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DESIGN FOR AN EXPERIMENTAL MODEL OF INDUSTRIAL COMMUNICATION NETWORK BASED ON MODBUS RTU PROTOCOL

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ABSTRACT
Modbus RTU is an open serial protocol derived from the Master/Slave architecture originally developed by Modicon (now Schneider Electric). It is a widely accepted serial level protocol due to its ease of use and reliability. Modbus RTU is widely used within Building Management Systems (BMS) and Industrial Automation Systems (IAS). This protocol primarily uses an RS-232 or RS-485 serial interfaces for communications and is supported by almost every commercial SCADA, HMI, OPC Server and data acquisition software program in the marketplace. This makes it very easy to integrate Modbus compatible equipment into new or existing monitoring and control applications. This paper is the result of building an experimental model for training on industrial communication networks based on Modbus RTU and RS485 standards. The controllers used are PLCs of different manufacturers and field devices equipped with the Modbus RTU standard.

Key word:
MODBUS RTU; PLC; RS-485; Remote Monitoring, SCADA System; DCS System.

INTRODUCTION
Although new analyzers, flowmeters, and PLCs may have a wireless, Ethernet, or fieldbus interface, Modbus is still the protocol that most vendors choose to implement in new and old devices [1-5]. Another advantage is that it can run over virtually all communication media, including twisted-pair wires, wireless, fiber optics, Ethernet, telephone modems, cell phones, and microwave [6]. This means that a Modbus connection can be established in a new or existing plant fairly easily. In fact, one growing application is providing digital communications in older plants, using existing twisted-pair wiring.

Modbus is a master-slave system, where the master communicates with one or multiple slaves. The master is typically a PLC (programmable logic controller), PC, DCS (distributed control system), or RTU (remote terminal unit). Modbus RTU slaves are often field devices, all of which connect to the network in a multi-drop configuration [7]. When a Modbus RTU master wants information from a device, the master sends a message that contains the device's address, data it wants, and a checksum for error detection. Every other device on the network sees the message, but only the device that is addressed responds. Slave devices cannot initiate communication; they can only respond. In other words, they speak only when spoken to. Some manufacturers are developing hybrid devices that act as slaves but also have write capability, thus making them pseudo-masters at times.

In Modbus RTU, data is coded in binary and requires only one communication byte per data byte. This is ideal for use over RS232 or multi-drop RS485 networks, at speeds from 1,200 to 115 Kbaud. The most common speeds are 9,600 and 19,200 baud. Modbus RTU is the most widely used industrial protocol, so most of this discussion will focus on its basics and application considerations [8].

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RS-485 is known as the most common wired serial communication protocol in industrial automation. RS-485 interface is able to support for distance of maximum 1200 meters with multiple devices (up to 32 devices) on the same bus [9].In the RS-485 system, the master device polls each slave device, waits for the responses, and then polls the next slave device. This phenomenon allows a deterministic behavior by avoiding collisions of data packets. Most measuring devices in industry are compatible with RS-485 communication protocol [10 – 11]. Due to these advantages, this study used RS-485 wired communication protocol for the communication between master and slave devices. This paper presents the construction of an experimental model of industrial communication network for training purposes at universities.Many types of PLCs and controllers of different manufacturers are used in this model to communicate and create a communication networkby modbus RTU protocol according to RS485 standard.

EXPERIMENTAL MODEL DESIGN

Fig.1 shows the typical MODBUS RTU communication protocol, which is used in industry. MODBUS Remote Terminal Unit (RTU) is type of protocol that is used for serial communication to create a Master-Slave. It is a widely accepted protocol due to its ease of use and reliability. Remote terminal units (RTU's) are connected to sensors and actuators to interface with the physical systems.

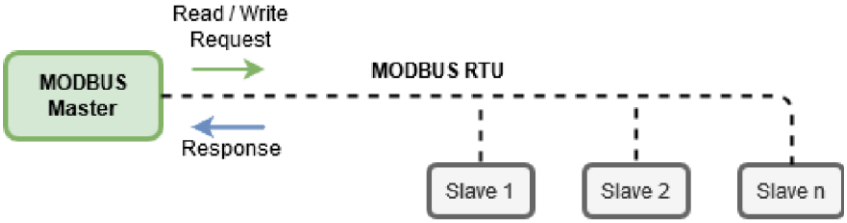

Fig.1. MODBUS RTU Communication Protocol

In this study, an experimental model of industrial communication network according to Modbus RTU protocol and RS485 standardwas created for training students in electrical engineering universities. The structure diagram of the system is shown in fig.2.

