Automatic Bottle Filling and Capping Machine using SCADA with the Internet of Things

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Abstract: In today's fast-paced, fiercely competitive industrial environment, a business must be adaptable, efficient, and well-organized if it hopes to survive. Streamlining operations in speed, dependability, and product output has led to a significant need for industrial control systems and automation in the process and manufacturing industries. As a result, automation's impact on daily life and the global economy is growing. This study aimed to develop an IoT-based SCADA for an automatic bottle-filling and capping system. The WinCC Explorer software used to design the production contour and monitor and control it is intended for use in this simulation. Delta was used to develop and test the ladder diagram. To reduce the number of rejected bottles, the system was designed to utilize a retentive timer instead of an on/off delay timer. The system's primary characteristics included low power consumption, low operating costs, minor maintenance, and less fluid loss. All of these factors ultimately improved cost-effectiveness and raised the profit margin. Fully automated bottling facility that achieves vital energy and efficiency savings through speed control. It is advised to employ a completely automated system rather than a traditional control system in light of the findings and recommendations.

Keywords: Bottle Filling, IoT, SCADA, Energy Efficiency, Speed Control of VFD, Manufacturing sector, Industrial Competency.

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1. Introduction

Automation is a product of technology used to control and track the production and delivery of various goods and services. It carries out tasks that people previously handled. Many fields use automation, including production, transportation, utilities, defense, facilities, operations, and data technology. Most industrial processes, including those in the chemical and steel industries, power generation, etc., use IoT-based SCADA systems. PLC and SCADA applications in automation processes improve dependability and flexibility while reducing production costs. For example, industrial electric drive systems are more accurate and effective when PLC is interfaced with power converters, personal computers, and other electric equipment. Automation, as a result, sharply increases production, redeemable time, and pricing in several trades.

Nevertheless, despite advancements in automation, manual intervention is typically advised even though the tool can do most jobs. The motor's outstanding energy economy and speed control have made variable frequency drive (VFD) a popular choice. A VFD can lower the starting current by up to 80% without compromising the starting torque compared to a mains-powered motor with direct starting. Water, iced tea, and other liquid items are packed by machines using the filling method. With the help of this method, individual bottles can be loaded onto a conveyor belt and filled.

Hussein, H.K., Abdullah, O.I., and Abbood, 2020.[1] An interactive design technique was used to develop an automatic liquid filling system. With the use of PLC, the researchers created and tested their Industrial Crane Automation & Monitoring logic. Soft wiring benefits from programmable logic controllers are substantial. As a result, it is a crucial part of PLCs. A.N. Abubakar, S.L. Dhar, A.A. Tijani, and A.M. Abdullahi, 2022.[2] Robotic arm conveyor-equipped automated liquid filling device for small-scale companies.

This strategy has many benefits, including accuracy, little maintenance needs, low operational expenses, and low power usage. In MICROLOGIX software, they created the ladder logic tested in Allen Bradley. Unfortunately, a typical application's ladder logic program frequently produces complex software challenging to handle during configuration, especially during maintenance. The issue is a ladder logic-exacerbated issue with line real-time control software.

Pankaj Prajapati (2019) created a ladder for automated bottle filling and capping using PLC.[3], [13] This was accomplished using PLC and SCADA. By adjusting the frequency of the electrical current delivered to the motor, a variable-frequency drive (VFD) [4], [5] is used to regulate the speed of the electric motor. As a result, a wholly automated bottling facility was built, and the necessary work was done to achieve high efficiency, energy conservation, and speed control. The main goal of the entire system was to manage the plant without the aid of people. Utilizing PLC and SCADA gives any industry complete automation [6]. This one is more adaptable, dependable, time-saving, and user-friendly than other systems.

