BUILDING A PLANT FOR SIMULATING STEPS OF OPERATION IN A CEMENT PRODUCTION LINE SEQUENTIALLY

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ABSTRACT

The cement industry plays a crucial role in providing construction materials, directly contributing to infrastructure development and economic growth. Being interned at a cement manufacturing factory is an invaluable experience for engineering students in learning automation solutions in industry. During the internship at Hamaco Co., Ltd., a plant/model for simulating some steps in a Cement production process was built. This model integrates a SCADA system on WinCC Unified that enables monitoring and control of the production process from raw material intake, processing, blending, to packaging. Additionally, IoT technology based on the E-RA IoT platform was explored in order to introduce manufacturers innovative technological solutions. This model can also serve as a teaching tool that helps engineering students with practical experience in working with industrial systems.

1. INTRODUCTION

The cement industry is critical to Vietnam's economy, producing 100-105 million tons annually that makes the country one of the world's largest cement producers (Ky Anh, 2022). However, cement factories face challenges such as high energy consumption, environmental pollution, and demands for high-quality products. Therefore, adopting automation technology to optimize production processes not only enhances product quality but also saves energy, reduces environmental impact, and brings economic benefits to the industry.

Ray et al. (2013) evaluated the effectiveness of variable frequency drives (VFD) in reducing energy consumption and increasing process efficiency in the cement industry. VFDs have been applied to equipment such as fans, crushers, conveyors, and kilns to facilitate smooth startups, efficient speed control, cost savings, and reduced energy losses and pollution.

Heshmat et al. (2013) applied ARENA software to study and analyze a real cement production line. After 12 days of simulation, different bottlenecks, workstations utilization, buffer capacities and the line production rate were identified. This data was then used to reallocate buffers and thus improved line efficiency.

IoT technology has also been applied to industrial production for enhancing real-time data collection, analysis, and control of machinery to proactively improve quality and reduce costs (Umran, 2021; Nguyên, 2022; Điển, 2019). Similar to other fields in the industry, the future of advanced process control in cement production would rely on Artificial Intelligence Augmented Plants (AIAP), where human expertise is integrated with AI to optimize complex operations, moving towards smarter and more automated factory management (David, 2024).

For engineering students, internships in industrial environments provide important opportunities to gain insights into production technology, their fields of study, and career orientation. Therefore, this work focused on applying academic knowledge on automation to mimic key stages of cement production at Hamaco Co., Ltd such as material input, mixing process and cement product.

2. METHODS

2.1. Overview of the model

The model is constructed using PVC pipes for the frame (80x110x30 cm), and an aluminum plate for mounting LED indicators (Figure 1a). Table 1 lists the main components of the plant:

Table 1. Main components of the plant

No.	Components	Quantity
1	Laptop	1
2	Main Circuit Breaker (MCP, MP6-C310)	1
3	Programmable Logic Controller (S7-1200 DC/DC/DC)	1
4	Communication Module (CB 1241 RS485)	1
5	Arduino Uno R3	1
6	Ethernet Shield W5100	1
7	ESP32	1
8	Optocoupler-Isolated 4 Channel DC 5V Relay Module	1
9	Indicators (LED, 24V)	11
10	3-Phase Motor 0.75 kW	1
11	Variable Frequency Drive (VFD, Siemens Sinamics V20 0.75kW 1 phase 220V)	1
12	Power Supply (Hanyoung DPS-30S-24 30W 24VDC)	2

Source: authors, (2024).