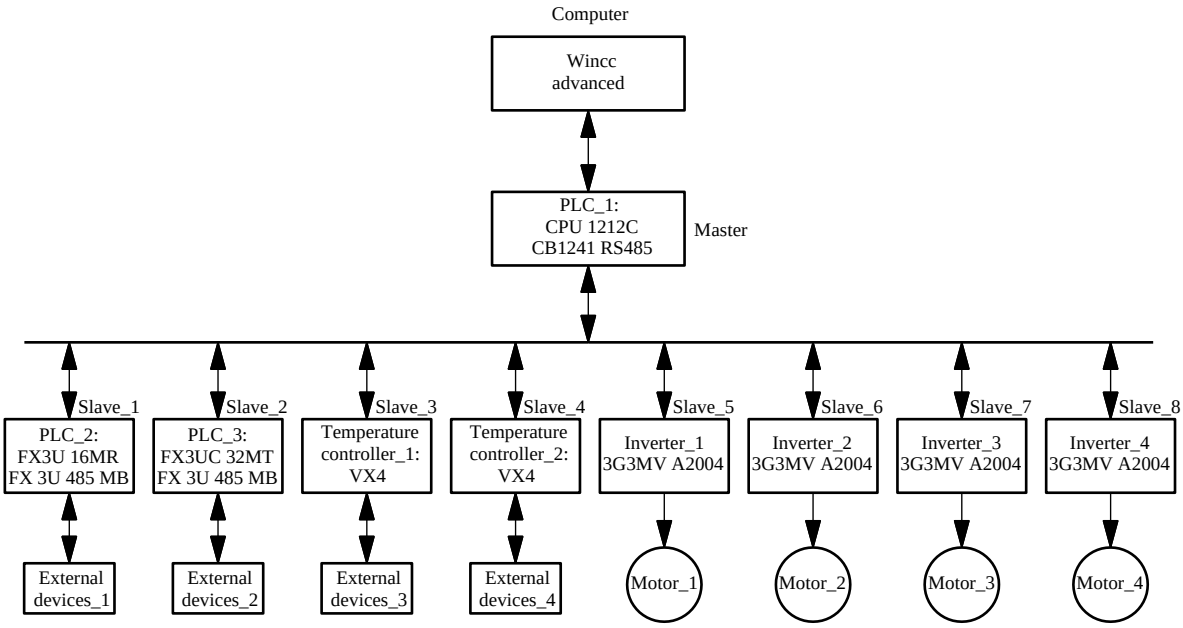

Fig.2. The structure diagram of the system

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In which:

Computer: Compuer is the highest level device, located in the central control room. Wincc software is installed on the computer to control and monitor the entire system.

PLC_1:PLC_1 is a master control system, including PLC S7 1200/CPU 1212C and Board CB1241 RS485. This PLC receives commands from the computer and communicates with the slaves via Modbus RTU protocol and RS485 standard. It writes or reads data with the slaves, then sends the results to the computer.

Salves: Connection of the master device with slave devices was made by using the RS-485 communication standard . The composition of the RS-485 cabling must be carried out with a meshed screen cable with a maximum distance of 1,200 meters between the device and the master unit. This bus was able to connect to a maximum of 32 measuring devices.In this study, we used 8 slaves. The slaves are field level controllers. They are connected to I/O devices and communicate with the master to exchange data with the master.

The specifications of devices are shown in table 1.