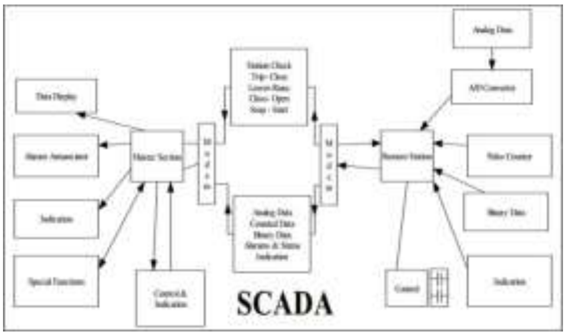

Figure 1: Two-Way Communication Channel

The scanning mode of the SCADA systems was used to provide information about generating stations, generating units, transformer substations, etc. In addition to Automatic Control and Protection Systems, complex traditional wired SCADA systems were set up to carry out several tasks. Currently, SCADA is utilized in conjunction with protection relays, control relays, and control systems to control generating stations and transmission systems automatically. Only initiating devices may differ or be omitted with fully automatic SCADA control. For instance, the sub-section control room operator or the mechanical voltage control relays linked to the transformer's protection panel may generate tap changing.

2. Internet of things scada system

The fourth generation of SCADA systems adopted the Internet of Things and commercial cloud computing, lowering the SCADA systems' infrastructure costs. Therefore, compared to earlier SCADA systems, fourth-generation SCADA systems are simpler to manage and integrate. Additionally, these SCADA systems may report statuses in real-time by exploiting the horizontal scale provided by cloud computing, which makes it possible and sufficient to design more complex control algorithms on conventional PLCs [7]. Additionally, open network protocols like TLS embedded inside the internet of things can be used to resolve the security issues related to decentralized SCADA implementations, such as a heterogeneous mix of proprietary network protocols [8], by providing a transparent and manageable security barrier.

Situational monitoring based on IoT is beginning to take shape. Real-time electrical energy monitoring has been put into place [9–10]. Voltage, current, and neutral current are all measured during data monitoring. The data is used to monitor how much electricity is used. IoT-based monitoring solutions for solar power plant efficiency have also been developed by the authors [11]. They employ the Raspberry Pi and the Message Communication Protocol (MCP) for smartphone access. Enhanced DC Performance of motor controls is improving as IoT-based monitoring develops. A PID algorithm was used to establish the author's control system. The majority of businesses have embraced the technology known as the Internet of Things. It makes it easier to do activities without using manual labor or human aid. This integrated technology enables the object to make more competent judgments by interacting with internal states or the outside environment.

a) Data communication

While massive systems like railways and power plants commonly use SONET/SDH, SCADA systems have historically used radio and direct-wired connections [12]. A SCADA system's remote administration or monitoring operation is frequently called "communication." Some clients share the network with other programs or have SCADA data through their current business networks. However, the residue of the initial low-bandwidth protocols is still visible. SCADA protocols are made to be extremely brief. The master station typically only polls the RTU when data is transmitted. RP-570, Control, Profibus, and Modbus RTU are examples of standard historical SCADA protocols. Each communication protocol is exclusive to a single SCADA manufacturer, although being widely used and adopted. Acceptable protocols are IEC 61850, DNP3, and IEC 60870-5-101 or -104. All significant SCADA vendors accept and standardize these communication protocols.

TCP/IP extensions enable a number of these protocols to function. Although the distinction between traditional and industrial networking is blurred by standard networking specifications like TCP/IP, each serves fundamentally different requirements. The infrastructure can be created to be self-contained, have built-in encryption, and fulfill the availability and reliability standards established by the SCADA system operator. These are the main benefits. First, consumer-grade VSAT has a track record of poor performance. Contemporary carrier-class systems provide the level of service required by SCADA. Second, industry interoperability standards were not widely adopted when RTU and other autonomous controller devices were created. Thus, several control protocols were created by developers and their management. The more well-known vendors had incentives to develop their policies to "lock in" their clientele. Here is a list of automation protocols. OLE for process control (OPC), which was initially not meant to be a part of an industrial network, has recently gained popularity as a solution for intercommunicating various hardware and software.

b) Data presentation

The SCADA system often gives the operational staff the data in a fake diagram. This shows that the operator has a conceptual understanding of the control system. The operator can then turn the pump off. The fluid flow rate in the pipe will also be displayed in real-time by the HMI software. Mimic diagrams can also illustrate different process components using digital images, line graphics, and schematic symbols. The drawing software typically included in the SCADA system's HMI package allows the operators or system maintenance personnel to change how these points are described in the interface.