a

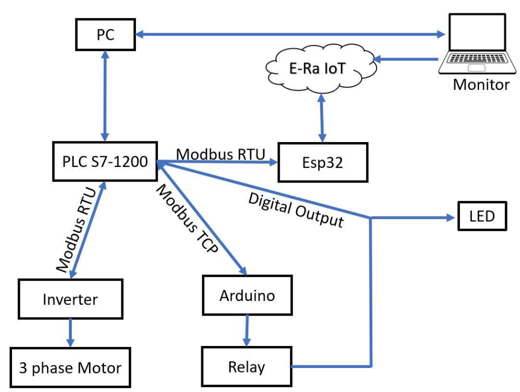

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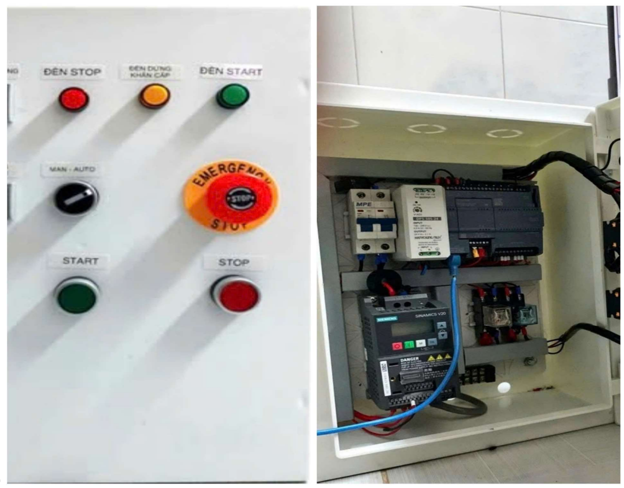
Figure 1. a) Plant/Model; b) System diagram



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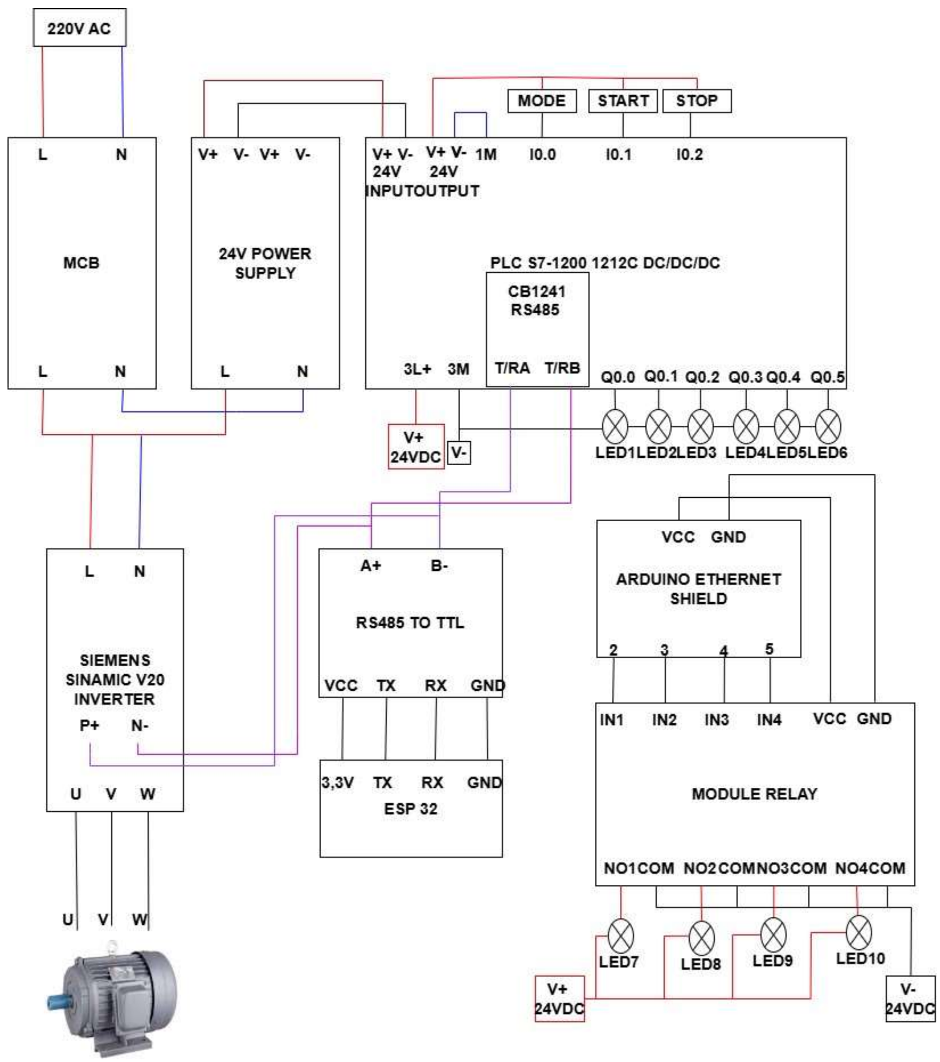