Table 1: The specifications of equipments

No.	The name and image of devices	The specifications of equipments
	Master: PLC_1	
1.	PLC Siemens S7 1200 – CPU 1212C AC/DC/RLY	+ Work memory 75 KB + Power supply 120/240VAC + DI8 x 24VDC + DQ6 x relay + AI2 on board; + 4 high-speed counters and 4 pulse outputs on board; + Signal board expands on-board I/O; up to 3 communication modules for serial communication; + up to 2 signal modules for I/O expansion; 0.04 ms/1000 instructions; PROFINET interface.
2.	Simatic S7-1200, communication board CB 1241	RS485, screw connector supports message based freeport.
	Salve_1: PLC_2	
3.	FX3U 16MR/ES-A	+ Power supply: 100/240VAC + Communication connection: RS422, support to expand RS232, RS485 + High speed counter: max 100Khz with CPU, 200kHz + High-speed pulse generation: max 100 Khz with CPU + Total I/O: 32 + Expandable up to 256 I/O via module or 384 I/O via CC-Link network.
4	FX3U 485 ADP MB	+ Product type : Modbus Serial Communication Adapter. + Transmission standard: RS-485 standard, conform to the RS-422 standard. + Communication procedure: .MODBUS (master or slave); No-protocol communication, computer link, parallel link and simple PC-to-PC link; inverter communication. + Communication speed MODBUS communication: 300/600/1200/2400/4800/9600/19200/38400/57600/115200 (bps).

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Salve_2: PLC_3		
5.	FX3UC 32MT/D	+ Power supply:24VDC + Communication connection: RS422, support to expand RS232, RS485 + High speed counter: max 100Khz with CPU, 200kHz + High-speed pulse generation: max 100 Khz with CPU + Total I/O: 32 + Expandable up to 256 I/O via module or 384 I/O via CC-Link network.
6	FX3U 485 ADP MB	+ Product type : Modbus Serial Communication Adapter. + Transmission standard: RS-485 standard, conform to the RS-422 standard. + Communication procedure: .MODBUS (master or slave); No-protocol communication, computer link, parallel link and simple PC-to-PC link; inverter communication. + Communication speed MODBUS communication: 300/600/1200/2400/4800/9600/19200/38400/57600/115200 (bps).
Salve_3 and Slave_4: Temperature control VX4		
7 - 8	Temperature control Hanyuongnux VX4	+ LCD display with wide viewing angle + Dimensions: 48x48x63mm +Various input signals: K,J,E,T,R,B,S,LN,U,W,PLII, Pt100, JPt100, 1~5V (4~20mA),0~5V,0~10V ,0~50mV,0~100mV + Output: Relay, SSR, 4-20mA, RET 4~20mA, with auxiliary output (1~4 relays) + Control type: PID, On/Off + Control mode: Hot and cold at the same time + Communication: RS485.
Salve_5 to Slave_8: Inverter 3G3MV A2004		
9 - 12	Sysdriver 3G3MV A2004 Inverter	+ Power supply: 3-phase, 200 to 230 V, 50/60 Hz + Rated capacity: 0,4kw + Ratedcurrent: 3A (3-phase 200VAC) + Output frequency range: 0.1 to 400 Hz + Starting Torque: 150 %/ Hz + Overload current rating: 150% rated output current for one minute + Control Method: Sine wave PWM (V/f control or voltage vector control, selectable); + Multi-function inputs + Multi-function outputs, PID feedback loss detection + Communication: MOBUS communications (RS-485/422, max. 19.2 K bps).

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The wiring diagram of the model is Fig.3.

In which:

+ Slaves_1 and slave_2 control outputs (DO) via input signals (DI) or receive communication commands from the computer to the master. Number of turns on/off at the output (DO) is send to the computer.

+ Slaves 2 and slave 3 receive the temperature setting value from the computer and control the thermistor to heat the furnace according to the PID algorithm. The temperature of the furnace is also sent to the computer.

+ Slave 5 to slave 8 receive the frequency setting value from the computer and control the motors. Parameters such as current, voltage, frequency are communicated to the master to display on the computer.