c) Data Acquisition

The majority of contemporary PLCs may connect to other systems over a network, like computers running SCADA (Supervisory Control and Data Acquisition) systems or web browsers. Peer-to-peer (P2P) communication between processors is possible for PLCs in more extensive I/O systems. This enables various components of a complicated process to operate independently while allowing the subsystems to communicate and work together. These communication channels are frequently utilized for HMI components like keypads or workstations that resemble PCs. When the processor lacked a network connection, several manufacturers used to sell dedicated communication modules as an add-on feature. Future-oriented automation concepts must include the communication ability of devices and subsystems and a consistent information approach. More and more communication coincides vertically via many organizational levels and horizontally at the field level. Industrial communication systems are layered and coordinated, such as Process Fieldbus (PROFIBUS), with lower-level interfaces that interface to Interface and upper-level interfaces that interface to Ethernet using PROFI net.

3. Variable frequency drive (vfd):

Induction motors are utilized in most industries due to their affordability, dependability, and durability. However, the usage of induction motors in industrial applications requiring variable speed is constrained due to the inefficiency and high costs associated with the present control approaches. The advancement and innovation in power electronics led to the creation of ac motor drives, also known as (VFDs), which are presently utilized to control the speed of induction motors at lower production and maintenance costs with more efficiency. A variable frequency drive (VFD) is a device that controls the frequency of electrical power sent to an alternating current (AC) electric motor to regulate rotational speed or torque.

An adjustable speed drive, known as an AC drive, adjustable frequency drive [14], frequency converter, microdrive, or inverter drive, is a variable frequency drive. By transforming the grid's frequency into movable values on the machine side, it regulates the speed of the electric machine, enabling it to swiftly and efficiently change its speed to the desired value. A variable frequency drive's two primary purposes are to regulate the output frequency and provide power conversion from one frequency to another. Small appliances to the most significant mine mill drives and compressors are all powered by variable-frequency movements. Variable frequency motors on fans are also frequently employed in ventilation systems for large buildings because they allow the volume of air moved to fit the system demand while saving energy. They are also utilized on drives for machine tools, conveyors, and pumps.

The first AC induction motor [15] was created by Nikola Tesla in 1888, replacing the DC motor with one more dependable and effective. Controlling the speed of the AC, though, proved difficult. Due to its effective and affordable means of correctly managing speed, the DC motor has replaced the AC motor in situations where precise speed control is necessary. AC speed control did not start to compete until the 1980s. Over time, AC Drive technology evolved into a competitive alternative to conventional DC control that is affordable and dependable. Now that full torque has been reached from 0 RPM to the maximum rated speed, an AC controller can control speed.

The variable frequency drive is a specific type of variable-speed drive used to regulate the speed of an AC motor. A variable frequency drive controls the frequency of the electrical current supplied to the motor to prevent its rotational speed. An application can alter the motor speed in response to the load by including a variable frequency drive, which ultimately saves energy. A variable frequency drive is frequently employed in various applications, including ventilation systems, pumps, conveyors, and machine tool drives (Figure 2: VFD circuit diagram).