b)

Figure 2. a. Control cabinet; b. Wiring diagram

The operating principle of the plant is shown in *Figure 1b*. Because of the complexity of the whole system and the duplication of some modules, a few steps of cement production such as material input, mixing process and cement product are simulated in this plant via LEDs controlled by a PLC as will be explained more detail in section 2.2.3. For the lack of PLC outputs, a low-cost Arduino Ethernet Shield is exploited to bridge an Arduino Uno and the PLC for controlling some other actuators. In addition, the model also uses a VFD to control the speed of a 3-phase motor using Modbus RTU protocol (via Module Siemens CB 1241 RS485) to simulate some key stages in the line, such as silo loading, conveyors, screw conveyors, and mixing motors. The entire system is controlled and monitored by a SCADA interface built on WinCC Unified software. Additionally, users can remotely monitor the system's operation via the local internet using a computer or smartphone thanks to the combination of PLC, ESP32, and the E-Ra IoT platform. This IoT based-control and supervising interface are built independently as their simultaneous operation with WinCC has not been supported yet.

2.2. Design and implementation

2.2.1. Mechanical part

SolidWorks was used to create a system 3D model *(Figure 3)* before proceeding with 2D drawing generation and implementation. The result is a complete physical model as introduced in *Figure 1a*.

2.2.2. Control cabinet

As shown in *Figure 2a*, external parts of the Control cabinet include buttons for operating the system in manual mode and the corresponding indicating lights. Internal parts include: a main controller (PLC) for processing signals from push buttons, sensors, and outputting control signals to the end devices; a VFD for adjusting motor speed; an MCB for protecting the entire system from overload and short-circuit; and some Relay/contactors for switching actuators. The Wiring diagram of the whole system is shown in *Figure 2b.*

