz)	Rotor Speed Response (rpm)		
	Tachometer	VSD	Rotary Encoder
5	265.7	298	262
10	557.8	598	554
15	847.9	900	850
20	1143	1201	1183
25	1439	1502	1437
30	1741	1804	1766
35	2041	2105	2041
40	2343	2404	2345
45	2643	2707	2679
50	2930	3000	2962

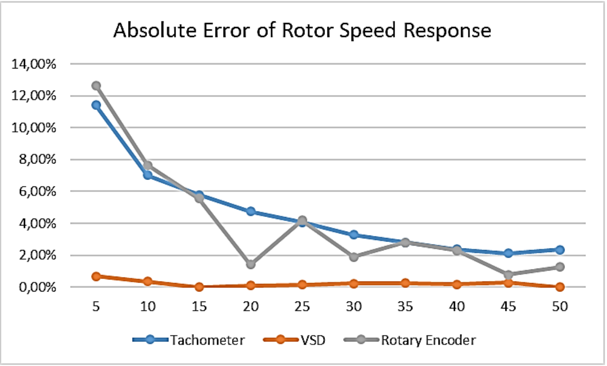

Figure 9. Error percentage of rotor speed response

Increasing the value of the supply frequency will affect the increase in rotor speed at IM. It also affects the increase in the voltage and current value in each IM phase, as shown in Table 7. The increase in the voltage amplitude value will be directly proportional to the value of the supply frequency. IM will reach the optimal voltage if the value of the supply frequency reaches more than 45 Hz.

Table 7. Three Phase Rotor Voltage and Current Response

F (Hz)	Rotor Voltage – Current Response			
	U (Volt)	V (Volt)	W (Volt)	Phase Current (Ampere)
5	43.4	43.5	43.4	1.31
10	65.5	65.5	65.5	1.40
15	87.1	87.1	87.1	1.20
20	109.2	109.2	109.2	1.42
25	131.6	131.6	131.6	1.36
30	154.5	154.5	154.5	1.17
35	176.7	176.8	176.8	1.15
40	199.0	199.0	199.0	1.10
45	221.6	221.6	221.6	1.60
50	231.0	231.2	231.2	0.95

IV. CONCLUSION

The research discussed implementing the conventional V/F method for three-phase IM control. The systems build with an IIoT, which can be accessed anytime in any location. The hardware design of this system uses the standard industrial component. So, the IIoT can be accessed as long as it is connected to the cloud. Monitoring rotor speed response, current, and voltage can be done through HMI and smartphone. The data from VSD was delivered to the HMI using Modbus communication. The control of IM is based on supply frequency command. The results show that low supply frequency makes the absolute error of rotor speed response high. The absolute error will be in the error steady state error range when the supply frequency is higher than 20 Hz or 1200 rpm. An increase in the supply frequency makes the voltage magnitude increase proportionally.

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