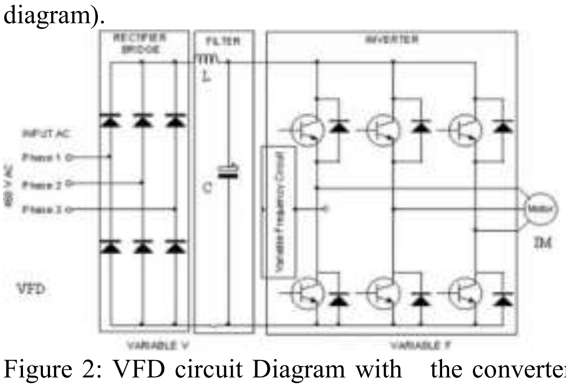

Figure 2: VFD circuit Diagram with the converter operation

I. SCADA (Supervisory Control & Data Acquisition):

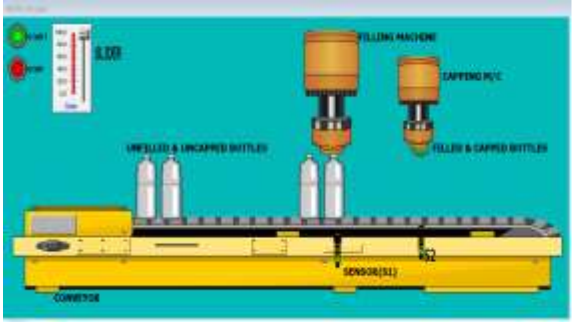

Figure 3: Implementation of the intelligent SCADA system to the Bottle cap

II. SCHEMATIC DIAGRAM OF THE PROCESS:

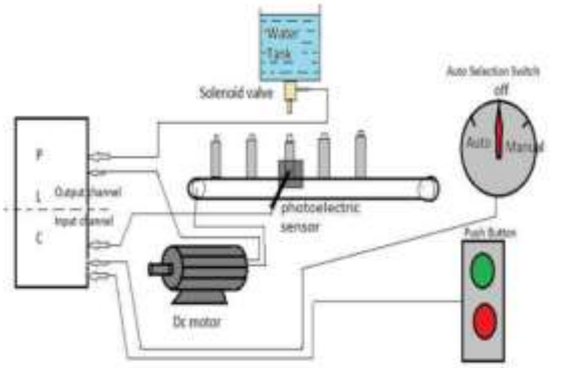

Figure 4: Schematic Diagram of bottle filling procedure

ALGORITHMS:

STEP 1: Press the "START" button.
STEP 2: The "MOTOR" starts, and the conveyor moves forward.
STEP 3: If the sensor detects the Bottle's presence, which is in the position with the valve, then the conveyor will stop.
STEP 4: If the sensor does not detect any presence of the Bottle, the conveyor keeps on moving.
STEP 5: After some delay, the valve turn "ON," and the Bottle will get filled till the timer gets off.
STEP 6: After the Bottle is filled, a delay of 20 seconds is provided, and then after the delay, the MOTOR starts running.
STEP 7: And the process repeats itself from STEP 3.

a) Procedure for the developed work:

When starting push button is switched on, the level situation of the tank will be checked. If it is low, the tank feeding pump will be opened to fill it, and then the conveyer belt will operate. On the other hand, if the tank level is medium, both feeding pump has to fill the tank, and the conveyer belt will work.

If the tank level is complete, only the conveyer belt will operate. Then the counter will ensure that there are six or more bottles in the line because the system has six injectors that fill them simultaneously. After that, the solenoid valve will open for one minute. If the bottles are in the correct position of the coverage machine detected by the sensor, the Bottle will be enclosed, and the coverage arm will return to its regular work. Then the conveyer belt will move. The capacitive proximity sensor will read the fluid level in the bottles, and if it's at the average level, the conveyer will move; if it's less than the middle level, the Bottle will be rejected. After that, the packaging machine will pack each Bottle together

b) Graphical designing of SCADA:

Inserted the system components from the library of WINCC in graphic designer and the system during operation as shown in Figure 5; also, the properties of every element are automatic bottle filling [16].

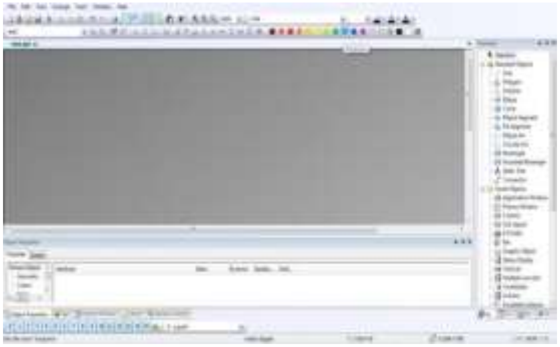

Figure 5: Graphic designer page

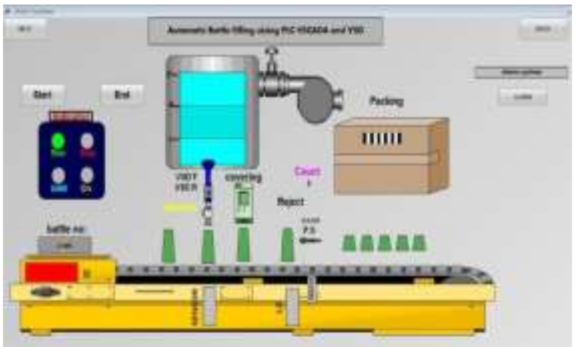

Figure 6: The system during operation

Control programs using ladder languages in the industrial process can be used for many forms depending on the control program that will be written. Explained in the PLC control program [17] and SCADA system animation, each procedure is described in the following. Any system needs manual start-up, shutdown, and emergency stop. The figure below shows the starting and stopping of the system; when pressing on starting push button (I0.0), the primary system will operate (M0.0). I0.1 indicates the stop button, so when it is switched on, it will stop the whole system. I0.12 implies that the emergency button gives an alarm and contains the system when pressed. Figure 7 explains the chart of the points mentioned earlier.