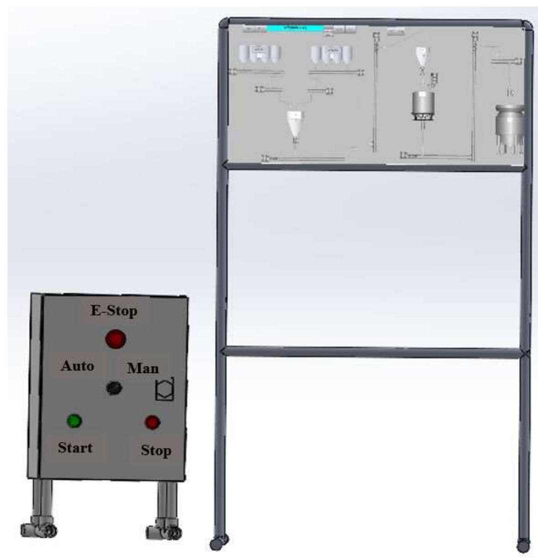


Figure 3. 3D model

2.2.3. Control program

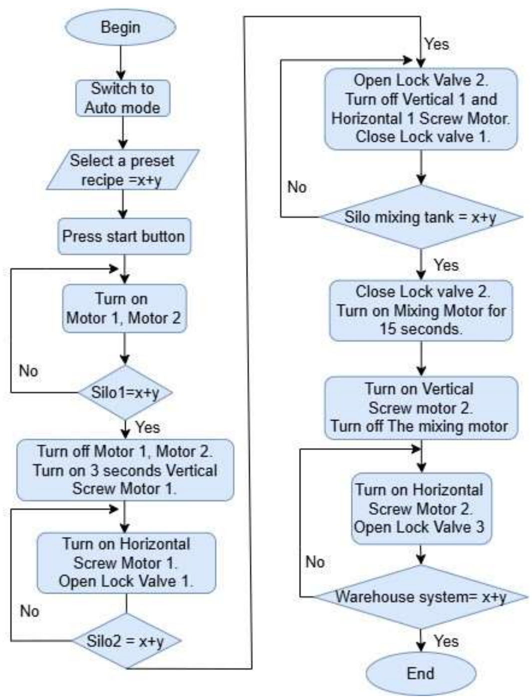


Figure 4. System's Flow chart in auto mode

The control program is finished in TIA Portal V17 software that offers two modes of operation: Auto and manual mode.

The flowchart of the automatic mode is presented in Figure 4. When the START button is pressed, Motors 1 and 2 will operate according to the initially selected formula, and raw materials will be loaded into Silo1. Once Silo1 is full, Vertical screw conveyor 1 will start; Motors 1 and 2 will stop, and the system will continue running until the initial materials reach the storage system, therefore completing the process. Note that, to avoid material congestion, when the system starts, the motor of the later device will run first; when the system stops, the motor of the earlier device will stop first. Manual mode is primarily used to inspect the condition of equipment, allowing users to control each device individually to check its status.

2.2.4. Supervisory and control interface

The Supervisory and Control Interface for the system (Figure 5) was developed using TIA Portal V17 integrated with the WinCC Unified. This interface has 3 pages designed with some main functions to select an operating mode (Auto/Manual); to start/stop/reset the system; to select a formula; to enter a frequency for the VFD; to choose among each page; to activate alert mode; to export an Excel file to monitor the amount of material in the storage silos; or to plot values of an instance over time.

Moreover, the application of certain IoT platforms in industry has increased in recent years with the standard term Industrial Internet of Thing (*IIoT*) to recognize. In this work, E-RA IoT, a platform developed by Vietnamese engineers, has been employed in this model via the Modbus RTU protocol of PLC S7-1200 and the ESP32 Gateway (Figure 2b). The steps for implementation are as follows:

Step 1: Use the E-RA IoT platform to design a control interface on web, including components such as control buttons and system management features. Once completed, save and deploy it on the online system.

Step 2: Configure E-RA IoT for the PLC S7-1200 by entering the PLC's IP (Internet Protocol) address into the platform through the integrated library.

Step 3: Fine-tune and finalize the interface using the available tools and features on the E-RA IoT web server platform (Figure 6a) such as charts, control buttons, or monitoring tables to display information and control the system.

In addition, a supervisory and control interface for mobile phones has been designed (Figure 6b) through the E-RA IoT application. This enables remote connection and control of the PLC S7-1200, as well as easy and convenient system monitoring.