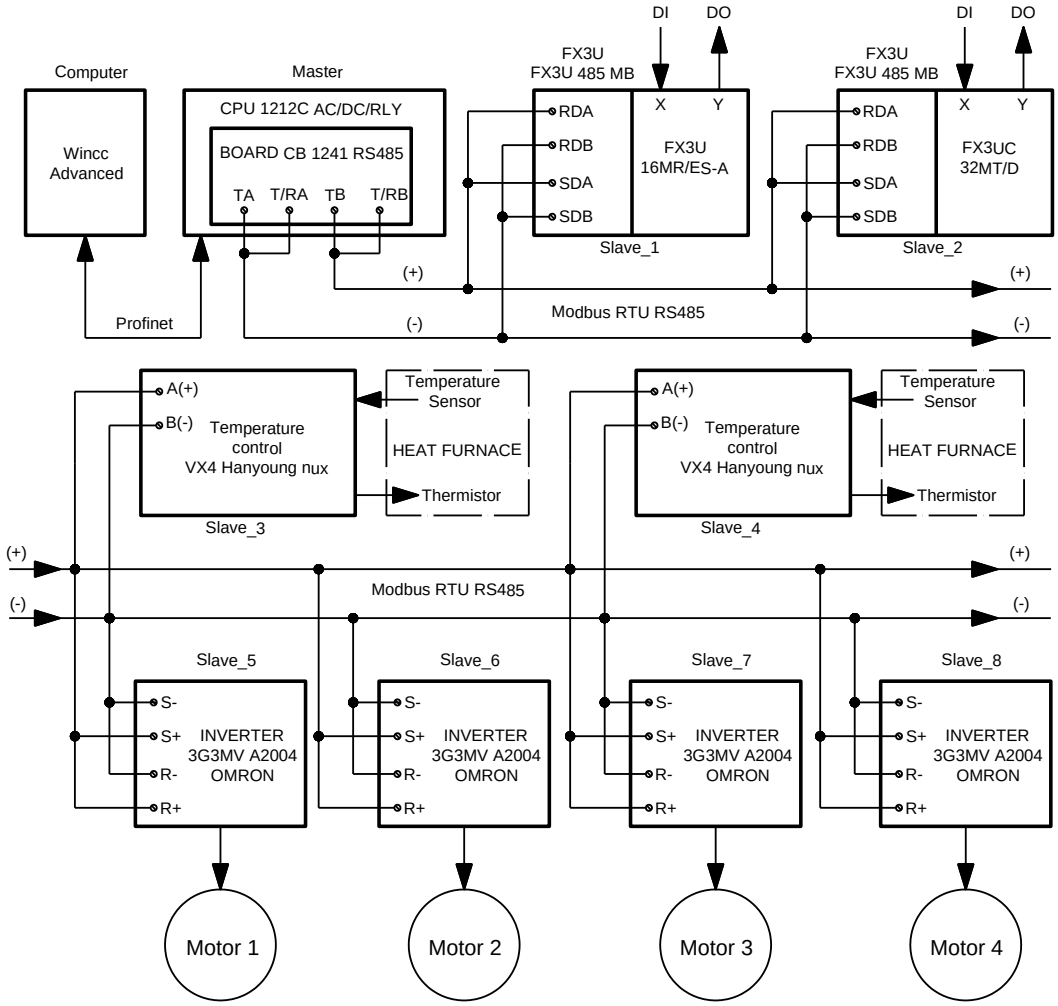

Fig.3. The communication wiring diagram of the model

The communication format of the system is set as follows:

+ Data length: 8bit
+ Stop bit: 1
+ Parity: No parity
+ Baud rate (bps): 9600
+ H/W type: RS485
+ Protocol Select: Modbus RTU

The process of exchanging data between the master and slaves is shown in fig.4

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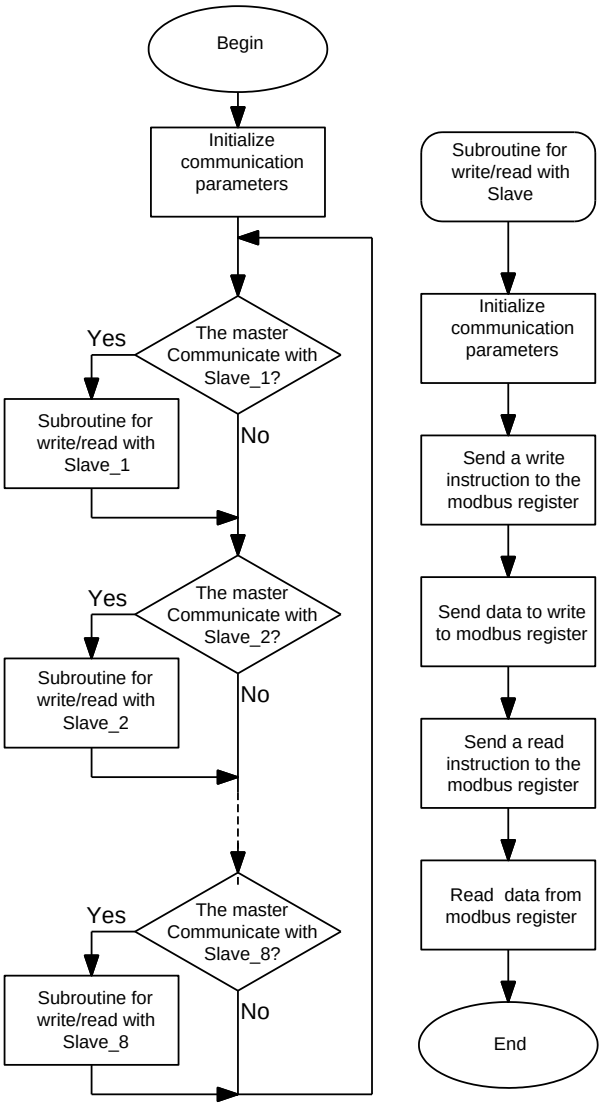