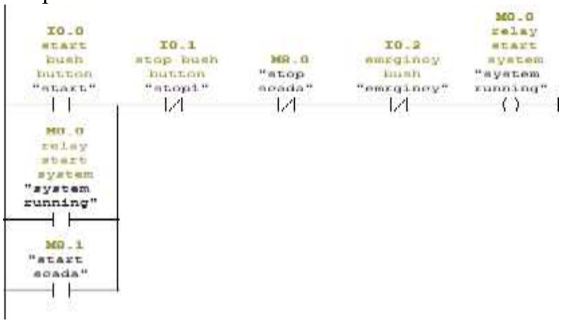

Figure 7: Main starting and stopping of the system

The following block explains the fluid level in the tank; it has been recalled into the organization block. I0.5 indicates a low liquid level in the tank, meaning the tank feeding tank will operate to fill the tank, and the conveyer will not operate until the tank is full. I0.4 indicates the medium fluid level in the tank; in this case, both the tank feeding pump and the conveyer belt will operate. Finally, I0.3 indicates the whole liquid level in the tank; this will stop the feeding pump and use the conveyer belt.

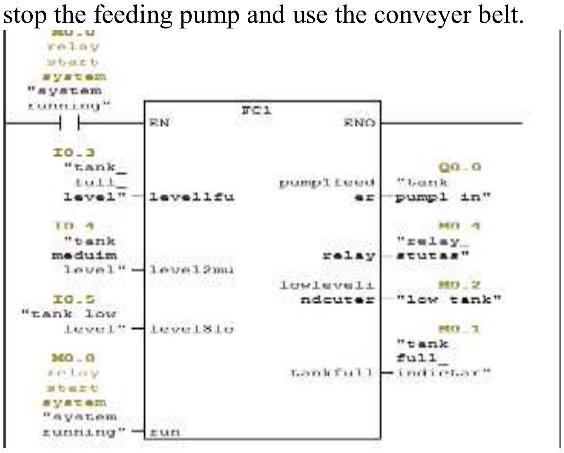

Figure 8: Tank state

The C0 indicates the counter, and it has to ensure that there will be no less than six bottles in the conveyer belt. I1.0 is responsible for the counting of bottles on the conveyer belt

III. RESULTS AND DISCUSSIONS*:*

This study demonstrates an IoT-based SCADA-based automated bottle filling and capping system. A filling is entirely under control, and capping is accomplished. The current technology will make numerous automation-related applications possible, particularly in heavy production industries were many components may be processed and handled swiftly. Increased production is required.

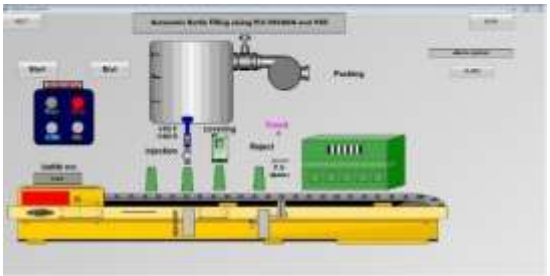

Figure 9: Implemented on the SCADA

The position sensor was situated at the conveyer belt as the empty bottle was sent into the filling area. The proximity sensor confirmed the ideal position of the bottles for filling. The solenoid valve and retentive timer run simultaneously for one minute to fill the bottles once the motor that drives the injection arm hits the lower limit switch. The Bottle will be shipped for capping after it has been filled. The nozzle alignment to the neck of the bottle should be given more attention in the capping section introduced following the programmed filling section part. The capacitive proximity sensor will determine how much liquid is in each container. They will start packing if they are in the necessary book. They will be rejected if the volume is less than what is required. Because there is no external pump needed during the filling process, the proposed automatic system has reduced human labor. Therefore, the outcome of the practical research is quite positive.