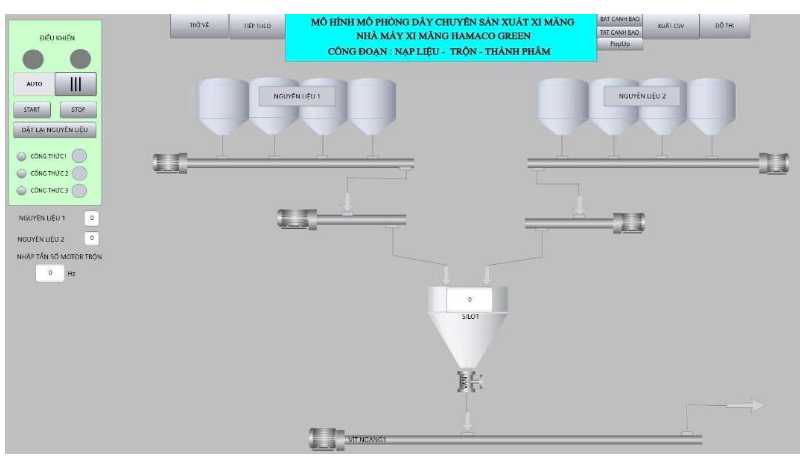
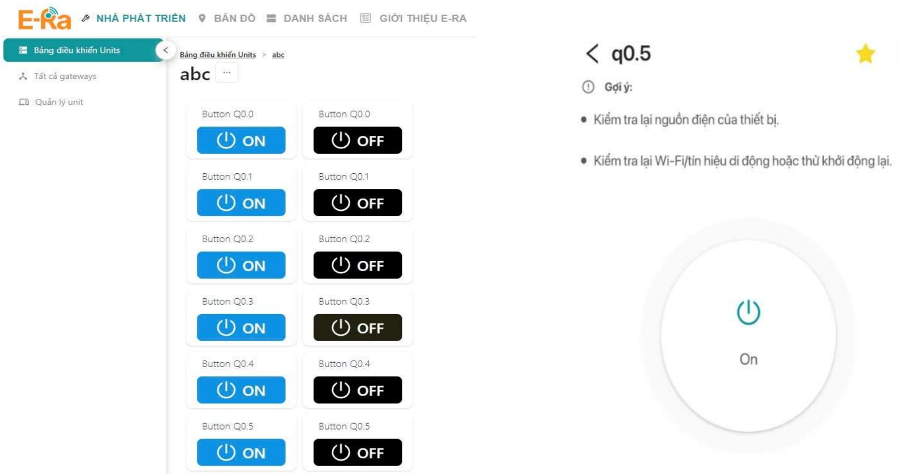


Figure 5. Supervisory and control interface



a b

Figure 6. (a) web server interface; (b) mobile interface on E-RA IoT platform

3. RESULS

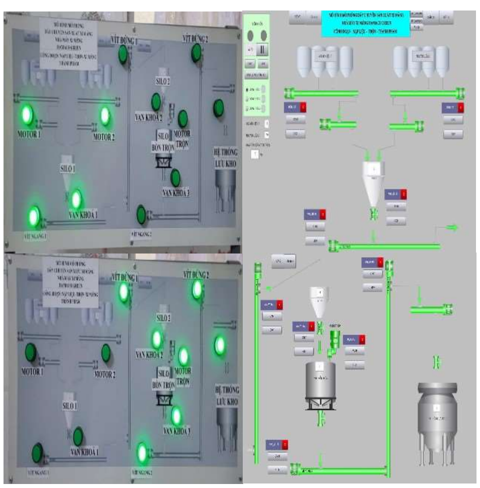


Figure 7. Operation in auto mode

Running the plant 10 times shows that it operates stably and correctly as designed. In Auto mode, the plant clearly displays the working status of the production line following the pre-programmed sequence. Indicator lights on both the interface and the panel light up simultaneously to indicate the current stage of the system (Figure 7). At stages involving motor operation, preset or entered frequency is transmitted to the VFD via the Modbus RTU protocol to adjust the motor speed.

In Manual mode, operators can directly control devices such as screw conveyors, lock valves, motors, etc. When switching to this mode, the devices will be controlled manually by the operator.

The warning feature is illustrated in Figure 8. When giving the VERTICAL SCREW 1 a trigger current exceeding the threshold, a warning will appear on the interface. Once the current stabilizes within the allowable threshold, the system operates normally.