Fig.4. The process of data exchange between the master and the slave

TIA_V14 software is used to program the master which is shown in fig.5. In which, the Data blocks are declared to contain data to write/read (fig.5a). The MB_Comload instruction is used to initialize the communication parameters and he MB_Master instruction is used for communication (fig.5b).

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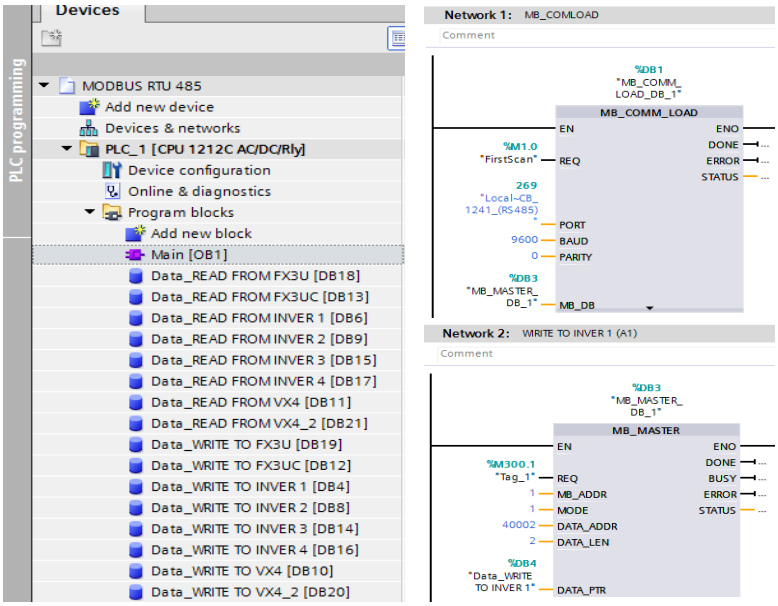

a. Data blocks b. Communication instructions

Fig.5. TIA_V14 software is used to program the master

Wincc Advanced software is built on the computer to control and monitor the system (fig.6). The computer communicate with the master via profinet communication standards.