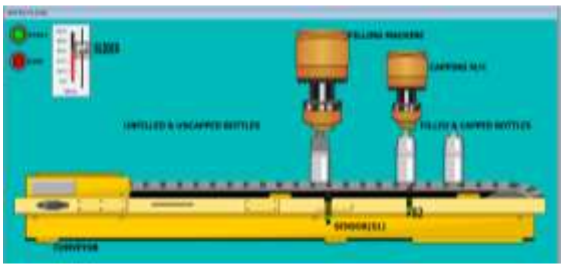

Figure 10: Development page of SCADA

RESULTS:

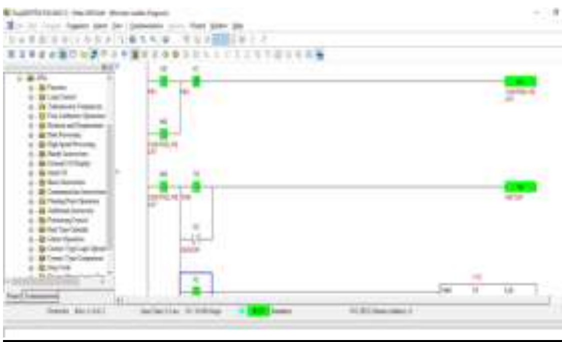

Figure 11: Results showing the DELTA PLC

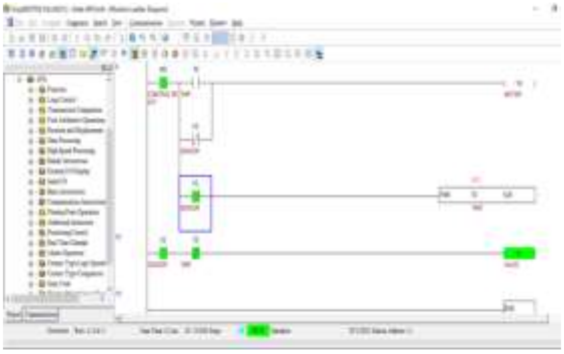

Figure 12: Results showing the DELTA PLC

Ladder logic is the language used to program the PLC; since most industrial applications employ this language, it is pretty helpful. SCADA implementation [17] is one of the system's additional features.

The system is much more effective than a base microcontroller because of the use of Programmable Logical Controllers (PLC). Remote system maintenance has been made much easier by the SCADA implementation. It is more trustworthy because of the safety system installed. Automation implementation boosts productivity, which lowers production costs. Although this project has a high starting cost, it may be very cost-effective. Numerous other capabilities are available, including user-defined volume specifications and the ability to add multiple liquids to the same bottle with a volume specification. It is also possible to incorporate a continuous filling procedure with a higher safety protocol. A retentive timer has been used in this study to reduce the number of rejected bottles. The retentive timer is better than the on/off delay timer and off delay timer because, in the former, the preset value will be reset if the electric current is disconnected, causing all bottles to be rejected at filling time. However, when a retentive timer is used, the preset value will be maintained even when the electric current is disconnected, lowering the number of rejected bottles.

This system's created programming is adaptable, rapid, and straightforward. This will enhance production, resulting in considerable financial gains and cost savings. This idea can be applied to the beverage, milk, pharmaceutical, and mineral water industries. Although installation is not cheap, it can operate effectively for a very long time.

IV. CONCLUSION

IoT-based SCADA systems have been used as part of the overall research. The primary goal of this research is to fill safely and cap bottles used in businesses for various tasks, including packaging liquids (such as milk, water, etc.) and storing harmful chemical containers in bottles. The liquid in the tank, the bottle position capping procedure, and the volume of the liquid in the bottle are all measured using various sensors. The packing system begins after the capping step and when there are a certain number of bottles. IoT is also utilized to control the process, while SCADA monitors the parameters. Increased production is required since many components must be processed and handled quickly. Continuous monitoring using SCADA WinCC software improves automation further. The proposed model was created and tested in several LAB experimental labs, with the best outcomes coming from Delta and AB.

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