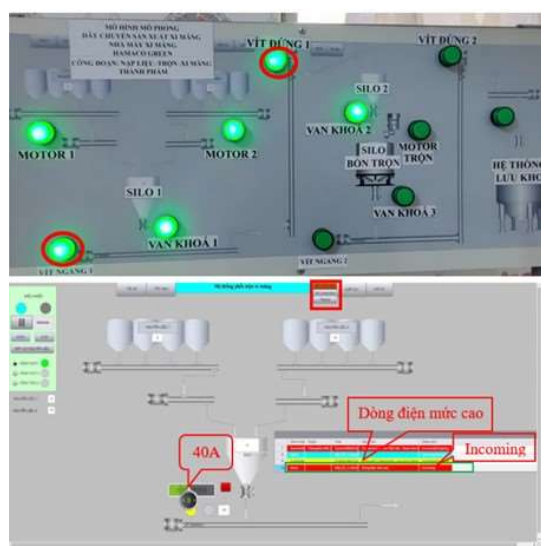


Figure 8. Alert function in action

The "Export CSV" feature also works fine, which allows operators to easily generate and store data during the process operation. Finally, the Graph feature allows tracking the parameters in the process visually.

The E-RA IoT interface allows flexible operation in both computers and mobile devices. This enables users to easily control the plant and to accurately monitor the status of each device in real-time (Figure 9). However, E-RA IoT platform is currently not totally supported to work with WinCC, that leads to some limitations in data synchronization and system control. This may impact the ability to implement advanced features such as real-time monitoring, alarm configuration, or direct data management from WinCC on this platform.

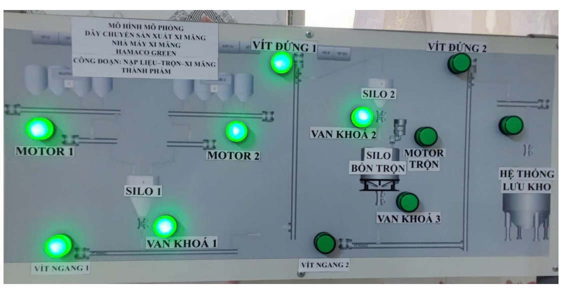


Figure 9. Plant operation via E-Ra IoT

4. CONCLUSION

An automated plant simulating a cement production process has been successfully developed. The model provides an economical solution to understand and apply academic knowledge to automating an industrial process. With its modular structure, the model can be easily assembled, disassembled, and upgraded, allowing it to adapt to the changing of user needs. In addition, the model's ability to integrate with other industrial devices (for example, via Modbus communication) opens up many potential applications in everyday life and production. Finally, IoT technology based on the E-RA IoT platform was explored, revealing its potential as well as challenges in order to be applied to an industrial system.

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XÂY DỰNG MÔ HÌNH MÔ PHỎNG TUẦN TỰ BƯỚC HOẠT ĐỘNG TRONG MỘT DÂY CHUYỀN SẢN XUẤT XI MĂNG

TÓM TẮT

Ngành công nghiệp xi măng đóng vai trò quan trọng trong việc cung cấp vật liệu xây dựng, góp phần trực tiếp vào phát triển cơ sở hạ tầng và tăng trưởng kinh tế. Thực tập tại một nhà máy sản xuất xi măng là một trải nghiệm quý giá đối với sinh viên kỹ thuật trong việc học hỏi các giải pháp tự động hóa trong công nghiệp. Trong thời gian thực tập tại Công ty TNHH Hamaco, một mô hình mô phỏng một số bước trong quy trình sản xuất xi măng đã được xây dựng. Mô hình này tích hợp hệ thống SCADA trên WinCC Unified, cho phép giám sát và điều khiển quá trình sản xuất từ khâu tiếp nhận nguyên liệu, chế biến, phối trộn đến đóng gói. Ngoài ra, công nghệ IoT dựa trên nền tảng E-RA IoT cũng được nghiên cứu nhằm giới thiệu một giải pháp công nghệ tiên tiến cho các nhà sản xuất. Mô hình này còn có thể được sử dụng như một công cụ giảng dạy, giúp sinh viên kỹ thuật có thêm kinh nghiệm làm việc thực tế với các hệ thống công nghiệp.

Từ khóa: *Mô hình, PLC, SCADA, winCC unified*