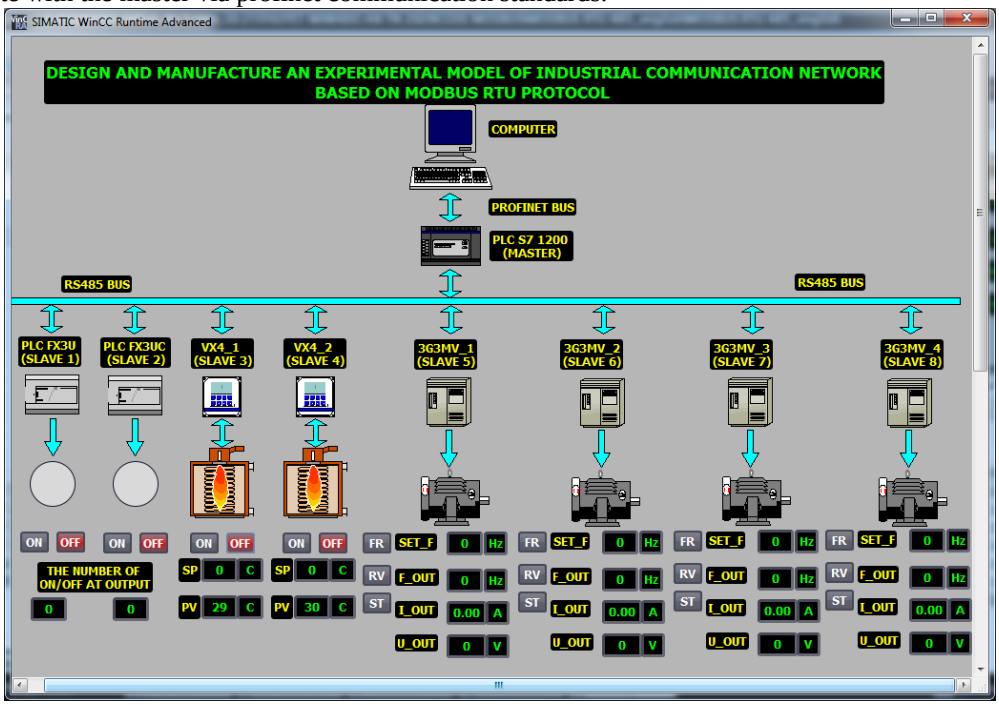

Fig.6. Wincc Advanced software is built on the computer to control and monitor the system

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EXPERIMENTAL RESULTS

The experimental model is shown in fig7. The inverters control the speed of 3-phase asynchronous motors with the rated voltage of 220V. The rated power of the motors are respectively: 0.1kW; 0.2kW; 0.2kW and 0.5kW.

The test results of the model are shown in table 2 and fig.8 to 9.

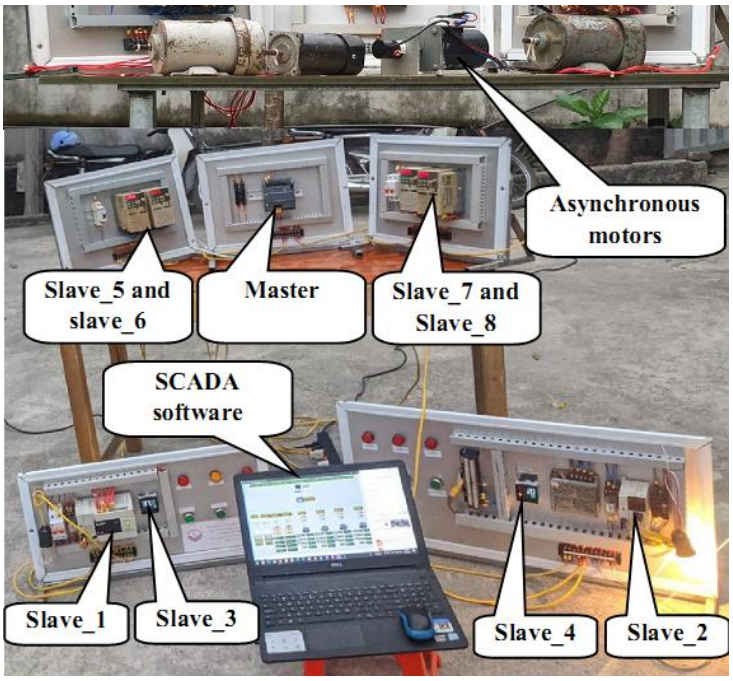

Fig7. The experimental model of industrial communication network based on Modbus RTU protocol

Table 2: The test results of the model

Setting value (SP)	**Process value (PV)**	**Setting value (SP)**	**Process value (PV)**
The first of the test		**The second of the test**	
Slave_1		**Slave_1**	
The number of ON/OFF at output: 02	02	The number of ON/OFF at output: 04	04
Slave_2		**Slave_2**	
The number of ON/OFF at output: 03	03	The number of ON/OFF at output: 05	05
Slave_3		**Slave_3**	
Temperature: 60^0C	60^0C	Temperature: 90^0C	90^0C
Slave_4		**Slave_4**	
Temperature: 70^0C	70^0C	Temperature: 98^0C	98^0C

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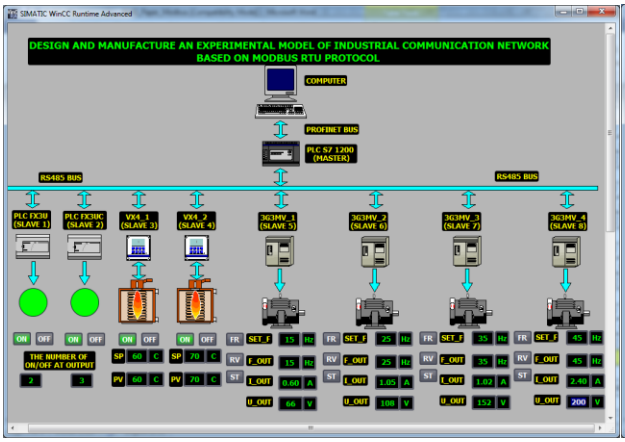
Slave_5		Slave_5	
Frequency setting: 15Hz with forward or reverse rotation	F_OUT = 15Hz I_OUT = 0.6A U_OUT = 66V	Frequency setting: 20Hz with forward or reverse rotation	F_OUT = 20Hz I_OUT = 0.58A U_OUT = 86V
Slave_6		**Slave_6**	
Frequency setting: 25Hz with forward or reverse rotation	F_OUT = 25Hz I_OUT = 1.05A U_OUT = 108V	Frequency setting: 30Hz with forward or reverse rotation	F_OUT = 30Hz I_OUT = 1.02A U_OUT = 130V
Slave_7		**Slave_7**	
Frequency setting: 35Hz with forward or reverse rotation	F_OUT = 35Hz I_OUT = 1.02A U_OUT = 152V	Frequency setting: 40Hz with forward or reverse rotation	F_OUT = 40Hz I_OUT = 1.00A U_OUT = 175V
Slave_8		**Slave_8**	
Frequency setting: 45Hz with forward or reverse rotation	F_OUT = 45Hz I_OUT = 2.4A U_OUT = 200V	Frequency setting: 50Hz with forward or reverse rotation	F_OUT = 50Hz I_OUT = 2.3A U_OUT = 218V



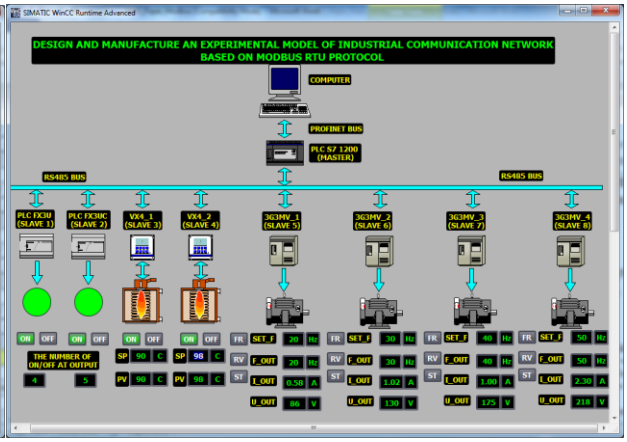


Fig.8. Thefirst test results of the modelFig.9. The second test results of the model

Experimental results show that the communication system works stably, the values written and read with the slaves are processed with a scan cycle of 0.1s. However, Modbus is a master/slave protocol, so there will be no way

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for the device to "report an exception". Therefore, the master node must regularly poll each device and look for changes in the data. This will consume bandwidth and network time in applications.

CONCLUSION AND DISCUSSION

The use of industrial communication networks, especially fieldbuses, to replace the classic point-to-point connection between industrial equipment brings a series of benefits as follows:

+ Signals are transmitted on 2 lines with distances up to 1200m.
+ Reduces the number of wires connected to the PLC.
+ Helps save a large amount of PLC expansion module.
+ Saving the space off installation because the converter is designed to be slimmer and more compact than the expansion modules of the PLC.
+ Has high stability and less noise than 4-20mA analog signal.
+ Modules are designed independently, so they are easy to manage.
+ Can be used for different manufacturers with Modbus RTU standard.

DATA AVAILABILITY

The practical data of the road profile used to support the findings of this study have been collected, measured, and processed by the research group under grant no. SV2020-12. The road profile data used to support the findings of this study are available from the corresponding author upon request.

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